Constraints representing a meta-stable régime facilitate exploration during practice and transfer of learning in a complex multi-articular task

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Abstract

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Key words: Skill, Affordances, Practice, Transfer, Meta-stability, Constraints

1.1 Introduction

Learning complex multi-articular actions is influenced by the specific experiences of an individual under constraints present during practice (Seifert, Button, & Davids, 2013). Internal and external constraints on performance are inherently uncertain, requiring adaptation of movement patterns to regulate actions and their stability (Newell, 1991). Designing uncertainty into a practice environment may be functionally specific (supporting goal achievement) for performance in contexts towards which the transfer of skill or learning is intended (for definitions, see Carroll, Benjamin, Stephan, & Carson, 2001; for experimental data, see Travassos, Duarte, Vilar, Davids, & Araújo, 2012). Induced uncertainty can be designed into learning programmes through constraints manipulation at the task, individual and/or environmental levels (Chow, Davids, Button, & Koh, 2008; Orth, Davids, & Seifert, 2015; Ranganathan & Newell, 2013). A hallmark feature of practice under such constraints is movement variability. Movement variability can be functionally characterized in different ways such as noise (Schöllhorn, Mayer-Kress, Newell, & Michelbrink, 2009), movement regulation (Pinder, Davids, & Renshaw, 2012), health (Harbourne & Stergiou, 2009), complexity (Travassos et al., 2012) or exploration during learning (Cordier, Mendès-France, Pailhous, & Bolon, 1994).

An important issue is to investigate the functional role of induced movement variability throughout practice in order to address potential mechanisms underpinning rate of learning and transfer effects (Pacheco & Newell, 2015; Seifert, Wattebled, et al., 2016). For example, on the one hand, random variability appears to promote exploration (Huet et al., 2011; Schöllhorn et al., 2009) and maintain adaptive capacity in a movement system (Tumer & Brainard, 2007). On the other hand, *constrained variability* may allow the practitioner to adapt to individual factors such as skill (Davids, Araújo, Hristovski, Passos, & Chow, 2012), supporting a fit between the individual and context dependent factors that may help avoid deleterious effects of random processes (Simonton, 2003).

Inducing learning can be facilitated by challenging the equilibrium of stable movement patterns to invite other movement patterns to learn (Chow, Davids, Hristovski, Araújo, & Passos, 2011). Here we investigated how this process may be induced under conditions of meta-stability (Pinder et al., 2012). Specifically, meta-stable movement coordination régimes refer to regions of performance where individual and environmental influences on performance simultaneously coexist. This leads to the coexistence of competitive (less stable) and cooperative (more stable) coordination tendencies where neurobiological components (such as central nervous system components) support adaptation and emergence of new behaviors (Kelso, 2012).

Within the ecological dynamics framework (see, Davids, Araújo, Seifert, & Orth, 2015), a key assumption is that acquiring skill in multi-articular tasks involves the potential for different actions that can be adopted by individuals for achieving the same performance outcomes, reflecting inherent degeneracy of each individual movement system (Edelman & Gally, 2001; Mason, 2010). As the individual adapts to the dynamic environment, system degrees of freedom are exploited through continuous re-organisation as they utilise affordances (i.e.

perceived behavioural opportunities). Harnessing system degeneracy can help people manage in uncertain environments where more movement variability can reflect greater levels of exploration (Chow et al., 2008; Hristovski, Davids, Araújo, & Button, 2006; Pinder et al., 2012). By manipulating affordance landscapes (cf. Rietveld & Kiverstein, 2014), competitive (less stable) and cooperative (more stable) coordination tendencies can be represented, inviting exploration or learning processes (Seifert, Komar, Araújo, & Davids, 2016).

Operationally, an important indicator a system's stability and the related capacity in harnessing system degeneracy, is the degree of entropy that a constrained system exhibits (Edelman & Gally, 2001). For example, the geometric index of entropy (GIE) was developed by Cordier et al. (1994) as a spatial measure of entropy in climbed trajectories (i.e., the pathway of climbers' estimated hip positions, projected onto the surface of a climbing wall as a 2D coordinate system). Low levels of GIE suggesting behavioral certainty and stability (observed in straight forward and fluent performance behaviors) whilst, higher levels of entropy indicate behavioral uncertainty and instability (more complex, chaotic or less fluent movements) (for a recent review see, Orth, Button, Davids, & Seifert, 2016). Theoretically, measures such as GIE provide an indication of how effectively degeneracy is exploited in managing system stability (e.g., such as to avoid falling during a climbing activity) (Cordier, Mendès-France, Bolon, & Pailhous, 1994; Edelman & Gally, 2001).

Of additional operational concern is, that, previous investigations have shown individuals can be positioned to perform under a meta-stable regime by manipulating constraints so as to create an overlap in qualitatively distinct affordances (Hristovski et al., 2006; Pinder et al., 2012). For example, Hristovski et al. (2006) observed that designs which altered arm scaled distance of boxers to a punch bag during practice facilitated affordances to constrain the emergence of a rich range of hitting actions. These results showed that a feature of practice in a meta-stable regime is for different patterns of movement coordination to be explored spontaneously (Hristovski et al., 2006). Although, in operational terms, designing constraints that induce meta-stable behavior appears to be understood, the functionality of this system state to the learner is unclear.

Indeed, it is currently untested how individuals with different levels of skill might respond to practice under meta-stable design constraints. For instance, whilst extensive exploration of different actions can emerge under novel practice task constraints in inexperienced individuals (Chow et al., 2008), experienced individuals under similar constraints show minimal exploration (Chow, Davids, Button, & Koh, 2006; Seifert, Wattebled, et al., 2014). A feature of experienced individuals, in multi-articular tasks, is an immediate availability of movement patterns which support a functional response to satisfy interacting task and environmental constraints (Sanchez & Dauby, 2009; Seifert, Wattebled, et al., 2014). Hence, the learning dynamics of an individual in a meta-stable regime need to be investigated relative to his/her existing experience levels (Seifert, Wattebled, et al., 2013).

In this study, practice was manipulated to induce meta-stability in performance of the complex motor coordination task of climbing to observe exploratory behaviors in experienced and less experienced individuals. Meta-stability was represented in an indoor climbing task by increasing the number of available climbing affordances in the environment, allowing their usability to overlap. In the task of climbing, affordances refer to properties of a wall that are perceived by individuals for supporting grasping and climbing actions and that are also experience-dependent (Boschker, Bakker, & Michaels, 2002). Importantly, even novice climbers can perceive climbing affordances if they are within their ability level (Pezzulo, Barca, Bocconi, & Borghi, 2010), suggesting the potential to transfer fundamental capabilities such as ladder climbing to novel climbing environments (Seifert, Wattebled, et al., 2016). In this study, overhand- and side-orientated grasping actions were designed into the environment by modifying the number of edges and orientation of hand holds. Specifically, overhand grasping actions were supported by designing holds with a graspable edge that ran parallel to the ground. Vertically aligned grasping actions were supported by designing holds with graspable edges that ran perpendicular to the ground. It was anticipated that meta-stability in behavior would emerge in climber-environment systems if, at each hold, both an over-hand and a vertically aligned grip were available (note that a number of pilot studies have been undertaken in support of these assumptions, see Seifert, Boulanger, Orth, & Davids, 2015; Seifert, Orth, et al., 2014; Seifert, Orth, Hérault, & Davids, 2013).

The hypotheses included: 1) both skill groups would be induced to learn on the route where, at each hold, multiple actions were functionally available; 2) less experienced performers would show learning effects on routes where only a single action was supported, that was specific to climbing, whereas more experienced climbers would not, and; 3), that transfer of skill would be facilitated by experience on the different routes.

