# Hold design supports learning and transfer of climbing fluency

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**Abstract**

Being a discipline with a broad range of genres, rock climbing is an activity where participants aim to generalize the skills they learn. A training strategy for achieving skill transfer was explored in a group of experienced climbers. Specifically, we tested the effect of practicing on three routes, each of the same difficulty but where handholds supported opportunities for using either a single technical action or multiple actions. Transfer of climbing fluidity in terms of the geometric index of entropy (GIE) of the hip trajectory was then tested. GIE showed a learning effect only when practice was undertaken on a route designed with multiple graspable edges. Practice on the more complex route best explains why the participants' successfully generalized climbing fluidity under transfer conditions.

**Key words**

entropy, climbing affordances, skill transfer, motor learning, meta-stability

**Main text**

## 1. Introduction

Rock climbing is a discipline that encompasses a variety of genres (mountaineering, traditional climbing, sport climbing and bouldering). Due to the diversity of climbing genres many participants aim to transfer (or generalize) their learning. In order to promote participation across genres that manages the risks inherent to climbing, there is role for developing transferrable skills.

Experience in rock climbing has been previously shown to facilitate the transfer of climbing fluency to a novel climbing genre (ice climbing) (Seifert, Wattebled, et al., 2013). Experienced rock climbers are able to transfer climbing fluency by reducing behaviours devoted to exploration and through using a broader range of movement patterns (Seifert, Wattebled, et al., 2013). Seifert et al., (2013) suggested that a mechanism underpinning the rapid adaptation to the novel environment was in the rock climbers ability to perceive climbing affordances in the ice-fall during their traverse (Seifert, Wattebled, et al., 2013).

Climbing affordances are the behavioural opportunities for the use of structural features in climbing walls perceived by individuals (Boschker, Bakker, & Michaels, 2002; Pezzulo, Barca, Bocconi, & Borghi, 2010). Climbing affordances are determined by information-based relationships between structural characteristics of the climbing surface relative to the structural and functional characteristics of the individual (Seifert et al., 2014). Knowledge of climbing affordances supports: a more rapid adaptation to climbing a new route

(Boschker & Frank, 2002), more fluid climbing (Sibella, Frosio, Schena, & Borghese, 2007), more efficient exploration of the climbing surface (Seifert et al., 2014), and the transfer of climbing fluency (Seifert, Wattebled, et al., 2013). Determining information that specifies climbing affordances requires experience in climbing tasks (Boschker et al., 2002; Seifert, Wattebled, et al., 2013).

Induced movement variability during practice has been widely connected to improved retention and transfer of skills (Chow, 2013; Magill & Hall, 1990; Ranganathan & Newell, 2013; Schöllhorn, Mayer-Kress, Newell, & Michelbrink, 2009). The mechanisms that underpin the ability to reinvest learning to different conditions have been related to increased exploration of different movement patterns and the information-based relationships used to control them (Chow, Davids, Hristovski, Araújo, & Passos, 2011; Huet et al., 2011; Magill & Hall, 1990; Ranganathan & Newell, 2013; Schöllhorn et al., 2009).

Meta-stability is a regime of movement coordination where multiple affordances functionally overlap (Hristovski, Davids, Araújo, & Button, 2006). Meta-stability refers a regime of coordination where different parts of the movement system become loosely coupled allowing a reorganization to occur (Kelso, 2012). During practice in a metastable regime, movement patterns are spontaneously explored from trial-to-trial (Hristovski et al., 2006; Hristovski, Davids, Araújo, & Passos, 2011; Pinder, Davids, & Renshaw, 2012). Seifert and colleagues (2013) detailed an approach for setting up a meta-stable regime in climbing by using holds designed with edges that allowed either a slope grip (a grasping technique where the hold is taken with an over-hand grip, similar as one would take the rung of a ladder) or a pinch grip (a technique where the hold is taken with the knuckles running vertically with respect to the ground plane). In Seifert et al., (2013) A group of low experienced climbers (level 5c French Rating Scale of Difficulty (F-RSD)), practiced on a route (level 5c F-RSD) over four trials. It was found that exploration in terms of touching but not grasping holds was induced. As the exploration resolved with practice, the use of pinch style grasping increased and the ratings of the hold usability also increased (Sanchez & Dauby, 2009; Seifert, Orth, et al., 2013).

