

Skill transfer specificity shapes perception and action under varying environmental constraints

SEIFERT, Ludovic, WATTEBLED, Léo, ORTH, Dominic, L'HERMETTE, Maxime, BOULANGER, Jérémie and DAVIDS, Keith <<http://orcid.org/0000-0003-1398-6123>>

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Published version

SEIFERT, Ludovic, WATTEBLED, Léo, ORTH, Dominic, L'HERMETTE, Maxime, BOULANGER, Jérémie and DAVIDS, Keith (2016). Skill transfer specificity shapes perception and action under varying environmental constraints. *Human Movement Science*, 48, 132-141.

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

3

4 Ludovic Seifert¹, Léo Wattebled¹, Dominic Orth^{1,2}, Maxime L'Hermette¹, Jérémie
5 Boulanger¹, Keith Davids^{3,4}

6

7 ¹ CETAPS - EA 3832, Faculty of Sport Sciences, University of Rouen, France

8 ² School of Exercise and Nutrition Science, Queensland University of Technology, Brisbane,
9 Australia, Queensland University of Technology, Brisbane, Australia

10 ³ Centre for Sports Engineering Research, Sheffield Hallam University, Sheffield, United
11 Kingdom

12 ⁴ FiDiPro Programme, University of Jyväskylä, Finland

13

14 **Funding:** This project received the support of the CPER/GRR1880 Logistic, Mobility and
15 Numeric and FEDER RISC N° 33172.

16 **Conflicts of Interest and Disclosure:** The authors declared no conflict of interest.

17 **Corresponding author:** Ludovic SEIFERT, Faculty of Sports Sciences, CETAPS, University
18 of Rouen, Boulevard Siegfried, 76821 MONT SAINT AIGNAN cedex, FRANCE, @:
19 ludovic.seifert@univ-rouen.fr, Tel : (+33) 235147784, Fax : (+33) 232107793

20 **Running title: Generality and specificity of skill transfer**

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22 Word count: 5431

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24

25 **Abstract**

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

42

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

45

46

47 **Introduction**

48 Adapting perception and action couplings when regulating multi-articular movement patterns
49 is a hallmark property of expertise, facilitating consistent performance achievements under
50 different task and environmental constraints (Stone, North, Maynard, Panchuk & Davids,
51 2014; Panchuk, Davids, McMahon, Sakadjian & Parrington, 2013; Warren, 2006). Previous
52 studies have provided insights on the adaptability of skilled performers, defined by their
53 capacity to exploit functional variability in coordinating actions with dynamic performance
54 environments. The data have illustrated how expert behaviours remain flexible, and are not
55 stereotyped and rigid (Seifert, Button, et al., 2013; Warren, 2006). Traditional views on
56 expertise acquisition, exemplified by the deliberate practice approach, have proposed that
57 athletes need to accumulate 10,000 hours of intensely dedicated and specific practice
58 (Ericsson, Krampe, & Tesch-Römer, 1993). This idea fails to account for how transfer
59 processes may shorten the period of specialised practice needed for gaining expert status (for
60 pertinent criticisms see Davids, 2000; Tucker & Collins, 2012). For example, in a study of
61 chess masters, an astonishing range of 3,016–23,608 hours has been reported for the
62 achievement of expertise (e.g., Grandmaster level) (Hambrick et al., 2014). These data on
63 individual differences raise pertinent questions on how transfer processes can influence the
64 timescales for expertise acquisition in different performance environments (Davids, 2015).