2.1 Methods

2.1.1 Participants

A total of 14 participants were recruited based on their self-reported red-point levels (where red-point refers to route climbing ability after practice, see (Draper, Dickson, et al., 2011)). One group, (the less-skill group), comprised participants (n=7), 20.9 ± 5.7 years; mean height: 165.4 ± 8.5 cm; mean weight: 69.1 ± 6.8 kg, with a level 5b-5c on the French rating scale of difficulty (F-RSD) (i.e. a difficulty scaling from 1-9, (Delignières, Famose, Thépaut-Mathieu, & Fleurance, 1993)). These individuals had no more than 10 hours of training experience on indoor climbing walls and had been trained on the safe use of climbing equipment under top-roped conditions (detailed below). With respect to the intervention routes, this group might be considered as corresponding to a coordination stage of learning (Newell, 1996). A second, more-skilled, group of seven individuals (24.9 ± 4.7 years; mean height: 175.4 ± 6.8 cm; mean weight: 69.1 ± 6.8 kg), were recruited on the basis of having a F-RSD level between 6a-6b (Draper, Canalejo, et al., 2011; Draper, Dickson, et al., 2011). These participants reported roughly 3 years of climbing experience and might be considered at a control stage of learning with respect to the intervention routes. Participants provided informed consent and the study conducted with ethical approval.

2.1.2 Experimental Procedure

Data were collected on four separate days, with at least two days separating each session and over a two week period. All sessions started with participants being fitted with a harness and climbing shoes. After a climbing specific warm up, they completed three previewed, top-roped climbs. Each climb was on a different experimental route, the order of which was counterbalanced so that the order of treatment of each route from one session to the next was diversified across participants. Between each climb, a seated 5-minute rest was enforced. On the fourth session, climbers also undertook a transfer test at the end. For each climb participants were instructed to self-pace their ascent, with the following task-goal: explore the way to climb in the most *fluent* manner, i.e., without falling down and by minimizing pauses in the rate of body displacement vertically on the wall surface.

2.1.3 Instrumentation

Participants were equipped with an LED marker positioned at the centre of the harness at the posterior body midline. Video footage of each ascent was captured with a frontal camera (Sony EX-View Super HAD, Effective pixels:768x520, that allowed a resolution of 560 lines, with a 2.6mm lens that offered a 120° angle of view) fixed 9.5m away from the climbing wall and at a distance of 5.4m from the ground. A calibration frame, 10.3m vertical x 3m horizontal and composed by 20 markers, was used to correct for distortion and calibrate the digitized trajectory from pixels to metres (done using a semi-automatic tracking procedure with the Kinovea 8.15 software).

2.1.4 Behavioral data

Behavioral data that reflected learning in the form of exploratory activities were collected in analyses of hand and hip movements. Specifically, exploration was indexed using: (i) the total number of exploratory actions with the hands (where a hold is touched by the hand, and during this contact not subsequently used to move or weight the body and the next action of the hand was either to move to another hold or to release the hold and then change the hand's position on the same hold; and (ii), the geometric index of entropy (GIE), calculated from the trajectory of the climbers' hip (using the 2D trajectory of an LED positioned at the hip projected onto the plane of the climbing wall during each ascent). Also note that additional performance data were collected, including: falls and the relative use of hand holds (ratio of number of holds used to holds contained in the route, or up to the point of falling).

Geometric index of entropy. More formally, the GIE is a ratio of the path length of a trajectory to the perimeter of its convex hull (Cordier, Mendès-France, Pailhous, et al., 1994) and is a uniquely spatial indicator of performance behaviour. GIE is given for a given trajectory $x : [O, T] \rightarrow R^3$, letting Δx be the trajectory length:

$$\Delta x = \sum_{i=1}^{N} \sqrt{x_i^2 + y_i^2} \qquad (1)$$

and $\Delta c(x)$ the convex hull perimeter.

The GIE is then given by:

$$GIE_x = \frac{\log(2 * \Delta x) - \log(\Delta c(x))}{\log(2)} \qquad (2)$$

noting that the division by log(2) places the GIE in dimensionless terms (bits) . Thus, in recalling the discussion above, GIE can assess, in spatial terms, the amount of fluency of a curved trajectory. The higher the entropy value, the higher the disorder of the climbing trajectory (Cordier, Mendès-France, Bolon, et al., 1994). On the other hand, the lower the GIE value the more simple and straight forward the trajectory (Sibella, Frosio, Schena, & Borghese, 2007). When considered over successive trials GIE is also a useful measure of learning because of it relates to route finding behaviors (Boschker & Bakker, 2002; Cordier, Mendès-France, Pailhous, et al., 1994) indicating the ability of climbers to pick up information from a surface to find paths through the route that afford fluid continuous traversal (Cordier, Mendès-France, Pailhous, et al., 1994). For a visual example of GIE the reader is referred to Sibella et al., (2007).

Touch and withdraw. Pijpers and colleagues (Pijpers, Oudejans, Bakker, & Beek, 2006) also distinguished between exploratory and performatory movements at the hand level, revealing behavioural certainty specifically with regards to hold use. Climbers tend to reduce the time spent in states of three-limb support because it increases the force required at other limbs to remain fixed to the wall (Bourdin, Teasdale, & Nougier, 1998; Sibella et al., 2007), tending to limit exploration, where a hold is touched but not subsequently used to support the body weight, to periods of uncertainty. Following Pijpers et al., (2006), the number of touch and withdraw actions were computed as the total number of actions made at the hands for each climb, where a hand hold was touched and not subsequently used to support hip displacement and which the following action with the same hand was to withdraw contact from the hold to then make a new contact with the same or another hold.

2.1.5 Routes

Three experimental routes were designed based on the orientation and number of graspable edges at each hold (20 holds per route were used). Route-1 contained only holds with a horizontally-graspable edge (with the knuckles running parallel to the ground plane). Each hold in Route-2 had a single, vertically-graspable edge (with the knuckles running perpendicular to the ground plane) and, Route-3 included at each hold a graspable edge that was horizontally aligned in addition to an edge that was vertically-graspable. This latter route was considered to represent meta-stability as it afforded the choice of two grasping actions at each hold i.e. those grasping actions supported by Route-1 and Route-2 (see Figure 1 for details). The transfer route (Route-4) was made up of six horizontal holds, and seven vertical holds, as well as seven holds with both edges. The transfer test was designed to determine whether experience on the practice routes supported performance on the new route finding problem. The transfer route was also designed to represent the different constraints experienced during practice and primarily the uncertainty involved in route finding on a new route. Furthermore, the aim was not to expose participants to qualitatively different technical demands which is why similar grasping opportunities to practice were represented. Each route was designed by an experienced setter and the difficulty level held constant at level 5b F-RSD. The ratings were confirmed by consensus with two additional and fully qualified route setters.

>>Figure 1<<

2.1.6 Data analysis

A mixed methods ANOVA for the trial (4) x route (3) x group (2) effects were used to evaluate the learning effect separately for the GIE and touch and withdraw data. Prior to undertaking the analysis Mauchley's test was used and confirmed homogeneity of sphericity for the repeated measures. For explaining the size and nature of differences, as well as interaction effects, planned contrasts were then performed. Following effects are reported significant at $p \leq .05$, noting that effect sizes were only calculated from contrasts and main effects that involved a single degree of freedom, see (Kirk, 1996)).

Contrasts were designed with the expectations that entropy values and hold exploration would reduce with practice, that more complex route design would increase entropy and hold exploration, and that more experienced climbers would display lower entropy and hold exploration. Of particular interest was whether interaction effects between route, trial number and skill would emerge to suggest that skill level interacted with specific route design properties, influencing whether learning effects were induced. For follow-up tests, Bonferroni adjustments controlled for inflation of the type I error. Being based on categorical data, instances of falls were assessed using non-parametric tests (Freidman's and Wilcoxon's) and the data with respect to the number of holds used, relative to those available, were assessed with repeated measures ANOVA.