Through inducing exploration of climbing affordances, practice in a meta-stable regime may support the acquisition of generalisable skills, and would be evident in learning behavior and the ability to transfer skill to a different climbing route representative of a practice route. In representative design, skill is generalizable from one context to another (such as between a laboratory and a day-today setting) on the basis that features in the environment and task, across settings, support similar information-movement relationships (Araújo, Davids, & Passos, 2007).

A major unresolved problem surrounding skill in climbing is how to effectively understand the transfer of skill. Although practice effects have been observed (Boschker & Frank, 2002; Cordier, Dietrich, & Pailhous, 1996; Cordier, Mendès-France, Bolon, & Pailhous, 1993, 1994; Cordier, Mendès-France, Pailhous, & Bolon, 1994; Seifert, Orth, et al., 2013), studies are yet to have directly considered transfer related to practice interventions. The aim of this study was to determine whether practice in a meta-stable regime supports the transfer of climbing fluency to another route.

## 2. Methods

### *2.1 Participants*

Six participants (mean age = 23.6) were recruited based on their self-reported red-point level under top-rope conditions (level 6a F-RSD). They were observed under informed consent with ethical approval.

### *2.2 Experimental Procedure*

Data were collected over four days, with at least two days separating each session. All sessions involve participants upon arrival being equipped with a harness and climbing shoes. A LED was fixed to the harness over the sacroiliac joint. Participants then completed a climbing specific warm up. They then completed three top-roped climbs. Before each climb, individuals were allowed three minutes to visually look at the route (called route preview). Each climb was on a different experimental route, the order of which was counterbalanced. Between each climb, a seated 5 minute rest was enforced. On the fourth day of collection, climbers undertook a transfer test at the end (also with route preview and a top-rope). Data collection was via a fixed video that captured each entire traverse.

#### *2.2.1 Routes*

The three experimental routes practiced on by all participants, included a horizontal-only edged route, a vertical-only edged route and a double edged route (each hold had two graspable edges, a horizontally orientated and a vertically orientated edge). A transfer route was also climbed by all participants and was made up of a mixture of the holds used in the experimental routes. Each route was set by an experienced setter and the difficulty level held constant at level 5c. The ratings were confirmed by consensus with two other route setters. All routes were 10.4-m in height and consisted of 20 holds. For a summary of the experimental procedure see Figure 1, Panel A.

***Data treatment***

The primary variable of interest was the geometric index of entropy (GIE) of the displacement of the hips in the frontal plane.

The geometric index of entropy (GIE) is calculated by recording the distance of the path covered by the hips (L) and the perimeter of the convex hull around that path (c).

GIE = log2(2L/c)

According to Cordier, Mendés-France, Pailhous et al. (1994) the geometric entropy can assess the amount of fluency of a curve. The higher the entropy, the higher the disorder of the climbing trajectory. Skilful climbing can be reflected in a low entropy value because it is associated with a low energy expenditure, less variation in acceleration, and use of more technically advanced actions {Sibella, 2007 #170}.

To assess the GIE, video footage of each climb was corrected for distortion using Virtual Dub© (http://www.virtualdub-fr.org). The position of the LED during each climb was then digitized using a semi-automatic tracking procedure with

Kinovea© (http://www.kinovea.org) (see Figure 1, Panel B). The horizontal and vertical positions of each entire traverse were then used to determine the GIE for each climb.

***Figure 1 about here***

Statistical tests involved repeated measures ANOVA for the trial (4) and route (3) effects. Planned contrasts were then designed anticipating an interaction effect between route and the rate of change in GIE trial-to-trial. Follow-up t-tests were then used to compare the final trials on each route to the transfer test.

## 3. Results

### *3.1 Main effects*

No violation of heterogeneity was detected. There was a significant route effect, **F** (2, 10) = 5.49, **p** = .025 but, no significant trial effect, **F** (3, 15) = .516, **p** = .68. A significant route by trial interaction confirmed expectations and suggested that trial effects were present but, were dependent on which route the climbers were practicing on, **F** (6, 30) = 6.43, **p** < .001.