65 In an ecological dynamics theoretical framework, the capacity to transfer perceptions,
66 cognitions and actions between performance environments is a critical feature of expertise
67 that has been somewhat neglected in past research (Seifert et al., 2013). Skill transfer emerges
68 from the influence of prior experiences under a specific set of interacting constraints on
69 performance under a different set of conditions compared to those where the skills were
70 originally acquired (Newell, 1996; Issurin, 2013; Rosalie & Muller, 2012). We have argued
71 that *specificity* of transfer can emerge when the existing intrinsic dynamics (i.e. performance

72 disposition or tendencies) of an individual *cooperate* with the dynamics of a new task to be
73 learned, facilitating successful performance behaviours (e.g., Davids et al., 2015). In contrast,
74 *general* transfer can occur when intrinsic and task dynamics do not cooperate closely.
75 Specificity and generality of transfer can be influenced by the intrinsic dynamics of each
76 individual learner, which are shaped by learning and previous experiences under specific task
77 constraints (Davids et al., 2015).

78 These theoretical ideas have implications for implementing transfer processes that could
79 constrain the degree and rate of performance improvement, as suggested by some important
80 data from laboratory studies of coordination in finger movements (Zanone & Kelso, 1997).
81 Despite these ideas, there have been few empirical studies of transfer processes during
82 coordination of multi-articular actions in different performance environments (Rienhoff et al.,
83 2013; Rosalie & Muller, 2012). Here, we sought to examine this relevant issue for expertise
84 acquisition in performance environments requiring multi-articular actions by investigating
85 whether the intrinsic dynamics of climbers who practise regularly on an indoor climbing wall
86 might cooperate or compete with the task dynamics of climbing an ice fall. On an indoor
87 climbing wall, routes consist of holds composed of similar smooth synthetic materials, which
88 afford gripping with the fingers in an unchanging internal environment (e.g. ambient
89 temperature remains the same during a climb). In ice climbing, properties of an icefall require
90 use of tools on the feet (crampons) and in the hands (ice tools) and performance conditions
91 can change markedly within and between climbs (Batoux & Seifert, 2007; Blanc-Gras &
92 Ibarra, 2012). Ecological dynamics suggests that functional adaptation of existing perception-
93 action couplings might be constrained by *specificity and generality* of transfer processes
94 induced by such performance environments (Davids et al., 2015). *General* transfer is
95 exemplified when processes of perception and action are generalised to a new set of
96 performance constraints that, although different, maintain couplings among key system

97 components. For example, this sub-system maintenance might include the coupling of visual
98 and motor systems or the use of similar limb coordination patterns, but invoking different
99 types of action patterns with the hand and feet when climbing (Seifert et al., 2014)). Other
100 examples of *general* transfer between indoor and ice fall climbing might include the use of
101 cognitions, perception and action to seek ascent routes, to manage weight with respect to the
102 environmental constraint of gravity and the discovery of surface properties with exploratory
103 actions. *Specific* transfer processes enhance the stability of certain perception-action
104 couplings, which are refined through practice under highly particular task constraints to
105 enhance performance, exemplified in ice fall climbing by the way that particular tools are
106 used to ascend the surface. In indoor climbing such tools play no part in ascending a surface.
107 An important research challenge is to effectively characterise different performance ecologies
108 along each axis of transfer (specific and general), in order to predict how processes of skill
109 transfer might support performance (through adaptation of an individual's intrinsic dynamics),
110 shortening the timescales of learning. This is because the relationship between two
111 performance environments is captured by numerous, dynamic and interacting constraints:
112 environmental, task and personal (both structural e.g., strength, flexibility, height, and
113 functional e.g., decision making, attunement and calibration to specifying information for
114 action) (Davids, Button, & Bennett, 2008; Newell, 1986). Transferability of behaviours such
115 as cognition, perception and action, between two performance domains hinges on the
116 functionality of existing perception-action couplings and how much they may need to be
117 specifically adapted for use in a different performance environment.

118 The issue of generality or specificity of transfer particularly relates to the capability of an
119 individual to pick up information and utilise specific affordances under different performance
120 conditions (Davids et al, 2015). The richness of the landscape of affordances raises important
121 questions over the nature of learning designs that can help an individual to utilise relevant

122 affordances in a given performance environment, i.e., through attunement and calibration to
123 specifying information to regulate adaptive behaviours (Fajen, Riley, & Turvey, 2009).