To assess transfer, an omnibus of t-tests was planned on both variables at the within- (between Trial 4 on the double-edged route and the transfer route) and between-group levels of analysis (less skill vs. more skill) with Bonferroni adjustments. We chose to compare Trial-1 on the double edged route and the Transfer test because these represented on-sight conditions under the most complex or uncertain conditions (i.e., since both involved double-edged holds).

3.1 Results

The mean values and their respective standard errors of the mean, and significant main effects and interaction effects are summarised in Figure 2 where in, Graphs A-E refer to the analysis of hip entropy and in Graphs F-J relate to hand hold exploration data.

>>Figure 2<<

The following results are organized in relation to the research questions of interest, that: 1) both groups would be induced to learn on the meta-stable route; 2) the less experienced group would show learning effects on routes that require climbing specific experience whereas, the more experienced climbers would not; and 3), that transfer would be supported in both groups.

3.1.1 Effect of practice on meta-stable route

There were significant interaction effects at both the route x practice and group x practice level for the outcome of entropy: $F\ (3, 36) = 2.274$, $p = .05$, $r = .40$; $F\ (3, 36) = 6.256$, $p = .002$, respectively. However for the outcome of hand exploration there was only a significant interaction at the group x practice level; $F\ (3, 36) = 3.323$, $p = .03$. In examining the estimated marginal means for entropy and hold exploration for the route by practice interaction (Figure 2, graphs D and I respectively) it is clear that the less experience climbers showed a distinct global learning effect whereas the more experienced climbers did not. For the condition by practice effect, the marginal means show that primarily for the double edged and vertical routes there was a distinct trend from higher to lower amounts of entropy and hand exploration seen with practice (Figure 2, graphs E and J respectively). In order to determine if both groups showed a learning effect on the double-edged route follow up tests were undertaken where repeated measures ANOVA were used for each condition across each group. These results are summarised Table 1.

>>Table 1<<

The significant findings showed that for the more experienced climbers, the double edged condition induced a learning effect, $F(3, 18) = 6.258$, $p =.004$. Planned contrasts comparing Trial 1 to Trial 4, Trial 2 to Trial 4 and Trial 3 to Trial 4, showed that this effect was primarily driven by the significantly higher GIE at Trial 1, $F(1, 6) = 26.078$., $p = .002$, $r = .902$.

For the less experienced group, a significant learning effect was also shown for the double edged route, $F(3, 18) = 5.820$, $p =.006$. The planned contrasts indicated the effect of practice on the double-edged route for the less experienced group was driven by the significantly higher entropy at Trial 1 compared to Trial 4, $F(1, 6) = 20.623$, $p = .004$, $r = .880$. Additionally, the less experienced group showed a significant learning effect on hold exploration on the double edged route $F(3, 18) = 7.000$, $p =.003$, with planned contrast showing that at Trial 1 exploration was significantly higher than Trial 4, $F(1, 6) = 6.299$, $p = .046$, $r = .716$.

3.1.2 Effect of route design and skill on learning

The findings shown in Table 1 also support the hypotheses that existing skill determined whether a specific route induced learning or not. In the more experienced group neither the horizontal route, $F(3, 18) = 1.347$, $p = .291$, or the vertical route, $F(3, 18) = 0.987$, $p = .421$, induced a learning effect, whereas the double edged route showed a significant learning effect with regard to entropy (Table 1). There were no significant effects related to hand hold exploration across any route in the experienced group.

In contrast, in the less experienced group, both the double edged route and the vertical edged route, $F(3, 18) = 6.552$, $p = .003$, induced a learning effect, whereas the horizontal edged condition showed no significant effect, $F(3, 18) = 1.574$, $p = .230$. Similar to the double edged route, on the vertical edged route, the planned contrasts showed that entropy was significantly higher at Trial 1 compared to Trial 4, $F(1, 6) = 5.847$, $p = .052$, $r = .703$.

Wilcoxon's tests, examining route effects, also showed that no route was associated with having a significantly greater probability of falls compared to any other. Throughout the course of practice, there were 4 falls on the horizontal (across 28 trials of practice per route), 7 on the vertical and 13 in total on the double edged route. Further at the level of practice (excluding route specific effects), there were 10 falls at Trial 1, 8 falls at Trial 2, 4 falls at Trial 3, and 2 falls at Trial 4. It can also be noted that Wilcoxon's test between Trial 1 and Trial 4 showed a significant reduction of falls, $z = -2.00$, $p = .046$ when considering only the effect of practice.

3.1.3 Transfer effect

To address the impact of practice on performance and behavior during transfer, comparisons were undertaken on entropy and hand hold exploration (see Table 2). The key findings revealed that: a) neither entropy or hand hold exploration was significant in distinguishing between groups at the final trial of practice on the double edged route; b) neither between group (less vs. more skill), or between condition (trial 4 on the double edged route vs. transfer route) entropy were significantly different; c) only hand exploration distinguished between the two groups (less vs. more skill) under the transfer test conditions, $t(12) = 4.47$, $p = .001$, $r = .79$, and; d) in the less experienced group, the hand hold exploration significantly increasing under transfer conditions relative to the amount of exploration on the fourth trial of practice on the double edged route, $t(6) = 4.804$, $p = .003$, $r = .89$. This observation suggests that the experienced group transferred skill in terms of low entropy. In contrast, the less experienced group showed a capacity to transfer low entropy at the hip, however showing a high amount hand hold exploration. In fact, it was the two outcome variables in combination that differentiated the two groups under transfer conditions. With regard to falls, there were no significant effect between the first trial of the double edged route and the transfer route in the less experienced group, whilst none of the more experienced climbers fell. Nor were significantly more hand holds used in the Transfer route in comparison to Trial 1 of the double edged route.

>>Table 2<<

4.1 Discussion

The purpose of this study was to consider potential interactions between prior experience and environmental properties on behavioral certainty during learning and transfer, when performing an indoor climbing task. The first hypothesis, that learning could be induced using meta-stable design principles was confirmed, and regardless of the initial skill level of the individuals. However, this evidence was only shown at the hip level in more skilled climbers, as opposed to both at the hip and hand levels in less experienced climbers.

The second hypothesis was also confirmed, with data suggesting that the existing experience level of the participants interacted with specific route design properties. It was particularly interesting that findings suggested that knowledge of the vertically orientated grasping pattern of coordination needs to be acquired through experience where only the less experienced group showed a learning effect on this route.

Finally, also confirmed is the third question, that, transfer contexts designed to represent similar levels of environmental variability, as those experienced under practice constraints, can facilitate the transfer of skill. Of particular interest was that transfer of skill seemed dependent on both entropy at the hip and hand hold exploration in combination. This finding also suggesting that the initial level of skill of individuals prior to practice, influenced the nature of the transfer. Specifically, the less experienced climbers, appeared to learn how to explore at the hand level, without increasing hip entropy (i.e. they learnt to explore more efficiently).

4.1.1 Meta-stable design properties induces learning in less and more skilled individuals

The data showed that both groups were induced to go through a learning process (a general reduction in behavioral uncertainty) when practising on the route that supported, at each hold, a choice of grasping actions, one choice supporting an over-hand grip and one that supported a vertical-hand grip (see Table 1, and refer to Figure 3, Graphs A and B). Noting the shape of the learning curves for GIE outcomes at the hip, it appears that the behavioral changes shared similar rates of improvement. However, at the hand level, exploratory activities were very different between groups (Figure 3, Graphs C and D). The less experienced climbers exhibited much greater levels of touching, but not grasping holds (Figure 3, Graphs D). This finding suggests both general (route finding) and differential (hold graspability) effects of how the double edged route might have facilitated an improvement in performance through practice dependent on initial skill level.