### *3.2 Route by trial*

The route by trial interaction indicated that trial-to-trial changes in entropy associated with practice differed according to what route was being practised on. To break down this interaction, contrasts were performed comparing each single edge route (vertical and double-edged routes) relative to the double-edged route across each trial-to-trial comparison (Trial 1-to-Trial 2, Trial 2-to-Trial 3, and Trial 3-to-Trial 4). The horizontal-only to double edged condition contrasts showed there was a significant difference between conditions when going from trial 1 to trial 2, **F** (1, 5) = 16.195, **p** = .010. The same trend was shown when comparing the vertical-only to the double-edged condition with contrasts showing there was a significant difference between conditions when going from trial 1 to trial 2, **F** (1, 5) = 40.089, **p** = .001. Although not part of the planned contrast, in comparing the effect of a different rate of change in entropy between trial 1 and trial 2 between the horizontal only and vertical only conditions there was no significant difference, **F** (1, 5) = .005, **p** = .947. Overall these data confirmed that practice effects were dependent on the route.

In examining the marginal means of the GIE plotted according to the condition and trials (see Figure 2), it is clear that the rate of change on the double-edged route showed a decreasing trend from trial 1 to trial 2, as opposed to both the horizontal-only and vertical-only edge routes that show an immediately lower amount of entropy compared to the double edged condition, and that remained fairly constant through practice.

*****************Figure 2 about here*****************

### *3.3 Transfer effect*

Dependent t-tests between each condition and the transfer test confirmed that the climbers' entropy values on the horizontal, **t** (6) = 0.671, **p** = .532, vertical, **t** (6) = 0.446, **p** = .674, and double-edged, **t** (6) = 0.612, **p** = .567, routes were not significantly different to the transfer condition.

## 4. Discussion

### *4.1 The effect of meta-stable route design on fluency during practice*

The purpose of this study was to determine if practice under a meta-stable regime could induce learning and facilitate the transfer of climbing fluency. In the single edge-only conditions data showed that both horizontal grasping and vertical grasping were already stable, acquired behaviours in the sample of climbers we observed. Furthermore, because the double-edged route induced learning, it suggests that the reason movement fluency was elevated was due to the effect of choice during route finding. Similar to findings by Cordier et al., (1994) participants needed to fine-tuned the ways in which they transitioned from one hold to the next through practice.

In Cordier et al., (1994) when individuals were presented with a novel route finding problem, climbers showed an initially elevated GIE, followed by a rapid reduction and asymptote. Their data followed a similar pattern to our data only in the double edged route. The key point of difference between our study and Cordier et al., (1994), is that our data indicated that it is not only the novelty of a route that is important for inducing learning, but how the route design supports variability in performance constraints.

### *4.2 Transfer of climbing fluency*

On the transfer route, climbing fluency remained at a level no different to the final trial of each of the three routes. These data are taken to indicate that it was the design of multiple grasping options in the double-edged route that drove the transfer of climbing fluidity. This is because the transfer route was made up of holds with characteristics of each of the three routes. If the climbers had not practised on the double-edged route, climbing fluency would have diminished and shown similar levels of entropy as on the first trial of practice on the double edged route. This interpretation of the data is further supported in that neither the vertical-only, nor the horizontal-only routes induced increased entropy at trial 1.

### *4.3 Implications and future research*

By making multiple affordances functionally available during practice, learning can be induced without needing to increase the absolute difficulty of a task (the likelihood of failure). This is an important finding especially in climbing where safety is a concern (Collins & Collins, 2012; Davids, Brymer, Seifert, & Orth, 2014). When different climbing affordances are made functionally available during route finding, a degree of uncertainty is represented requiring the climber to adapt. Because learning under these constraints is on an emergent basis (not instructed) this may facilitate the transfer of skill to a new set of representative constraints {Davids, 2014 #68}.

A practitioner can expect that inducing meta-stability will initially involve some form of movement variability that is stabilized with practice. The skills acquired that support climbing fluency appear to be available for reinvestment under similar levels of uncertainty during route finding on a new route. From an applied perspective in route design (for example in commercial, pedagogical, performance contexts), these findings open a new strategy for designing routes that is based on a theoretical framework {Davids, 2014 #68}.

