12 What current research tells us about skill acquisition in climbing

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Skilled movement has been defined as a refined organization of behaviours to optimize the ratio of mechanical work to energy expenditure in satisfying the interacting environmental, task and individual constraints (Newell, 1996). This chapter discusses how current research on learning in climbing can be used to support improvement in skill performance by managing practice task constraints during training. The aims of this chapter are twofold: first, to review the effects of practice constraints on skilled behaviour in climbing, and second, to develop a theoretical framework for guiding perceptual-motor learning in route climbing through learning design.

Introduction

Climbing requires an individual to adapt to a more or less vertical and ever-changing structure of a climbing surface with the task of completing a route without falling (Orth, Davids, & Seifert, 2015). Skilled behaviour in climbing is predicated on how an individual dynamically adapts actions to varied climbing surface properties (variations in shape, texture and relative distancing of features; Davids, Brymer, Seifert, & Orth, 2014). Due to the extreme postural constraints imposed by the small protrusive/sunken edges embedded into a sloped surface, climbers need to continuously regulate their use of the environment relative to their internal state during performance. For example, muscular fatigue reduces the ability to produce the required friction force at the fingertips (Vigouroux & Quaine, 2006) and can be intensified if an individual becomes 'blocked' (i.e. cannot perceive how to use holds to continue climbing; White & Olsen, 2010), uses inefficient movements (de Geus, O'Driscoll, & Meeusen, 2006), or does not perceive and exploit opportunities to rest (Fryer et al., 2012). Hence, improving climbing skill, in tasks requiring route finding (such as bouldering, sport and traditional climbing), can be facilitated by helping learners to detect and use relevant information sources during climbing to support successful performance and energy efficient actions (Orth et al., 2015).

In the emergence of skilled behaviour, three timescales of change (slow, moderately fast and fast) appear to exist. According to Cordier et al. (1993), 'fast' variables account for the dynamics of motor *performance*. Changes in the fast timescale, typically expressed in seconds, are observed as the temporary (re)organization of behaviours in a discrete performance trial. 'Moderately fast' variables, account for *learning*, refer to the relatively persistent adaptation of the individual to the environment, in a timescale perhaps expressed over several hours (Cordier, Mendès-France, Bolon, & Pailhous, 1993). The effects of learning can be observed over many performance repetitions (referred to as learning dynamics) and under retention and transfer conditions (Davids, Button, & Bennett, 2008). Finally, Cordier et al. (1993) defined 'slow' variables to account for the dynamics underlying the emergence of highly skilled behaviours. This timescale may be expressed across many months or years, and can be reflected in the structural/functional adaptations developed through progressive training (e.g. Bläsing, Güldenpenning, Koester, & Schack, 2014; Vigouroux & Quaine, 2006).

This chapter considers how skilled climbing is improved through learning, summarizing behavioural data observed as individuals negotiate climbing environments over repeated trials of practice and pre- and post-test interventions. Relatively few studies have reported learning effects during route climbing tasks and the aims of this chapter are twofold: to review effects of practice task constraints on skilled behaviours in climbing, and to propose a theoretical framework for enhancing perceptual-motor learning in route climbing. The chapter is organized into four sections. The first section considers the effects of skill on learning dynamics in climbing, considering potential mechanisms. Next we consider the perceptual-motor basis of skilled behaviour in climbing, leading to a framework for conceptualizing progressive improvement on the basis of skilled affordance perception in the third section. Finally, we discuss interventions that exemplify how the theoretical framework developed in earlier sections can be applied to a specific learning problem in climbing.