>>Figure 3<<

Indeed, the clearest indication of a skill dependent effect can be related to the overall larger amount of hand hold exploration shown by the less experienced group compared to the more experienced group. These data suggest that determining how to grasp and/or use holds were challenged in the less experienced group. In the more experienced group, it seems the overt hold exploration was unnecessary, possibly because the capacity to perceive information related to hold graspability had already been adapted through experience (Bläsing, Güldenpenning, Koester, & Schack, 2014; Boschker et al., 2002; Pezzulo et al., 2010). However, it is not clear exactly why learning (in terms of improved fluency at the hip) was induced in the more experienced climbers, but, one interpretation of the data would suggest that presentation of choice at each hold induced a route finding problem (Cordier, Mendès-France, Pailhous, et al., 1994). Future research at different levels, such as gaze, which can also be characterized by exploratory behaviors might support these ideas (Nieuwenhuys, Pijpers, Oudejans, & Bakker, 2008; Sanchez, Lambert, Jones, & Llewellyn, 2012).

4.1.2 Environmental design properties interact with the intrinsic dynamics of individuals to shape the nature of learning

The experience levels of the participants interacted with specific route design properties, influencing the nature of the transfer to each practice condition. The vertical and horizontal routes did not induce learning in the experienced group, suggesting these behaviors were already stable. In contrast, the vertical *and* double edged routes induced greater amounts of behavioral variability, both at the hand and hip levels, in the less experienced group compared to the horizontal route (see Table 1 and Figure 3, Graphs B and D).

The significant differences between both the vertical and double edged routes, compared to the horizontal edged route, suggest that the grasping actions associated with vertically aligned edges during route finding appeared to require experience. On the other hand, the grasping actions for horizontally aligned holds appeared to be easier to transfer to the route finding task. The less experienced climbers' transfer of skill to the horizontal route can be explained as a function these grasping opportunities perhaps matching fundamentally stable grasping actions, such as ladder climbing (Newell, 1996; Seifert, Wattebled, et al., 2016).

This result is similar to other findings showing that inexperienced individuals climbing ice-falls tended to adopt a similar movement pattern where the body resembles an X-shape (Seifert, Wattebled, et al., 2014; Seifert, Wattebled, et al., 2016).

It was somewhat surprising, that, in the less experienced group, the vertical and double edged route induced fairly similar amounts of exploration at the hand and hip levels. It would be expected that the double edged route could facilitate greater exploration with the hands, simply by virtue of there being more edges. Whilst this effect was statistically significant, the size of the difference was not so large as to overly emphasize the difference between vertical and double edged routes on hold exploration. For example, on the double edged route, the use of more unstable vertical grasping actions could have been explored whilst falling back to the use of the more stable horizontal actions, yet this opportunity was not exploited to a large effect relative the vertical edge condition. Related to this concern is the fact that a similar level of hand hold exploration was occurring on the vertical edged route, which in contrast, had half the number of edges. The finding that both the vertical and the double edged route induced similar levels of hold exploration may indicate that the need to stabilize vertical grasping was perhaps driving haptic exploration, but was being limited by the task of route finding. Specifically, if route finding becomes inefficient, this places constraints on the individual both at the postural and limb organization levels, possibly increasing the likelihood of falling (Bourdin et al., 1998). Indeed both conditions (vertical and double) were not differentiated by the amount of entropy at the hip in any significant respect and furthermore, as practice continued, hand hold exploration remained significantly elevated in comparison to hip entropy which, in contrast, systematically reduced. This latter point suggesting, that, as the route finding problem was relaxed, hold exploration levels were sustained, indicating an ongoing learning effect at the hand level. One hypothesis might be, that, as the less experienced climbers determined an efficient way to regulate the pathway at the hip, their continued exploration at the hand hold level suggests an ongoing concern with how to grasp or use holds in different ways (Seifert, Wattebled, et al., 2014).

4.1.3 Future challenges in understanding the transfer of skill

Here we consider implications in the more experienced group that the transfer of skill might be accounted for by the learning effect induced on the double edged route. Arguably, if the climbers had not practised on the double edged route, climbing fluency would have likely worsened to levels similar to those observed on the first practice trial on the double edged route. This interpretation of the data is supported by the observation that neither the vertical, nor the horizontal routes, induced increased entropy levels at Trial 1. Rather, exposure to increased uncertainty on the double edged route during practice may have supported performance on the transfer route. The mechanism for this transfer effect may be the behavioural variability induced by choice posed at each hold in the double edged route. Future research should consider adapting an independent group design in order to determine if a specific condition underpinned the transfer effects.

On the other hand, the less experienced climbers also showed a capacity to transfer climbing fluency at the level of the hip, but, in contrast to the more experienced climbers, they continued to exhibit a large amount of hand hold exploration (see Figure 3, Graphs E and F). This was striking, because, early in practice, both hand hold exploration and hip entropy were high, whereas in transfer, high hand hold exploration was associated with low entropy. This finding suggests the possibility that exploration at the level of the hand supported the transfer of route finding in the less experienced climbers. And indeed, the climbers who demonstrated the most exploration during transfer also successfully transferred performance (i.e. they did not fall, see Figure 3, Graph E and F). This finding is in stark contrast to the first trial of practice, where the more successful climbers demonstrated less exploration at the hand levels. On the transfer route, in this study, the evidence suggests that the reason climbers effectively transferred skill was because of a capability to explore at the hand level without disrupting hip stability.

In the case of the less experienced group, learning was induced in both vertical and double edged conditions. Because, at each session practice on each route was counter-balanced, this reflects variable practice conditions and may be the main the reason underpinning the transfer effects (Chow, 2013; Ranganathan & Newell, 2013). Similar to the discussion above, future research should consider implementing an independent group design in order to determine if a specific condition underpinned the transfer effects. For instance it may be for the less experienced climbers either the double edged or vertical edged route could have driven the transfer effect.

In general, the findings of this study open up a number of research questions related to the different forms of behavioural variability that can support performance under representative transfer conditions. Specifically, in the inexperienced group of climbers, it is impossible to determine whether exploration transferred due to exposure to any one of the three routes and future work should be aimed at determining whether exploration induced by practice on specific route designs is the main mechanism that supports transfer.

5.1 Conclusions

The key findings reported in this study are that, in a task involving climbing practice, learning emerged at the hands and body levels. The level and rate at which learning occurred was shown to be dependent on the existing skill levels of the climbers. Skill was shown to moderate the stability of specific climbing actions, where over-hand and vertically orientated grasping were immediately stable in experienced individuals and only over-hand grasping was stable in less skilled individuals. Learning was induced in a group of experienced climbers by manipulating the number of actions available and not by requiring them to learn new, unfamiliar climbing affordances, as in the less experienced group. It is argued that this practice design supported performance under transfer conditions in experienced climbers. On the other hand, performance under transfer in less experienced individuals was related to more exploratory actions at the hands.

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Reply letter re: manuscript No.: HMS-D-15-00043

Dear Professor Andreas Daffertshofer,

Please find below comments addressed for the manuscript, No.: HMS-D-15-00043 'Constraints representing a meta-stable régime facilitate exploration during practice and transfer of learning in a complex multi-articular task'.

Thank you again for taking the time to revise, make comment and coordinate comments on behalf of the reviewers.

Please see our responses detailed below which are given as tabbed text.

Changes are also highlighted in the manuscript.