Further research is needed to consider what sort of capacities for transfer would be observed in individuals who have not already stabilised movement patterns important for fluid climbing when using holds with a horizontal or vertical orientation. Previous work involving beginner climbers have suggested that individuals can rapidly adapt to horizontal climbing edges because they share similar affordances to day-to-day tasks (such as climbing ladders) (Seifert, Orth, et al., 2013; Seifert, Wattebled, et al., 2013). Beginners however, appear to require experience or intervention for finding affordances in handholds that require different hand and/or body orientations to those of ladder style climbing (Boschker & Frank, 2002). In respect to beginners, it can be tested whether meta-stability in route design is an effective strategy for coaching inexperienced climbers to acquire new skills. It can anticipated that beginners might benefit because they can more confidently use as a platform more basic movement patterns from which to explore affordances that need to be learnt (Davids et al., 2014).

For future research aimed at understanding the mechanisms of transfer, because exploration is often implicated in underpinning practice variability effects (Magill & Hall, 1990; Schöllhorn et al., 2009), future research can also consider measurement strategies to quantify exploration. A limitation of GIE is that it is a global indicator of learning (Cordier, Mendès-France, Pailhous, et al., 1994). Additional methods need to be developed to assess behaviours specific to exploration, such as the use of different movement patterns (Seifert, Wattebled, et al., 2013) or key periods during the use of handholds (Fuss & Niegl, 2008).

Related to the question of observing exploration is whether mechanisms that support transfer due to experience (as opposed to intervention) can also provide insights into more effective training design. Elite climbers (classified with ability levels greater than 7c+ and 8a+ F-RSD, females and males respectively (Draper et al., 2011)) are understood to very rapidly adapt to new constraints without displaying 'overt' exploratory behaviour (Fuss & Niegl, 2008; Seifert et al., 2014). As discussed in the introduction, experienced climbers are able to use information picked-up related to opportunities for action to more effectively perform in route preview (Boschker et al., 2002; Pezzulo et al., 2010) and route finding tasks (Sanchez, Lambert, Jones, & Llewellyn, 2012). It might be that in an elite group of climbers would immediately adapt to the task presented in this study through exploration that is at different levels of analysis, such as through visual exploration of information during preview.

### *4.3 Conclusion*

This study showed how informational properties in the indoor climbing context can be used to induce learning during route finding. Although experienced climbers may have a stable repertoire of movement patterns, it is important that they learn how to adapt these to new routes. By representing meta-stability through designing hand holds so that climbing affordances functionally overlap, learning can be induced and transfer of climbing fluency in route finding can be facilitated.

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## Figure Captions

**Figure 1.** Experimental design and data treatment. **Panel A.** The experimental design. **Panel B.** The semi-automatic tracking procedure on corrected footage.