The effect of skill on the rate and level of learning in climbing

In a series of innovative studies, Cordier and colleagues (Cordier, Dietrich, & Pailhous, 1996; Cordier et al., 1993; Cordier, Mendès-France, Bolon, & Pailhous, 1994; Cordier, Mendès-France, Pailhous, & Bolon, 1994) evaluated the effects of practice during ten trials on the same route (set at a French Rating Scale of difficulty [F-RSD] of 6a). Skill level effects were assessed by contrasting the performance of an advanced group (F-RSD between 7a and 7b), with an intermediate group (F-RSD between 6b and 6c). Each climber's position on the wall was analysed by digitizing the movement of a light-emitting diode (LED), attached to the back at the waist, and video recorded with a camera during climbing. Digitized trajectories were projected onto the climbing wall plane, and spatial and temporal characteristics of performance were analysed. From the positional data several variables were calculated to characterize overall stability including: the geometric index of entropy (Cordier et al., 1993; Cordier, Mendès-France, Bolon, et al., 1994; Cordier, Mendès-France, Pailhous, et al., 1994); spectral (Cordier et al., 1996); fractal (Cordier et al., 1993); harmonic (Cordier et al., 1996); and phase portrait analyses (Cordier et al., 1996).

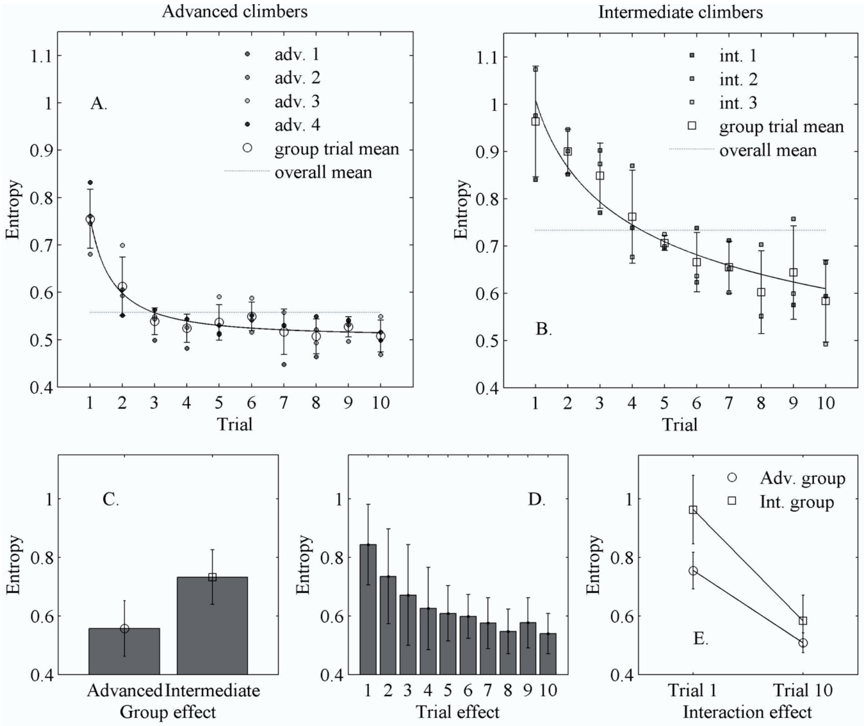

Figure 12.1 Data adapted from Cordier et al. (1993, p. 373) showing practice and skill effects as indexed by entropy of the hip trajectory when climbing the same route over ten trials. Int. = Intermediate climber, Adv. = Advanced climber. Error bars = ±1 standard deviation.

Cordier and colleagues showed how the existing skill level of learners affected their subsequent level and rate of performance improvement. Figure 12.1 summarizes the results of analyses undertaken by Cordier et al. (1993), displaying skill differences (Figure 12.1 Panels A, B and C); learning rates (Figure 12.1 Panels A, B and D), and level of learning (reflected in magnitude of change over ten trials; Figure 12.1 Panel E). The advanced group (Panel A) reached a stable state (a plateau in the rate of improvement) earlier (identified in Trial 3 in Cordier et al., 1993) than the intermediate group (Panel B) (identified in Trial 8 in Cordier et al., 1993). Both groups achieved a similar level of performance in terms of movement efficiency (captured by geometric index entropy) by the tenth trial of practice (see Figure 12.1, Panel E).

Cordier et al. (1996) emphasized that the advanced group typically used regular lifting movements (every 3 seconds [s] on average), whereas the intermediate group showed no clear tendency for displacements to recur at any particular frequency. Furthermore, phase portrait analyses of each group revealed that advanced individuals displayed more regular movement characteristics (stable dynamics), whereas intermediate climbers exhibited less predictable dynamics.