Sincerely, on behalf of the authors,

Dominic Orth

Response

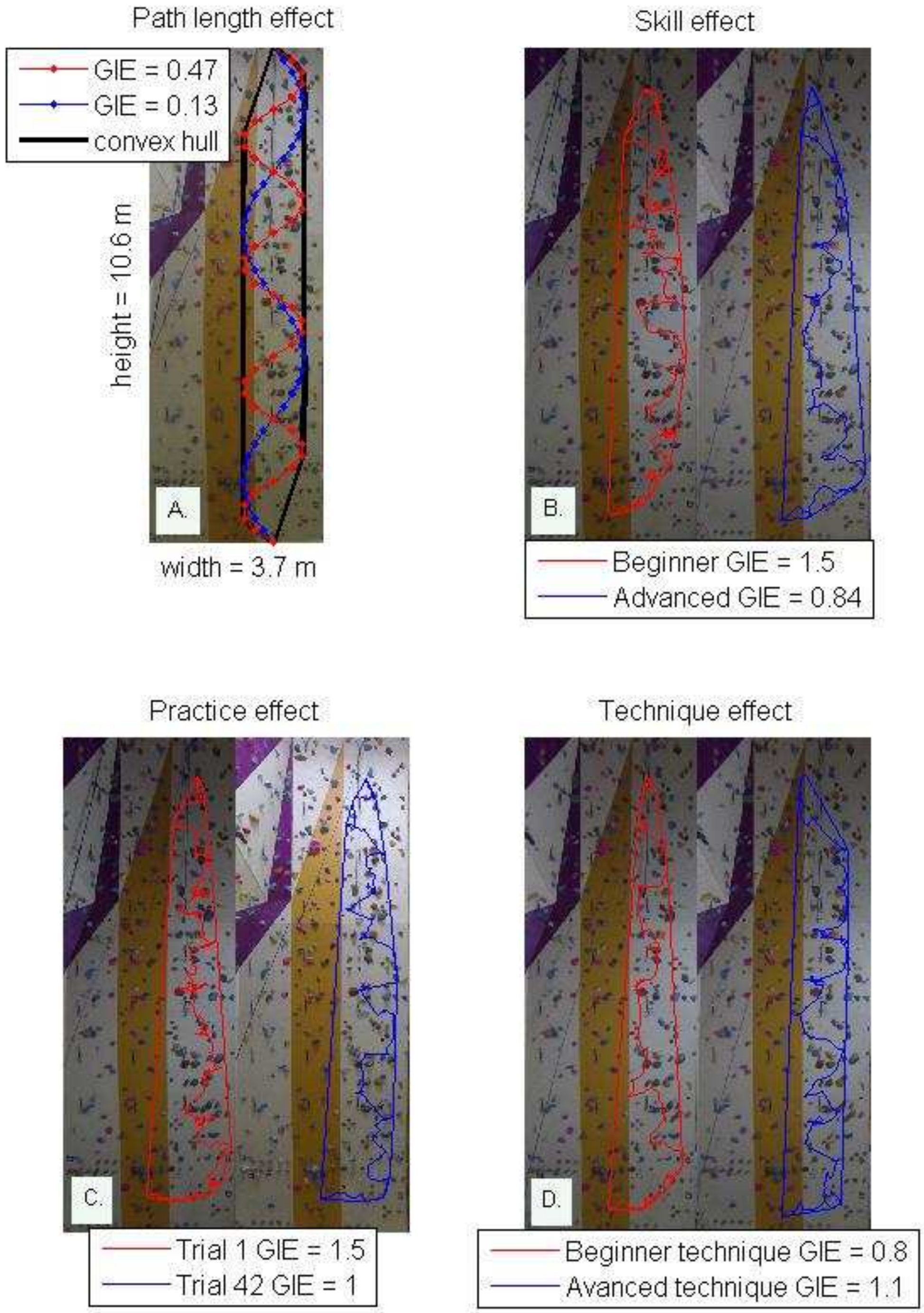
Section editor: Two expert reviewers assessed the manuscript and provided several detailed comments that can certainly help improving it. In particular reviewer #1 listed very detailed issues that ought to be addressed prior to considering the manuscript for publication in HMS. I would like to take the opportunity to stress the need for a detailed explanation of the encounter entropy measure and its precise implementation. The GIE is a mere measure of the path length relative to its convex hull and I cannot see why this would measure entropy. Entropy is a measure of disorder by virtue of a concave function. The classic (extensive) form is that of Boltzmann measuring the order in a statistical ensemble as \sum(p log p). This, by the way, has nothing to do with energy (in physics entropy and energy are both consider integrals of motion but they are independent apart from Landauer's erasure principle). How does the GIE fit in this view? I trust that the reports below further
suffice to provide a properly revised version.

> Thank you for your comments regarding the GIE as a representative entropy measure. It should be said that the GIE was introduced as a measure of spatial complexity following Cordier and colleagues [1-4] and has since been adapted to investigate skill [4, 5], practice [4] and route design [6] effects. To be clear, your concerns have been discussed elsewhere and for a full theoretical treatment I refer you to Cordier's 1994 and 1996 papers, both, published in Human Movement Science [1, 4] (and see also [3]). Aside from its theoretical consistency, a main interest of adapting GIE is, that, according to Cordier et al. [4] the GIE can assess the spatial fluency of the climbed trajectory. The higher the entropy value, the higher the irregularity of the climbing trajectory, whereas the lower the entropy value, the more regular is the route trajectory. GIE has a number of advantages over other reported spatial variables (such as the average movement distance [7]) in that it is readily interpreted with respect to climbing activity, accounts for climb height and, shown to be effective for detecting skill [2], practice [2], route [8] and technique effects in climbing tasks [5, 9]. Furthermore, data collection to perform an entropy calculation is relatively straight forward, involving use of a single camera [10]. Figure 1

shows how entropy is calculated (Panel A) and with respect to changing the length of an analysed trajectory. Also shown are skill (Panel B), practice (Panel C) and technique (Panel D) effects. In fact the main interests of using GIE in this study is that it is sensitive to when climbers become blocked at which point the typically begin to search for a route pathway. If this is done inefficiently, a large amount of hip displacement tends to occur, increasing GIE.

To address these concerns, we have updated the introduction to more fully detail the conceptualisation of GIE according to Cordier and colleagues. Thank you concerns regarding relationships between energy and entropy, we have rephrased our conceptualisation (which followed Edelman and Galley) as follows:

“Theoretically, then, measures such as GIE provide an indication of how effectively degeneracy is exploited in managing system stability (e.g., such as to avoid falling during a climbing activity) [3, 11].”


Path length effect
GIE = 0.47
GIE = 0.13
convex hull
height = 10.6 m
width = 3.7 m
A.
Skill effect
B.
Beginner GIE = 1.5
Advanced GIE = 0.84
Practice effect
C.
Trial 1 GIE = 1.5
Trial 42 GIE = 1
Technique effect
D.
Beginner technique GIE = 0.8
Avanced technique GIE = 1.1

Reviewer #1: The study examines the learning and transfer effects of the climbing tasks for performers of different climbing experiences. The hand-hold orientations were manipulated in practice. All the performers practiced 4 sessions of 3 trials and performed a transfer trial after the last practice session. The exploration behavior (number of touches without actual support) and the Geometric Index of Entropy of the climbing trajectory of the climbers' hips were used as the main dependent variables for analyses. The study suggested that both groups of climbers showed the learning effect on the double-hold route whereas the transfer effect was differentially exhibited in the different dependent variables from different groups of climbing experiences. The main focus of the study was based on the concepts of change of affordance from the ecological psychology perspective and the concept of intrinsic dynamics of the dynamical systems theory. Although the authors designed the experimental conditions accordingly, there are still related issues remained to be addressed.

For the climbing experience, the self-reported F-SRD 6a-6b and 5a-5b need to be described in more detail such as the range of the scale and a general description of the climbing ability.

Agreed, the range and relevant references have been included.

In the discussion, "…The less experienced climbers' transfer of skill to the horizontal route can be explained as a function these grasping opportunities matching fundamentally stable grasping actions, such as ladder climbing "… seems to suggest that these participants had no climbing experience other than the possible ladder climbing experience from the general daily chores. Other statements related to the experience of the participants, such as "… knowledge of the vertically orientated grasping pattern of coordination needs to be acquired through experience", and "… associated with vertically aligned edges during route finding appeared to require experience to stabilize", seem to suggest that the F-SRD 5a-5b had no experience of vertical holds, yet in the description of the route design, all routes used in the experiment were held constant at the level of F-RSD 5b. Is the orientation of the holds a factor considered in the route difficulty? If it is, how is it related to the levels of the two experimental groups? Why the data from the transfer trials were only compared with the first trials in the fall and use of hand hold but not in the entropy and touches? The discussions on the learning effects for the less experienced climbers were specific to the relation between the design of the routes and the level of the climbers, but little has been described about the nature of the skill levels of the two experimental groups.