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

144 The multi-articular action of climbing offers rich landscapes of available affordances for
145 studying effects of generality and specificity of skill transfer. This performance context is
146 characterised by varying performance environments (variations in surfaces, e.g. smooth

147 synthetics, rock or ice; surrounding conditions, e.g. variations in ambient temperatures, wind,
148 available light, dryness/wetness; textures, e.g., smooth, rough, rocky, and slippery; and tool
149 use, e.g., use of hands, feet, gloves, boots, ice tools, crampons, chalk). These environmental
150 and task constraints interact to shape the emergence of perception-action couplings that have
151 varying degrees of specificity with respect to the affordances available in different climbing
152 environments. To exemplify, rock and ice climbing environments involve interspersed periods
153 of behaviours dedicated to quadruped limb displacements on a vertical surface, alternated
154 with periods in more or less static positions dedicated to exploring and grasping surface holds
155 or ice tool anchorages (Fuss & Niegl, 2008; Pijpers, Oudejans, Bakker, & Beek, 2006; Seifert,
156 Wattebled, et al., 2014; Sibella, Frosio, Schena, & Borghese, 2007), posture regulation
157 (Bourdin, Teasdale, & Nougier, 1998; Bourdin, Teasdale, Nougier, Bard, & Fleury, 1999;
158 Testa, Martin, & Debû, 1999, 2003), upper limb release and resting (Sanchez, Lambert, Jones,
159 & Llewellyn, 2012), and “route finding” (Cordier, Mendès-France, Bolon, & Pailhous, 1993;
160 Cordier, Mendès-France, Pailhous, & Bolon, 1994). In particular, three main properties might
161 support general transfer of climbing experience between the task constraints of rock and ice
162 climbing (Seifert, Wattebled, et al., 2013): (i) the unpredictability of performance
163 environments requiring the continuous coupling of processes of perception and action, (ii)
164 alternation between maintaining body equilibrium (stability) and climbing quickly up a
165 vertical surface (transitioning), and (iii), the use of quadruped locomotion patterns
166 subsequently involving the extremities of each limb to negotiate an ascent. The task
167 constraints of ice climbing reveal at least three particularities in comparison to rock climbing
168 which might induce *specificity* of transfer between each discipline (Seifert, Wattebled, et al.,
169 2013): (i) Tools, such as ice tools for the hands and crampons for the feet, form parts of the
170 landscape of available affordances used by an ice climber to interact with surfaces properties
171 of an icfall, (ii) The icfall properties tend to be stochastically distributed throughout a

172 particular frozen waterfall surface (for instance, the icefall texture can vary greatly, presenting
173 more or fewer holes, thus inviting climbers to hook available holes or create their own holes
174 by swinging their ice tools), and (iii), climbers can discover their own climbing path since
175 they can create their own (more or less stable anchorages) with their tools and secure their
176 ascent by inserting ice screws into specific locations on an icefall.

177 Previous results have revealed that experienced rock climbers, who had previously acquired
178 multiple movement and coordination patterns, were able to transfer this large range of skills,
179 and climbing fluency, to the novel task constraints of ice climbing (Seifert, Wattedled, et al.,
180 2013). However, Seifert et al. (2013) did not examine whether the specificities of ice climbing
181 (i.e. tool use; variability and temporary distribution of icefall properties; freely chosen
182 climbing path) might induce *specific* transfer effects from climbing an indoor wall to an ice
183 fall. For example, route finding is an important climbing skill that could provide information
184 on the ability of climbers to utilise affordances from a surface to enhance their performance
185 fluency. The influences of surface affordances could be revealed by analysing the ratio
186 between different types of actions observed. In rock climbing, Pijpers et al. (2006)
187 distinguished exploratory and performatory movements according to whether a potential hold
188 on a climbing wall was touched, with or without it being used as support. Clearly, an
189 excessive duration spent immobile during route finding and hold exploration may
190 compromise climbing fluency, leading to enhanced physical and mental fatigue. Climbing
191 fluency has been assessed previously by: (i) measuring the geometric index of entropy
192 (Cordier et al., 1993, 1994; Sibella et al., 2007), (ii) the time spent in different states
193 (movement/immobility) (Billat, Palleja, Charlaix, Rizzardo, & Janel, 1995; Seifert,
194 Wattedled, et al., 2013; Seifert et al., 2014), and more recently (iii), by calculating the jerk
195 coefficient (i.e., third time derivative of position or the rate of change of acceleration; Flash &
196 Hogan, 1985; Hogan, 1984), previously used as an index of smoothness of 3D translations