These findings suggest how advanced climbers achieve a stable ‘coupling’ between their repertoires of existing capabilities and changing environmental features (changing as function of the climbers’ movements). In contrast, the relative difficulty of the route for the intermediate climbers meant that these less skilled individuals were less ‘coupled’ to the climbing surface throughout practice (Cordier et al., 1996, p. 805). The more sensitive temporal movement analyses placed into perspective the large learning effect along the spatial dimension shown by the intermediate climbers who achieved similar levels of movement efficiency (as indexed by entropy) relative to the advanced group (refer to Figure 12.1, Panel E), but still required practice to improve efficient temporal dynamics.

The practical implications of these findings suggests that once an individual finds a globally effective route pathway, a key constraint on improving performance on a given practice route, it should influence the temporal structuring of actions. For example, once an effective route path has been determined, a climber may further improve performance by linking movements in a more periodic fashion. For climbers where the gap between the route difficulty and their current ability is too small, as was the case with the advanced group, the learning effect may be limited, with subsequent trial-to-trial dynamics likely to follow a power law function (such as discussed in Guadagnoli & Lee, 2004; Newell, Mayer-Kress, Hong, & Liu, 2009). Emphasizing training at an easy relative difficulty may, therefore, be inefficient for progression of the individual’s red-point (highest performance grade achieved with physical practice) or on-sight (highest performance without prior physical practice) ability level. On the other hand, for individuals learning on a route that is close to the limit of their ability level it may be expected that a learning effect can continue to be meaningful over multiple days of practice.

The role of perception-action coupling and climbing affordances in learning

Perception-action coupling refers to the patterned relationships that are formed between human movements and perceived information in a performance environment. It is a concept that underpins the design of practice contexts (Handford, Davids, Bennett, & Button, 1997). The suggestion is that internal and external sources of information can be detected by the individual’s sensory system and perceived directly, providing affordances for action. Affordances are defined as opportunities for action in a performance environment with reference to a particular individual (Gibson, 1979). A major difference between individuals of varying experience levels is in the information attended to, and, therefore, the possible opportunities (affordances) available to be utilized.

The relationship between skill and affordance perception was examined in detail by Boschker et al. (2002). One experiment involved three groups of climbers: an advanced group (F-RSD from 7a to 7c+), a lower grade/intermediate group (F-RSD from 4c to 5c), and an inexperienced group (no climbing experience whatsoever). Participants were required to visually inspect a route of 23 holds (set between 5c to 6a F-RSD) for a defined period of time, and the task-goal was to recall the position and orientation of the holds needed to complete the route. In the first trial, an inspection period of 2.5 minutes was given; in subsequent trials participants were then given a 5 second view period. The average accuracy group values for successive trials are shown in Figure 12.2, Panel A (see also Boschker et al., 2002, p. 29). In another experiment, an inexperienced group and an advanced group undertook the same recall task as the first experiment, but participants were instructed to ‘think aloud during the reproduction task, verbally