> It is possible that the hold orientations can be interpreted as different levels of relative difficulty, which is a way of interpreting learning effects generally. However, as we state in the manuscript we only controlled for the absolute difficulty of the routes by having multiple route setters arrive at a consensus for absolute difficulty. Rather than focusing on relative difficulty, we focus the discussion on the specific manipulations made in hold design interpreted relative to the reasons there might have underpinned skill effects.

In Line 256, "…more complex route design would increase entropy and hold exploration….more experienced climbers would display lower entropy and hold exploration". How does complexity and difficulty relate to each other? Is there an operational definition of complexity since complexity has been manipulated in the design of route?

> Similar to the point above, we can talk about information similar to how we talk about complexity (and is one of the reasons GIE was used). The use of the complexity both a preference to nature of the manipulations in the hold designs and way use of GIE. The reader is free to interpret these manipulations along the lines of relative difficulty as a matter of theoretical position.

The entropy calculation needs to be explained in more detail. GIE is one of the main variables for analysis; it will be helpful to have an illustration of the actual climbing "path" and the perimeter of the convex hull around the "path" for many readers who do not have an intuitive idea of the measure.

> To be clear, your concerns have been discussed elsewhere and for a full theoretical treatment I refer you to Cordier's 1994 and 1996 papers [1, 4] (and see also [3]). The main interest of adapting GIE is, that, according to Cordier et al. [4] the GIE can assess the spatial fluency of the climbed trajectory.The updated, more explicit description for of the computation is given as follows:
>
> ***"Geometric index of entropy.*** More formally, the GIE is a ratio of the path length of a trajectory to the perimeter of its convex hull [4] and is a uniquely spatial indicator of performance. GIE is given for a given trajectory $x : [O, T] \to R^3$, letting Δx be the trajectory length:
>
> $$\Delta x = \sum_{i=1}^{N} \sqrt{x_i^2 + y_i^2} \quad (1)$$
>
> and $\Delta c(x)$ the convex hull perimeter.
>
> The GIE is then given by:
>
> $$GIE_x = \frac{\log(2 * \Delta x) - \log{(\Delta c(x))}}{\log{(2)}} \quad (2)$$
>
> noting that the division by log(2) places the GIE in dimensionless terms (bits) ."
>
> In order to address the concern regarding visualization we have referred readers to Sibella et al., (2007) who has already exemplified this nicely.

For the statistical analyses, the intuitive impression from figure 3 does not suggest a normal distribution from the exploration data. Did the exploration data fulfilled the normal distribution requirement for F/t tests ?

These data were omitted to keep the stats write-up as brief as possible. As stated in the methods, tests for spherecity were carried out and fulfilled assumptions.

Below is the SPSS output for Mauchly's test on the exploratory actions data set:

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.
Route	,760	3,019	2	,221
Practice	,394	9,974	5	,077
Route * Practice	,107	21,883	20	,373

It is also worth noting that all follow up comparisons were carried out with Bonferroni adjustments to the p values (stated in text and the table captions).

As for the non-parametric tests, it was not clear either in method or in results that how the tests were conducted (within the group among the sessions/routes, between groups). There was no report on the Friedman test result.

For the non-parametric tests, we have provided clarifying details to indicate practice and route comparisons.

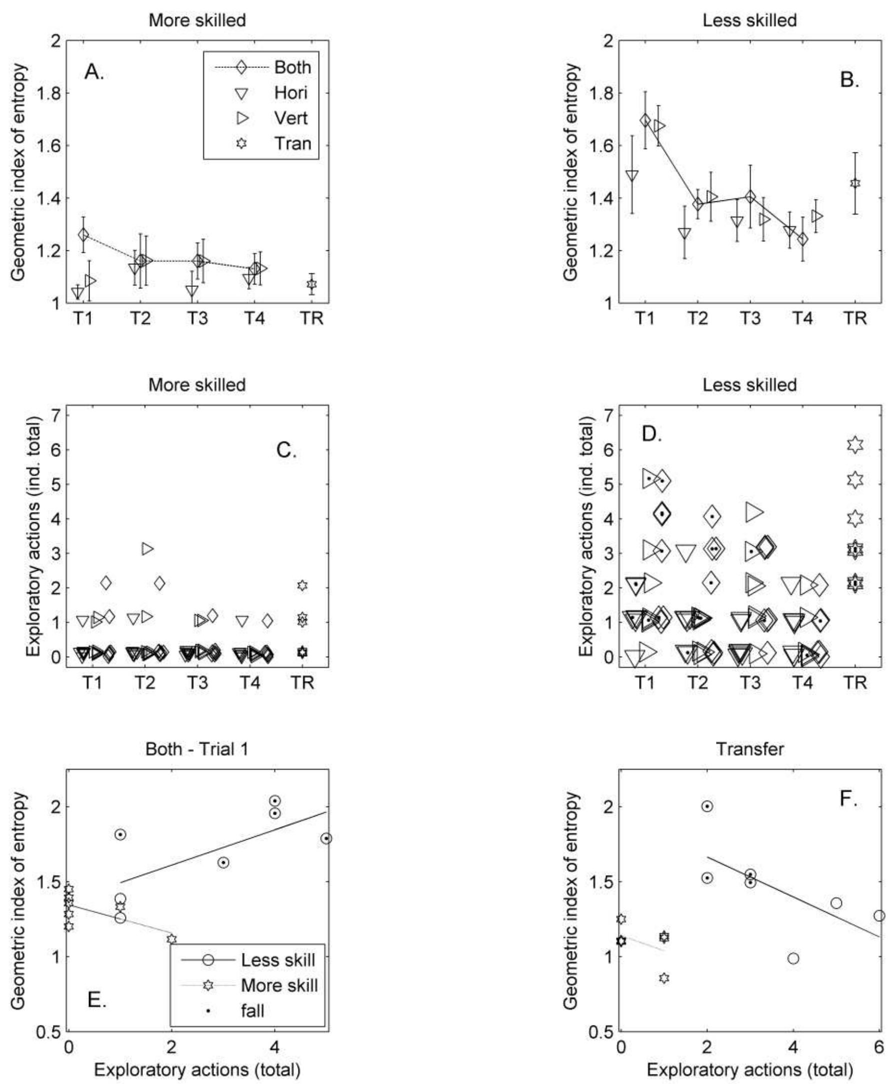
In Line 534, a statement of exposure to variability during practice supported the transfer effect was not founded. There was no control condition to contrast the variable practice condition to make such conclusion.

Agreed, we adjusted the interpretation accordingly and tempered the discussion including the statement that:

"future research should consider implementing an independent group design in order to determine if a specific condition underpinned the transfer effects. For instance it may be for the less experienced climbers either the double edged or vertical edged route could have driven the transfer effect."

Is there a relation between the two main variables analyzed? When the exploration remain unchanged over the practice sessions for the more experienced climbers, what would be the cause of the reduction of the entropy (complexity) measure?

Agreed, we have discussed this possibility as potentially being driven at the visual level. Typically a reduction in entropy indicates that climbers has adapted an efficient route pathway. A possible candidate is that hand hold exploration is induced either as an inability to determine how to grasp or use holds in the less experienced climbers. Additionally, there is the possibility these data are correlated (and is a point of discussion). Indeed, important relationships seemed to occur in the first trial of practice, and in the transfer test in the less experienced group (see graphs E and F):



These concerns are discussed in text.

Minor points

L168 Was the counter balance procedure performed among participants or within participant among sessions?

Yes, among participants, so that the order to treatment from one session to the next was diversified across participants. Updated in text.

L175 Is the luminous marker the LED mentioned in L191?

Yes, clarified in text.

L191 Need to define the position of hip

Clarified in text.

L198 The GIE formula, the "2" after Log sign a multiplier or a base for the logarithm? Since there were a couple of equations in the manuscript, numbering the equations is recommended

Clarified in text (see above the response to the major comment).