197 and 3D rotations of the hips (Seifert, Orth, et al., 2014).

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

215

216 **Methods**

217 **Participants**

218 Twelve recreational climbers who trained together at a local climbing facility, voluntarily
219 participated in this study (mean age: 22.5 ± 2.7 yr; mean height: 171.3 ± 7.5 cm; mean
220 weight: 69.6 ± 3.4 kg). These climbers had climbing experience of 3.8 ± 1.3 yr on an artificial
221 climbing wall, trained for 3.7 ± 1.6 hours per week and had a rock climbing ability of 6a on

222 the French Rating Scale of Difficulty (F-RSD) (Delignières, Famose, Thépeaut-Mathieu, &
223 Fleurance, 1993), which corresponds to an intermediate level of performance (Draper et al.,
224 2011). Climbing ability was defined as the most difficult ascent by top rope (Delignières et
225 al., 1993). However, these climbers had no previous experience of ice climbing environments.

226

227 **Protocol**

228 The sample of twelve climbers was split in two groups of six climbers. The first group
229 completed a 10-m high route on an artificial climbing wall in a top-roped condition,
230 composed of 20 hand-holds, at a grade rated 5b on the F-RSD, which goes from 1 to 9. The
231 second group completed 10-m high route on an icefall in a top-roped condition, in an air
232 temperature of -8°C, at a grade rated 4 on the French rating scale, which goes from 1 to 7
233 (Batoux & Seifert, 2007). Grade 4 is a common grade assigned to recreational performers and
234 involves an average slope of 75 to 80°, with steep or vertical sections (Batoux & Seifert,
235 2007). For this protocol, the icefall selected for the climbers was 10-m at around 80° slope.
236 Each route was set by a professional mountain guide certified by the International Federation
237 of Mountain Guides Association (IFMGA), who ensured that the grade of each route
238 represented an equivalent level of climbing difficulty in terms of environmental performance
239 constraints (according to Newell, 1986), and matched intermediate climbing levels.
240 Participants were given general instructions to self-pace their ascent, climb fluently and climb
241 without falling. Each ascent was preceded by 3 minutes of route preview, as a pre-ascent
242 visual inspection is a key climbing performance parameter (Sanchez et al., 2012). The
243 protocol was approved by the local University ethics committee and followed the declaration
244 of Helsinki. Procedures were explained to the climbers, who then gave their written informed
245 consent to participate.

246

247 **Data collection**

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

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

257

258 **Data analysis**

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

262 As stated previously, hip displacements of climbers not only correspond to 3D translations,
263 but also to 3D orientations (Cordier, Dietrich, & Pailhous, 1996; Sibella et al., 2007;
264 Zampagni, Brigadoi, Schena, Tosi, & Ivanenko, 2011). Therefore, in this study, climbing
265 fluency was measured by computing hip trajectory and orientation smoothness via calculating
266 the jerk coefficient. To determine either trajectory jerk or orientation jerk, the orientation of
267 the sensor is required, first by removing the component due to gravity, since acceleration is
268 measured in the sensor referential, and second, by determining the angular acceleration. By
269 combining the accelerometer, gyroscope and magnetometer raw data, it was possible to
270 compute orientation of the IMU with respect to the fixed frame of Earth reference (magnetic
271 North, East and gravity directions) (Madgwick, Harrison, & Vaidyanathan, 2011). From this