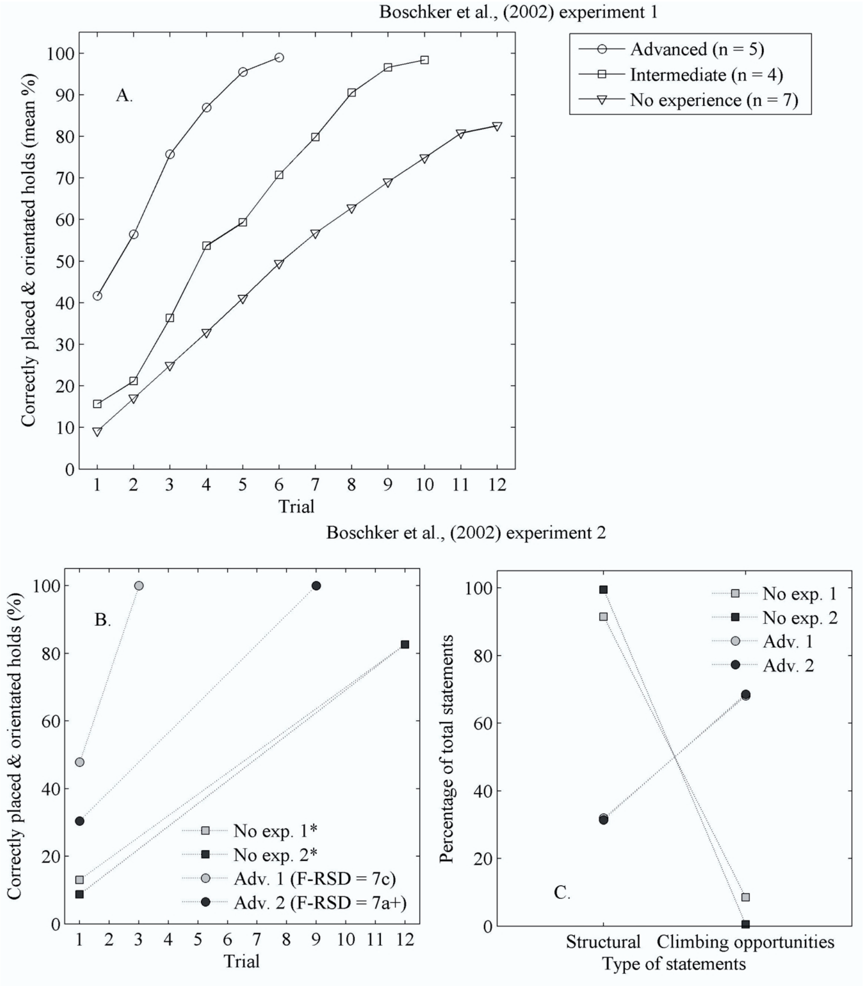

Figure 12.2 Recall performance and verbal reports during a route recall task reported in Boschker et al. (2002). The task involved a climbing route set between 5c to 6a F-RSD. Participants repeatedly attempted to reconstruct the route until it was fully and accurately reproduced or until the end of Trial 12. Adv. = advanced climber, No exp. = no experience in climbing, F-RSD = French rating scale of difficulty. * = actual values at Trial 12 were not reported. Trial 12 data for both inexperienced climbers in Panel B is instead taken from the estimated mean percentage of the no experienced group at Trial 12 from Experiment 1.

reporting everything they thought about, especially what was perceived when looking at the climbing wall and why they reproduced the holds in the way they did' (Boschker et al. 2002, p. 32). Verbal reports were divided into statements referring to 'structural features' or 'climbing opportunities' (for details refer to Boschker et al., 2002, pp. 32–33) (Figure 12.2, Panels B and C).

These results of Boschker et al. (2002) showed that the advanced climbers had more accurate recall than both intermediate and less experienced climbers after 2.5 minutes of preview (Figure 12.2, Panel A, Trial 1 data). Additionally, general experience in climbing tasks supported a higher rate of recall over repeated trials (Figure 12.2, Panels A and B). According to Boschker et al. (2002) the same mechanism underpinned superior Trial 1 performance and superior trial-by-trial performance. They proposed that individuals had picked up 'clustered'[1] information if they recalled more than nine items after the 5 s viewing period, thus exceeding short-term memory capacity (but see Wagman & Morgan, 2010). Specifically, to overcome inherent limitations on short-term memory, climbers must use different types of information allowing them to draw on experience (i.e. long-term memory) rather than storing more information in short-term memory.