L251 The effect size equation, parenthesis should be added for the denominator
Results The terminology used in the results (including the figure labels and captions) need to be consistent. (Route/condition, practice/trial)

Thank you, in fact we've chosen to remove the equation and instead provided a reference for the interested reader.

Agreed, the graphs have been updated.

L286 Check the DoF in F(1, 12)= 2.274 for the route x practice interaction

Thank you updated.

A 3-way mixed design ANOVA was indicated in the data analysis section, was there a 3-way interaction effect ?

No the 3-way tests were not significant. However, we followed up significant main and interaction effects.

L339 "10 falls at trial 1 (from a possible 21 total)" Was the possible total trial only regard one group?

Here we are dealing here with the group effect (includes all conditions).

L340 trial "4" instead of trial 1

Thank you updated

L348 missing b)

Thank you updated

L353 the amount "of"

updated

L412-414 "…..less chaotic route finding….", it is not clear what does the word "chaotic" mean here. Suggest to elaborate or rephrase it.

Rephrased to: 'in terms of improved fluency at the hip'

L460 "It was be expected " →It would be expected…

Rephrased

L463 overly "emphasis" → emphasise

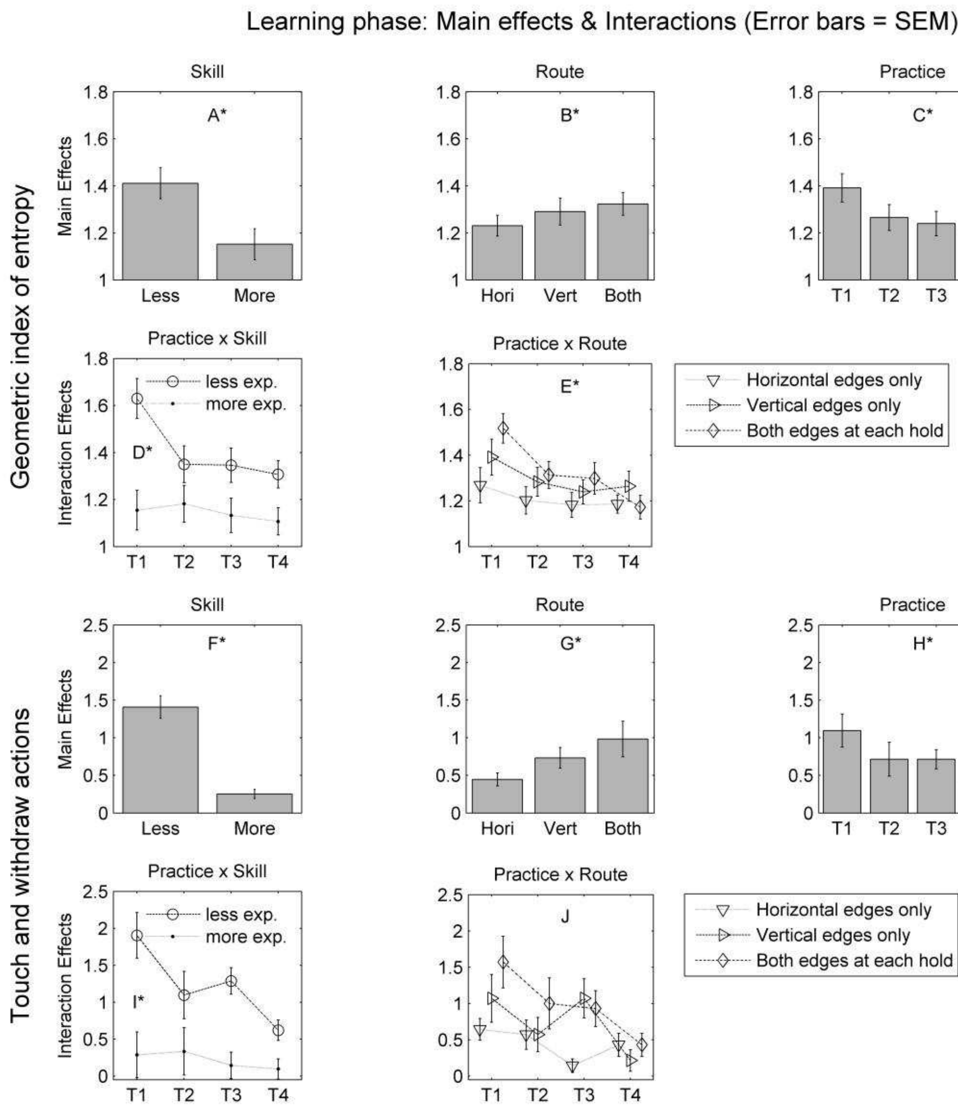
Updated

Figure 2 Since the interaction effects were the main focus, the 6 panels that show the 3 main effects may be taken away; the 3 main effects did not present meaningful information. The units of the vertical axes were missing. In caption, Graph E and "H" should be "J", check the DoF of the interaction of route and practice session.

Thank you, with regard to the taking out the main effects, although we were interested in the interaction effects, we feel the main effects provide a complete picture and we prefer to include these.

The vertical axis were provide to the left, we have updated the figure to clarify.

We have carefully examined the figure:



Reviewer #2: I had the opportunity to review the manuscript (ms) entitled 'Constraints representing a meta-stable regime facilitate exploration during practice and transfer of learning in a complex multi-articular task' submitted to Human Movement Science (HMS).

I actually found the present ms very well written and structured, as well as clear and precise. Overall, I think that the aims of the ms are clearly defined and followed; that the findings are well organised, and follow the hypotheses developed within the Introduction; and that the conclusions are justified by the findings. The illustrations (Figures, Tables and pictures of the holds) are both necessary and adequate. Lastly, the references are adequate - though I suggest the authors to consider, if they find it of interest when discussing their findings, a couple of publications in the field of sport climbing that used similar methods (e.g., behavioural data) and examined some of the aspects discussed (e.g., route previewing;

visuo-motor aspects).

(1) Would it be interesting to compare entropy values from other studies at all? I fully appreciate that the routes climbed elsewhere will have been different than the routes climbed in the present study but I wonder whether it would be of any use to compare, at least, the range of differences in entropy values between groups/levels across different studies to discuss some of the findings here. For instance, were the differences here as large as the differences in other studies (again, even though the conditions may have been different and the routes obviously were different). Just food for though that a leave to the authors with.

> Agreed, we have included a reference to a recent review providing more detail on entropy outcomes.

(2) Unless otherwise mistaken, I do not recall to have seen any indication that climbers did fall. I wonder whether this is the case. If they did fall-off, I wonder whether there could be further information given as to how that was dealt with (e.g., procedures, entropy measures). If they did not fall-off, which it may be the case given that the routes designed matched lowest climbing level of participants, may be it could be said - if this is the case and I missed it out, I do apologise in advance.

> Yes, these were detailed in the results section. One of the reasons we used GIE is that it is dimensionless (units are in bits), since we divide the trajectory length into the convex hull. In fact often prior to a fall individuals will extensively explore at the hip, leading to an increase in the GIE regardless of the absolute height to which they climb. Regarding the ability levels of the participants, we have discussed limitations in using the F-RSD approach. One possibility for future research is to consider adopting scanning procedures prior to recruiting participants.

(3) L62-65. Is it necessary to provide so many references here? Would not a couple do, may be preceded by e.g.?

> Agreed, updated.

(4) L158-60: Is there any rationale other than having equal numbers in both groups? I think it would have been better to divide participants into groups based on some climbing performance rationale or parameter, though I appreciate that (a) it may have been difficult to find participants given the research design adopted, and (b) at the end of the day, there are two different levels - though one could argue that 5c and 6a there may not differ that much (unless rationale provided…?!). Previous research has provided some kind of rationale to clarify group classification or explain participant level (e.g., Sanchez et al., 2010, 2012).