272 point, it is straightforward to calculate the acceleration of the hips in the fixed Earth reference
273 frame, and then determine the jerk coefficient (for more details about the method and
274 equations, see Seifert, Orth, et al., 2014). For a trajectory $x^{GF} \in \mathcal{C}^3([0, T])$, the jerk $J_{x^{GF}}$ was
275 defined as:

$$276 \quad J_{x^{GF}}(T) = C \int_0^T \| \ddot{x}_s^{GF} \|^2 ds \quad (\text{equation 1})$$

277 where C was a normalization constant to make the quantity dimensionless (Hogan & Sternad,
278 2009), depending on the height and the total climbing time T . In practice, instead of
279 computing x_t^{GF} (position on the wall) from a_t^{GF} with successive integrations, the term \ddot{x}_s^{GF}
280 was replaced by \dot{a}_t^{GF} . By derivation of a_t^{GF} , the constant gravity acceleration was removed,
281 leaving only the hip acceleration component. To compute the jerk coefficient $J_z(T)$,
282 measuring the hip 3D orientation smoothness, a definition similar to Equation (1) was used,
283 replacing the position acceleration by the angular acceleration (see Seifert, Orth, et al., 2014).
284 As stated previously, in rock climbing, Pijpers et al. (2006) distinguished exploratory and
285 performatory touching movements of potential holds on a rock surface, with or without it
286 being used as support during ascent. Assuming that affordances correspond to opportunities
287 or invitations for action in a performance environment (Gibson, 1979; Rob Withagen et al.,
288 2012), an analysis of the relations between exploratory and performatory movements could
289 explain how climbers utilise affordances of rock surface features, i.e., to perceive 'climb-
290 ability' of a surface and exploit environmental properties to act (Boschker, Bakker, &
291 Michaels, 2002; Boschker & Bakker, 2002; Pijpers et al., 2006). Therefore, the capacity to
292 utilise affordances in climbing performance could be approached by observing the ratio
293 between touched holds and grasped holds, according to the 'three-holds-rule': skilled climbers
294 negotiate a surface by touching fewer than three surface holds before grasping a functional
295 one. Thus, data on exploratory and performatory movements were collected from video

296 footage of performance, and the touched/grasped holds ratio was computed on the indoor
297 climbing route.

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

309

310 **Statistical analysis**

311 Normality of distribution and homogeneity of variance was checked before using parametric
312 tests. Comparisons between indoor wall climbing and ice climbing conditions for jerk of hip
313 trajectory $J_x(T)$, jerk of hip orientation $J_z(T)$, exploratory movements, performatory
314 movements, total number of actions, the exploratory/performatory ratio, and time of ascent
315 duration, were undertaken by Student t -tests with a level of statistical significance set at
316 $P < .05$. Then, effect size for a Student t -test (i.e. Cohen's d ; Cohen, 1988) was calculated,
317 given the mean (m_x) and standard deviation (S_x) for two independent samples of equal size:

$$318 \quad d = \frac{|m_1 - m_2|}{\sqrt{(S_1^2 + S_2^2)/2}}$$

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

321

322 **Results**

323 Table 1 indicates a significantly higher jerk of hip trajectory $J_x(T)$ and jerk of hip orientation
324 $J_z(T)$ in the ice climbing condition, supporting the view of lower levels of fluency when
325 climbing frozen waterfalls, than on an indoor climbing wall. Moreover, climbers exhibited
326 three times more actions and longer ascent duration to cover the same vertical distance in ice
327 climbing than under the constraints of the indoor climbing wall (Table 1). These findings
328 were explained by the fact that climbers realised significantly more exploratory movements in
329 ice climbing than on the indoor climbing wall (Table 1); in particular, we observed one
330 exploratory movement (i.e. one ice tool swing) for one ice tool anchorage during ice
331 climbing, whereas there was one exploratory movement observed (i.e. one touched hold)
332 during the whole ascent on the indoor climbing wall (i.e. 20 holds set by the setter).
333 Therefore, a significantly higher exploratory/performatory movement ratio was observed in
334 the ice climbing condition (Table 1).