In climbing, information can be nested in the form of climbing opportunities that reflect the functional properties of holds, which refer to their reachability, graspability, and stand on-ability, as well as opportunities for specific climbing moves (Boschker et al., 2002). For example, various climbing techniques require specific bodily configurations with respect to orientation and relative positions of numerous holds (Seifert et al., 2015). This allows multiple holds to be collectively perceived as a single, nested, climbing opportunity (Boschker et al., 2002, p. 31). Data reported in Experiment 2 (Figure 12.2, Panels B and C) support this contention, indicating that as individuals gain climbing experience, they perceive affordances that hold properties present (i.e. functional properties). Inexperienced individuals almost exclusively attend to the structural details of a surface (Figure 12.2, Panel C; see also Seifert, Wattebled, et al., 2014). This invites speculation that, should climbers perceive movements in series (as nesting of climbing actions in sequence), this skill might facilitate recall of more holds and may be one of the reasons recall performance increases with skill level (Boschker et al., 2002).

Practically, these findings imply that skilled behaviour is underpinned by perception of affordances that support effective and efficient climbing. An individual's attention during practice of a climbing route should, therefore, be guided toward the functional properties of the climbing surface that support skilled behaviour. Understanding what prevents holds from being perceived as climbing opportunities may help to improve skilled affordance perception. Fundamentally, this would emphasize designing route properties (such as the architecture of holds or wall slope) during training based on the individual's unalterable (such as anthropometrics) and trainable capabilities (such as strength) in order to ensure that climbing actions are within physical capabilities. Indeed, even inexperienced climbers can perform recall tasks at the same level as advanced climbers as long as the route is within their current climbing ability, whilst advanced climbers lose their recall performance advantage over inexperienced climbers when tested on an ‘impossible to climb’ route (Pezzulo et al., 2010). Following this line of reasoning, interventions that improve action capabilities, such as finger and hand grip strength and endurance (Vigouroux & Quaine, 2006) or upper-limb power and endurance (Laffaye, Collin, Levernier, & Padulo, 2014), may support training transfer (such as climbing unfamiliar routes in competition) on the basis of the behavioural opportunities made available this way. Indeed, this expectation suggests that certain exercises can enable positive transfer based on motor system adaptation; however, these expectations are not always reasonable, particularly in more advanced individuals (Issurin, 2013).

Improving skilled perception of affordances though constraints manipulations

Temporary constraints manipulation can be used to affect affordance perception and potentially lead to meaningful qualitative changes in behaviour. According to Gibson (1979), ‘The observer may or may not perceive or attend to the affordance, according to their needs, but the affordance, being invariant, is always there to be perceived’ (cited in Pijpers, Oudejans, & Bakker, 2007, p. 108). Pijpers et al. (2007) argued that, since an environment can contain many affordances (e.g. a hold can be grasped in different ways), many factors, such as an individual’s internal states, influences their selection. Design factors, such as climbing height (Pijpers, Oudejans, Bakker, & Beek, 2006) or top-rope versus leading conditions (Hardy & Hutchinson, 2007), reflect environmental and task constraints that do not change the available affordances, but that can interact with an individual’s intentions, changing affordance perception based on altered needs. For example, increased anxiety may lead an individual to focus their intention toward remaining fixed to a surface, with attention directed toward perceiving affordances that support stability. This can be observed in behaviours like reduced distance between grasped holds or a more proximal (closer to the body) attentional focus (Pijpers et al., 2006).

Figure 12.3 represents an integration of the concepts raised so far, placing into perspective the evolution of learning with respect to factors that affect skilled affordance perception. The model makes initial assumptions that affordance perception is qualitatively distinct based on actions supported, and that skilled affordance perception correlates with skilled climbing. Early in learning, fundamental affordance perception supports baseline needs such as avoiding falling. With more advanced performers, or through practice, affordances are perceived in terms of improving performance, such as periodically chaining movements. The model in Figure 12.3 is layered into concentric circles to indicate how affordances are nested atop relative to each other, where the perception of more advanced affordances entails the, perhaps, implicit perception of fundamental concerns. For example, perceiving hold usability can support remaining fixed to a surface although this may not be the intention of an individual, which may be instead efficient progression. The model also indicates that beginners can perceive skilled affordances, as a function of relative route difficulty. For example, a beginner inspecting a route with numerous and very large easy to grasp holds can