**Figure 2.** Geometric index of entropy for each trial for each condition.

# Figures

## *Figure 1*

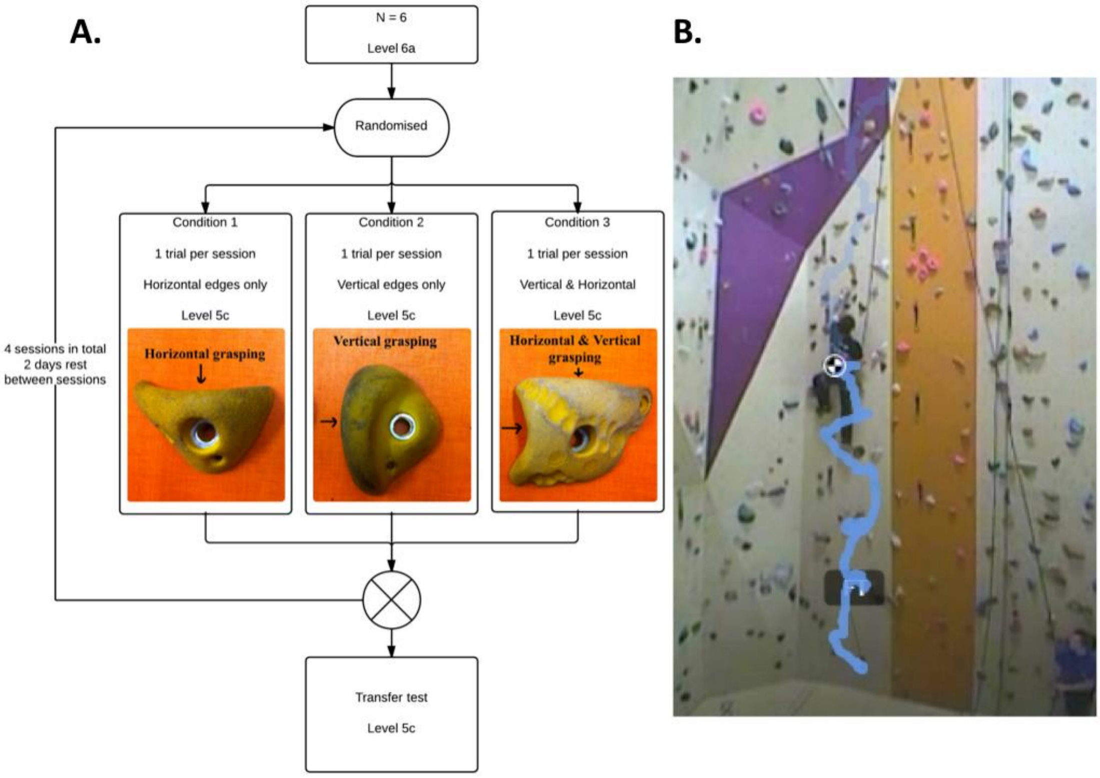
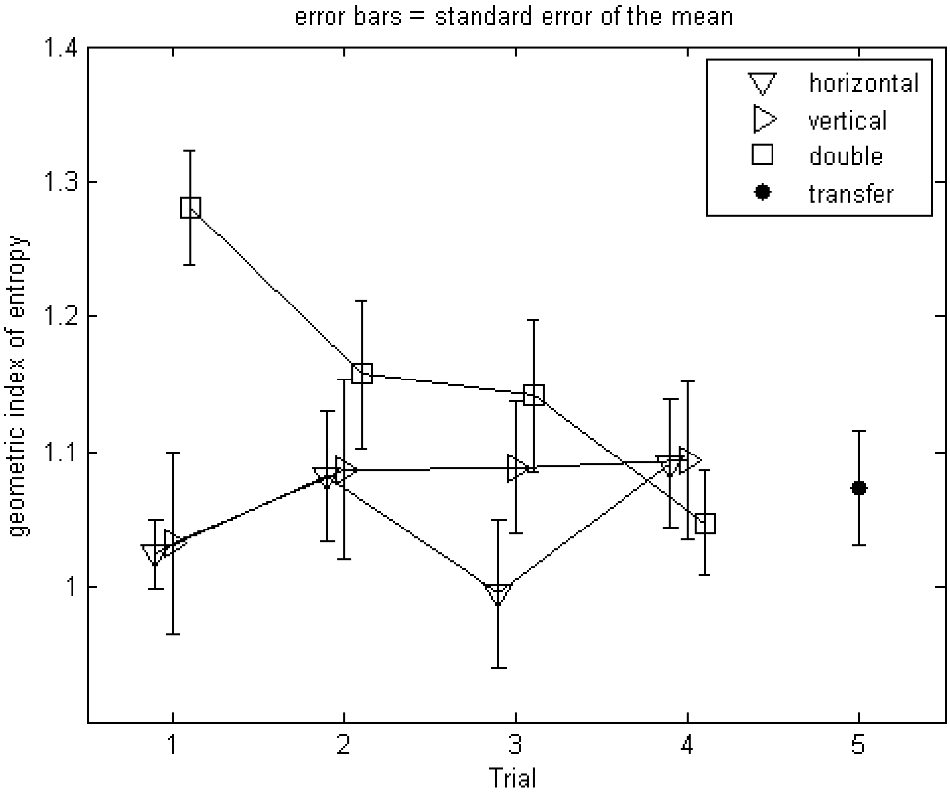


*Figure 2*


error bars = standard error of the mean
horizontal
vertical
double
transfer
geometric index of entropy
1.4
1.3
1.2
1.1
1
1
2
3
4
5
Trial