335 *Insert table 1 about here*

336 **Discussion**

337 The results of this study confirmed the positive transfer of performance between climbing on
338 an indoor climbing wall and ice climbing because all the participants were able to reach the
339 top of the route without falling and resting. On the one hand, these results revealed the
340 existence of *general* transfer processes between these two distinct task and environmental
341 constraints supported by affordances for: (i) controlling their body weight on a vertical
342 surface and counteracting the force of gravity, (ii) using different limb extremities to achieve
343 a vertical displacement trajectory, and (iii), continuously coupling perception and action

344 subsystems to negotiate the performance environments (e.g. exhibited by exploratory actions
345 which led to successful ascents in the rock and ice climbing tasks). These findings on the
346 effects of *general* transfer concur with data reported by Seifert et al. (2013) who showed that
347 climbers with previous experience of an indoor climbing wall were able to transfer their stable
348 perception-action couplings to an ice climbing task. Positive transfer at a *general* level was
349 revealed when their participants exhibited higher levels of climbing fluency, fewer
350 exploratory movements and a larger range of movement and coordination patterns than a
351 group of novices (Wagman & Van Norman, 2011; Withagen & Michaels, 2002). For
352 example, in the climbing task, transfer was observed to occur between performance on the
353 indoor climbing wall and icefall environments when the ice tool was readily adapted to
354 support the control of body weight and the use of extremities for ascent.

355 However, the more extensive exploration behaviours observed on the ice route,
356 suggested the need for more *specific* perception-action couplings in the icefall environment to
357 support the anchoring of the ice tool in existing *hook-able* structures, requiring further
358 attunement to properties of surface holes in the participants. With practice in rock climbing,
359 climbers seem able to calibrate hand-grasping patterns afforded by the shape of holds (Seifert,
360 Orth, Héroult, & Davids, 2013). Similarly, ice climbers seem able to calibrate the ice tool
361 actions (i.e. swinging vs. hooking) according to the density, thickness and temperature of the
362 icefall. These examples emphasized that, in both the rock and ice climbing tasks, climbers
363 were able to scale their perceptions and actions to environmental properties by exploiting
364 exploratory behaviours, supporting the notion of *general* processes of transfer between the
365 tasks. In other words, it seems that skill transfer from an indoor climbing wall to performance
366 on an icefall only provides opportunities for *general* transfer because in the ice climbing task,
367 skilled performance is predicated on the utilisation of specific affordances, i.e., a relationship
368 that emerged from matching the perceived physical features of the ice tool (i.e. weight,

369 location of centre of mass, camber of stick, blade resonance), of the icefall (e.g., density,
370 temperature, thickness of the ice) and of the individual (i.e. performance goals, capacity for
371 haptic perception, skill level, past experience).

372

373 These results confirmed that specificities of the ice climbing task (e.g. ice tool use) and icefall
374 environment properties (e.g. shape, temperature, thickness and ice density) require the
375 formation of specific perception-action couplings which can only emerge from climbing
376 performance on an ice fall. We postulated that in an ice climbing task, the acquisition of a
377 functional information-movement coupling would be facilitated through a circular coupling
378 between the individual, ice tool and icefall properties, supporting the idea that the *individual -*
379 *ice tool – icefall* system is supported by perception of *ice tool affordances*. This interpretation
380 signifies that the climber needs to perceive the icefall properties through the use of the ice
381 tools, and inversely, to use the ice tools, the climber must be able to pick up properties from
382 the ice fall performance environment. Seifert et al. (2014) showed that, depending on the
383 thickness and density of the icefall, the climbers could either hook existing holes with the
384 blade of the ice tool or swing the ice tool when the icefall was very dense. Inversely, the blade
385 of the ice tools could be used to perceive whether a hole was deep and “hook-able” or small
386 and fragile, requiring participants to swing their ice tools. Gibson (1979) foreshadowed these
387 observations in arguing that “*when in use, a tool is a sort of extension of the hand, almost an*
388 *attachment to it or a part of the user’s own body, and thus is no longer a part of the*
389 *environment of the user. But when not in use, the tool is simply a detached object of the*
390 *environment, graspable and portable, to be sure, but nevertheless external to the observer”*
391 (p. 41). Previous experiments have already explored the ability of individual to detect tool
392 affordance by dynamic touch, showing that the tool mass distribution in terms of the inertia
393 tensor provided basis to distinguish tool properties for actions (Wagman & Carello, 2001,