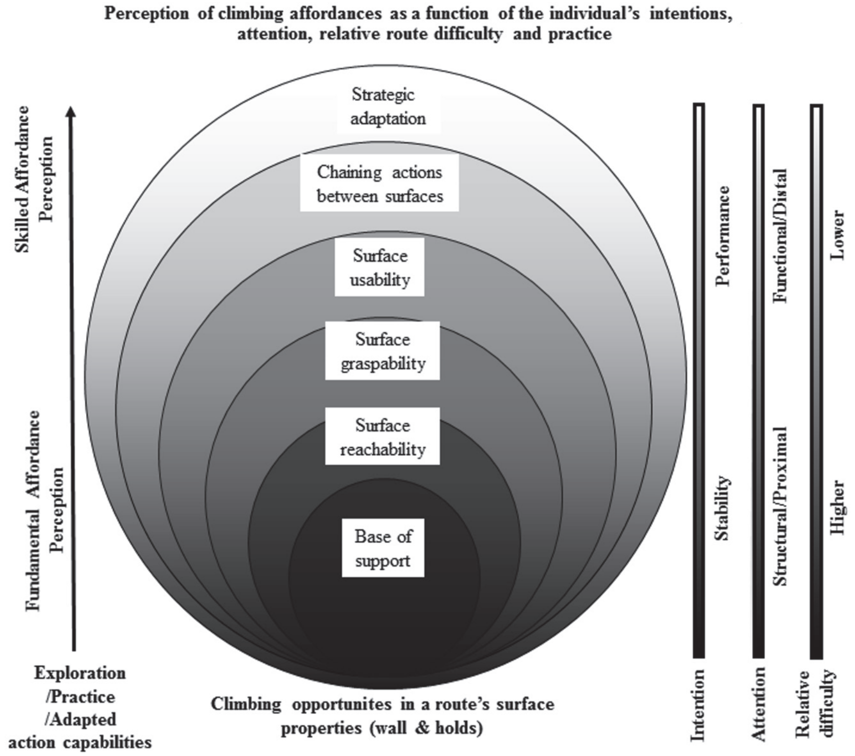

Figure 12.3 Affordance perception and skill in climbing.

still perceive hold usability. However, as task difficulty increases (e.g. holds get smaller), a beginner's action capabilities may require their needs to shift towards affordances for seeking out characteristics of holds that support stability.

Implementation: effect of constraints manipulation on learning dynamics and the transfer of skill in climbing

Learning design is based on the structuring of practice and provision of learning opportunities by managing interactions at the level of the individual learner and their training constraints (Renshaw, Chow, Davids, & Hammond, 2010). Practically, simple constraints manipulation, such as providing instructions (Boschker et al., 2002) or modifying hand hold properties (Orth, Davids, & Seifert, 2014), can directly impact upon whether climbing affordances are utilized. Thus, effective learning design involves managing the interaction between constraints that facilitate progression toward skilled affordance perception during training. In this final section, we exemplify a learning intervention regarding a specific training problem.

Orth et al. (2014) assessed the impact of practice under three different conditions on climbing entropy. Routes were designed assuming that participants would use

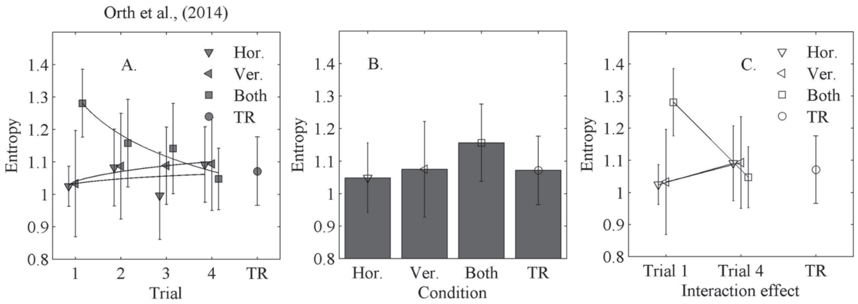

Figure 12.4 Caption needed. Hor. = horizontal-edge condition, TR = transfer, Ver. = vertical.

Source: Data adapted from Orth et al. (2014).

pre-existing experience to perceive affordances for supporting efficient traversal. Six individuals (with a self-reported red-point F-RSD = 6a) were observed over four separate days practising on three routes. On each day, participants climbed the three routes once each in counterbalanced order. Routes were each set at 5c F-RSD, but were different in terms of handhold orientation set into each route, including: handholds with horizontally aligned edges graspable with the knuckles running parallel to the ground; handholds with vertically aligned edges graspable with the knuckles running perpendicular to the ground; and handholds with both a horizontally aligned edge and a vertically aligned edge. The double-edged route was designed to allow climbers to explore a variety of grasping actions by presenting a choice at each hold. A transfer test was also included using a combination of the hold types from the three different learning conditions (Figure 12.4).

Data suggests that experienced climbers only displayed a learning effect on the double-edged route (Figure 12.4). Additionally, positive transfer can be inferred from the clear difference between Trial 1 (on-sight) on the double-edged route and the on-sight transfer test performance. Implications of these findings are twofold. First, in experienced climbers, an existing platform of expertise can support rapid adaptation to a route, even if unfamiliar. On the other hand, introduction of choice into handhold properties affords adaptation and problem solving at the level of route finding. Orth et al. (2014) suggested that successful transfer was induced because of the experience of climbers on the double-edged route. Specifically, the capacity to use existing experience to adapt rapidly to the multiple hold choices found in the new climbing route underpinned the positive transfer of skill. In a follow -p study, Seifert et al. (2015) used the same experimental procedure as Orth et al. (2014), but considered potential mechanisms underpinning positive transfer by assessing the number of exploratory actions in relationship to entropy. A key finding was that whilst Trial 1 conditions showed both high levels of entropy and exploratory behaviour, on the transfer test, more efficient performance was associated with higher amounts of exploratory behaviour. According to Seifert et al. (2015), these findings indicate that climbers can learn to explore efficiently. Thus, a potential behavioural mechanism underpinning positive transfer might be effective exploratory behaviours.

Practically speaking, any on-sight climb might be conceptualized as a skill transfer problem, requiring adaptations during performance with unfamiliar surface properties and in contexts with dynamic environments (such as outdoors). Assuming positive transfer is supported by skilled affordance perception, helping individuals to explore and learn how to find information specifying efficient climbing opportunities is one approach that might improve on-sight climbing ability. Similarly, motor adaptions, such as improving a beginner's ability to explore balance for longer periods of time, are likely to assist with the transfer of skill or learning (improved rate of learning in new contexts due to experience), because motor adaptations can support longer periods of remaining in contact with holds.

Future research and perspective: the role of exploratory behaviour in understanding the relationship between learning and affordances

Many of the ideas discussed imply that exploration during practice is a potential mechanism that can help learners to improve performance over time. In climbing, exploratory behaviour has been observed with respect to qualitatively different climbing affordances (Table 12.1). For example, exploratory behaviours related to the functional properties of holds can reveal opportunities for movement at the hips without subsequent displacement (Boulanger, Seifert, Hérault, & Coeurjolly, 2015). Exploration in postural regulation during periods of immobility suggest that prolonged pauses during climbing may still be useful to the learner. Postural exploration seems particularly relevant for beginners considering this may allow the individual to determine more efficient positions and new body–wall orientations that may be important for more advanced movements. On the other hand, the more advanced individual may benefit from immobility for different reasons. For example, one possibility is that static states can afford resting and recovery and should be distinguished from exploration as a performatory behaviour (Fryer et al., 2012). Another possibility is that the individual may benefit from immobility by visually exploring upcoming holds, perhaps indicated by the amount of fixations made and their relative distance to the individual during immobility (Sanchez, Lambert, Jones, & Llewellyn, 2012).