394 2003). Our study provided data on how each individual interacted with ice tool properties,
395 according to the icefall properties, and the task goal of anchoring the blade of the ice tool.
396 Skill-based differences have already been reported in previous work revealing how beginners
397 tended to swing the ice tool into the icefall to create their own anchorage because they were
398 unable to perceive affordances for anchorage from existing holes in the ice fall (Seifert,
399 Wattedled, et al., 2014). Conversely, expert climbers showed much more adaptive flexibility
400 in using their ice tools in many different manners: as a broom to clean the stalactites that
401 mask a dense zone of ice, as a hammer that they can swing into the icefall to create deep holes
402 when needed, and as a hook to use exploit holes or steps (Seifert et al., 2014). Skilled
403 individuals tended to adopt tool use behaviours that minimized biomechanical costs of
404 performance (Jacquet et al., 2012). Our results showed both greater frequency of exploratory
405 (i.e. ice tool swinging) and performatory movements (i.e. ice tool anchoring) on the icefall
406 rather than on an indoor wall climbing. These results indicated higher biomechanical costs
407 (exemplified by higher jerk coefficient of hip trajectory and orientation), lower tool
408 affordance detection and icefall affordances detection in ice climbing. In other words,
409 climbers practising on an indoor climbing wall are not able to *fully* exploit the specific
410 richness of the landscape of affordances offered when performing on an ice fall (i.e. including
411 both environmental and ice tool functional features that contribute to the landscape of
412 available affordances; Bruineberg & Rietveld, 2014). Therefore, climbers need to be able to
413 gain specific experience by exploring both environmental constraints and functional features
414 of tools to achieve their task goals in different climbing environments. Through analysis of
415 skill transfer processes from an indoor wall climbing to an ice climbing environment, our
416 study emphasized the ability of climbers to exhibit positive *general* transfer (i.e. ability to
417 reach the top of the route without falls and rests), but with lower levels of climbing fluency
418 due to the specificity of ice tool and icefall affordances. In particular, ice tool anchorage is

419 often viewed as a challenging action by beginners for whom a confident anchorage means a
420 deep anchorage where the blade does not move (Seifert et al., 2014). A deep and stable blade
421 anchorage is often achieved through repetitive ice tool swinging. The action of anchorage and
422 de-anchorage is specific to ice tool use and might explain the higher values of jerk
423 coefficients in ice climbing. In conclusion, our results demonstrated that an ice climbing task
424 provided specifying information for the performance of specific functional behaviours.
425 Notably, ice climbers need to be attuned and calibrated to key functional and dynamical
426 features of an icefall and ice tools. This study suggested that tasks, which involve specific
427 transfer processes would enable learner to perceive relevant functional affordances by
428 specifying adaptive movement patterns to satisfy interacting performance constraints.

429

430 **Acknowledgement**

431 This project received the support of the CPER/GRR 1880 Logistic Mobility and Numeric and
432 the FEDER RISC N° 33172. The funders had no role in study design, data collection and
433 analysis, decision to publish, or preparation of the manuscript. The authors declared no
434 conflict of interest.

435

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588 **Table caption**

589

590 Table 1. Comparison between indoor wall climbing and ice climbing conditions for jerk of
 591 hip trajectory $J_x(T)$, jerk of hip orientation $J_z(T)$, exploratory movements, performatory
 592 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 climbing				ice tool swinging	ice tool anchorage	Total number of ice tool actions	Ratio swinging/anchorage	Ascent duration (s)
	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

593

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

596

597 **Figure captions**

598

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

601

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

608



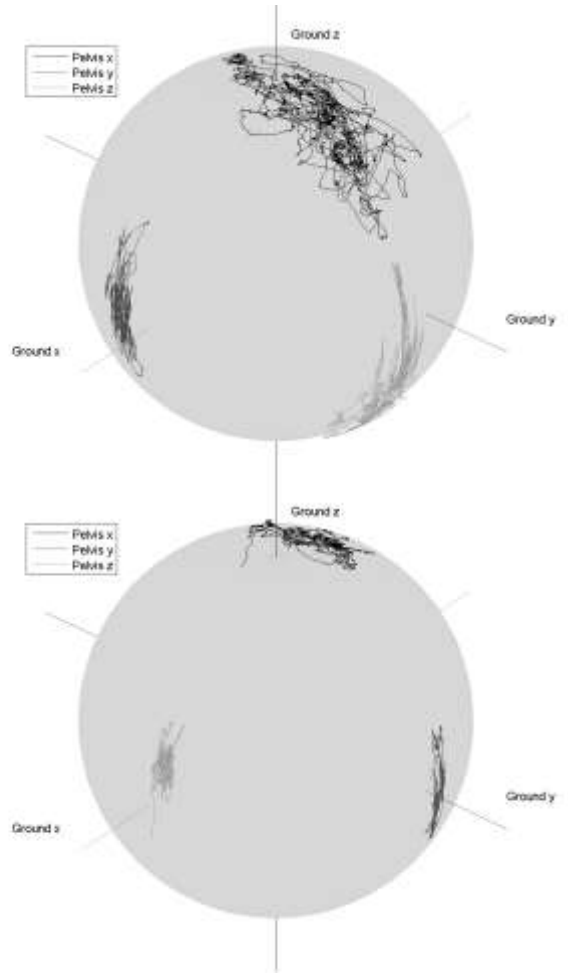
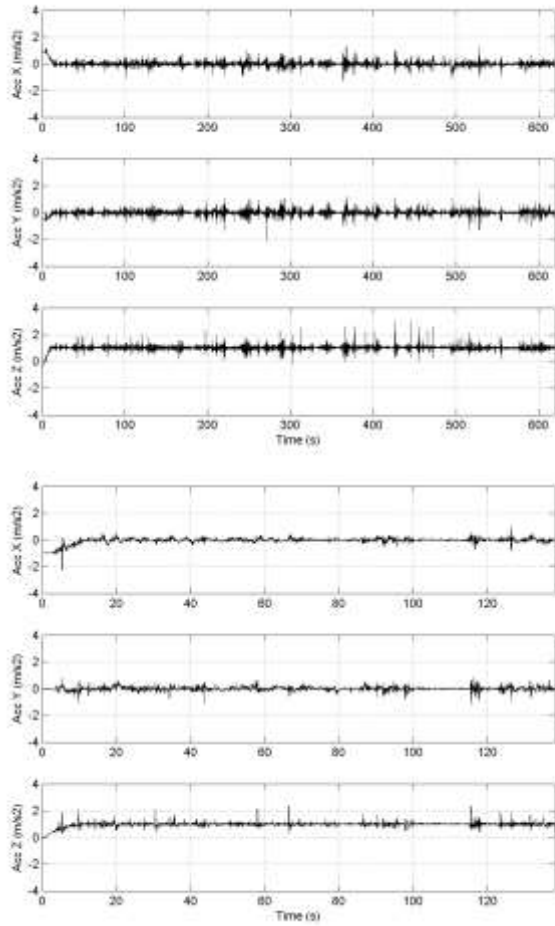
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Figure 1



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Figure 2