Another form of exploration includes reaching to touch a hold but not grasping it or using it to support the body weight (Seifert et al., 2015). This form of exploration is believed important for achieving an accurate body-scaling to the environment (Pijpers et al., 2007) and, perhaps, as different techniques, such as dynamic moves, become part of an individual's action capabilities this boundary of reachability may distinguish individuals of different abilities. Making adjustments in how a hold is grasped prior to using it to support displacement is also a form of exploration perhaps in terms of graspability or usability. For example, prior to applying force to a hold climbers can be seen, in some cases, to make adjustments to how they position their hand on a hold. Such exploratory behaviour may be important to improve the amount of friction that can be applied to the hold (Fuss, Weizman, Burr, & Niegl, 2013), or enable a qualitatively different way of using the hold, such as in cases where multiple edge orientations are available (Seifert, Orth, et al., 2014).

Table 12.1 Specific forms of exploration directed toward qualitatively distinct affordance

Affordance layer	*Movement pattern*	*Intention*	*Information foci*	*Example*
Base of support	'X' shaped, COM (centre of mass) immobile	Maintain contact with the surface	Holds for hands and feet	Seifert et al., 2011
Surface reachability	Touching not grasping, COM immobile	Explore reachability	Individual–surface distance	Pijpers et al., 2006
Surface graspability	Grasping actions without subsequent usage, COM immobile	Explore graspability	Surface geometric properties (structure)	Fuss et al., 2013
Surface usability	Performatory actions with progression, COM mobile	Use surfaces to prepare or achieve route progression	Movement opportunities (function)	Boschker et al., 2002
Chaining	Spatial-temporal efficiency of linked actions	Use upcoming surface to regulate current positioning	Distant surfaces, movements in series	Cordier et al., 1993
Strategic adaptations	Within route active recovery/ exploration	Use of surfaces to rest or plan	Distant surfaces, internal state	Fryer et al., 2012; Sanchez et al., 2012

It has also been speculated that exploration can support perception of opportunities for new climbing moves (Seifert, Orth, Herault, & Davids, 2013). This may be observed by examining how climbing actions are different over practice. For example, from one trial to the next, different route pathways, body orientations or grasping patterns might be used, reflecting exploration emerging during the dynamics of learning. Thus, during intervention the nature of learning behaviour may be better understood by evaluating the level at which exploration emerges. A substantial challenge, therefore, for future of learning research in climbing is in measuring exploration at different levels of analysis with respect to performance, both in technically manageable and theoretically consistent ways.

Conclusion

Here we discussed how skill acquisition in climbing can be understood, revealed through temporary interactions between the individual learner and the performance environment throughout practice. Pedagogical practice in climbing should focus on helping individuals to skilfully interact with climbing environments, where even inexperienced individuals bring to the task a unique set of adaptations that can form the basis from which to design a learning environment. Such a learning process entails a progression in the individual's capacity to efficiently adapt to new climbing routes, a process facilitated by skilled affordance perception.

Practical implications

- Observing performance over repeated trials of practice allows the evolution toward skilled behaviour to be assessed. Additionally, through pre- and post-test measures of performance, and testing the transfer of skill and learning, the relative importance of an intervention can be interpreted.
- The transition toward skilled behaviour involves developing exploratory behaviour across different levels (i.e. hands/feet, limb and hip orientations), which support each learner's current needs (such as stability or improved performance).
- The practitioner can influence affordance perception though manipulating constraints during training to influence each individual's intentions, needs and action capabilities. For example, a task or environment can be modified to encourage the individual to actively explore.

Summary

- Learners in climbing appear to first improve performance through route finding by determining an efficient spatial pathway, followed by improved temporal linking of movements by reducing stationary periods during ascent. A high degree of spatial-temporal efficiency enhances climbing performance.
- Dynamic internal (e.g. strength or confidence) and external (e.g. handhold positions and postural orientations) factors directly influence climbing opportunities (affordances) perceived and used by learners during practice.
- Skilled perception of climbing opportunities is essential for climbing efficiency. Early in learning, affordance perception provides a means of remaining fixed to a surface. Later in learning, a climber perceives affordances for linking movements in a more periodic manner, supporting efficient and effective performance.

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Note

1 The term 'nested' is preferred here because the term 'clustered' implies that only spatial information has been perceived, thus it does not effectively capture the possibility that perceiving affordances also includes temporal properties.

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