Agreed. It should also be noted that their training history differed significantly we have update the rationale following Newell:

"With respect to the intervention routes, this group might be considered as corresponding to a coordination stage of learning [12]…. These participants [the more skilled group] reported roughly 3 years of climbing experience and might be considered at a control stage of learning with respect to the intervention routes."

(5) L164: Could the authors provide a range, as it is not clear to me how long may have the testing taken? Unless I am mistaken, 'four separate days with at least two days separating each session' could be anything; that is, one climber could have been tested over a week while another climber could have been tested over a month…

Agreed, updated (the experiment was run over two weeks).

(5) L183 - Behavioural data: A couple of studies in sport climbing that the authors may find of interest to discuss some of the points they address in their Discussion had adopted similar methods too. Indeed, the authors may find of interest Sanchez and Dauby (2009) study in climbing and imagery and video-modelling (visuo-motor aspects) to discuss further 'number of actions available - functional learning strategy - vs more exploratory behaviours - descriptive learning strategy'). Similarly, the work in 'route previewing' (Sanchez et al., 2012) may be of interest to discuss route knowledge and route finding, a similar - though not exactly - mechanism/skill in sport climbing.

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Thank you, updated, agreed these studies support key points in the methods and discussion.

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Tables

Table 1

Table 1. Follow-up of the learning effect across each route for each group on entropy and hand hold exploration

Variable	Group by condition	Trial 1		Trial 2		Trial 3		Trial 4		
Entropy	**More Exp**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**ANOVA-RM**
	Horizontal	1.04	0.07	1.14	0.18	1.05	0.19	1.10	0.11	F(3, 18) = 1.347, p =.291
	Vertical	1.08	0.20	1.16	0.25	1.16	0.22	1.13	0.17	F(3, 18) = 0.987, p =.421
	*Both**	1.26^	0.11	1.16	0.12	1.13	0.13	1.05	0.09	F(3, 18) = 6.258, p =.004
	Less Exp									
	Horizontal	1.50	0.40	1.27	0.27	1.31	0.21	1.28	0.18	F(3, 18) = 1.574, p =.230
	*Vertical**	1.70^	0.37	1.41	0.22	1.32	0.17	1.40	0.31	F(3, 18) = 6.552, p =.003
	*Both**	1.70^	0.29	1.38	0.15	1.41	0.32	1.25	0.23	F(3, 18) = 5.820, p =.006
Touches	**More Exp**									
	Horizontal	0.14	0.38	0.14	0.38	0	0	0.14	0.38	F(3, 18) = 0.391, p =.761
	Vertical	0.29	0.49	0.57	1.13	0.29	0.49	0	0	F(3, 18) = 1.079, p =.383
	Both	0.43	0.79	0.29	0.76	0.14	0.38	0.14	0.38	F(3, 18) = 0.344, p

									=.794
Less Exp									
Horizontal	1.14	0.69	1	1	0.29	0.49	0.71	0.76	F(3, 18) = 1.895, p =.167
Vertical	1.86	1.68	0.57	0.54	1.86	1.35	0.43	0.79	F(3, 18) = 3.138, p =.051
*Both**	2.71^	1.70	1.71	1.70	1.71	1.25	0.71	0.76	F(3, 18) = 7.000, p =.003

*significant effect accounting for the six comparisons per outcome variable (required alpha level set at 0.006); ^Contrast relative to Trial 4 for the same condition was significant

Exp = experience; **RM** = repeated measures

Table 2

Table 2. T-test omnibus of between group and within the group effects on entropy and hand hold exploration between trial 4 of the double edged route and the transfer route.

Variable	**Group**	**Double-edge route (T4)**		**Transfer route**		
		Mean	**SD**	**Mean**	**SD**	Paired t-tests (2-tailed)
Entropy	**More Exp**	1.096	.155	1.185	.315	1.222(6) p = .27
	Less Exp	1.248	.226	1.456	.310	2.243 (6) p = .07
Independent t-tests (2-tailed)		1.45(12), p = .17		1.62(12), p = .13		
Touches	**More Exp**	0.143	.378	0.714	1.512	2.828(6) p = .03
	Less Exp	0.714	.756	3.571	.756	4.804(6) p = .003*, r = .89^
Independent t-tests (2-tailed)		1.79(12), p = .10		4.47(12), p = .001*, r = .79^		

*Significance adjusted for the eight comparisons (required alpha level set at 0.006)

^r = $\sqrt{(t^2/t^2+df)}$

Exp = experience

Figure(s)

Figures

Figure 1

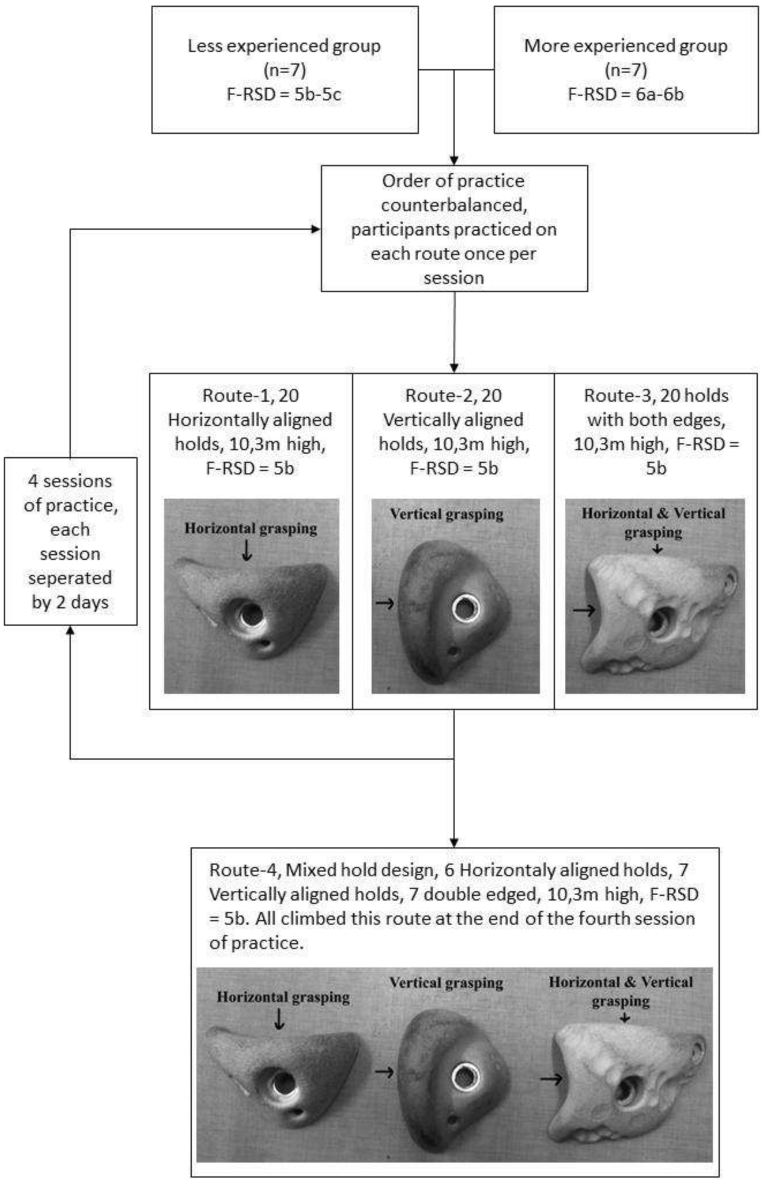

Figure 1. Orientation and shape of the holds for the experimental routes. The arrow indicates the grasping edge offered by the hold design. Route-1 was designed using holds graspable with an overhand grip (knuckles running parallel to the ground). Route-2 was

designed using holds graspable along the vertically aligned surface (knuckles running perpendicular to the ground). Route-3 was designed using holds that each were graspable horizontally and vertically. The transfer test included all three types of holds.

Figure 2

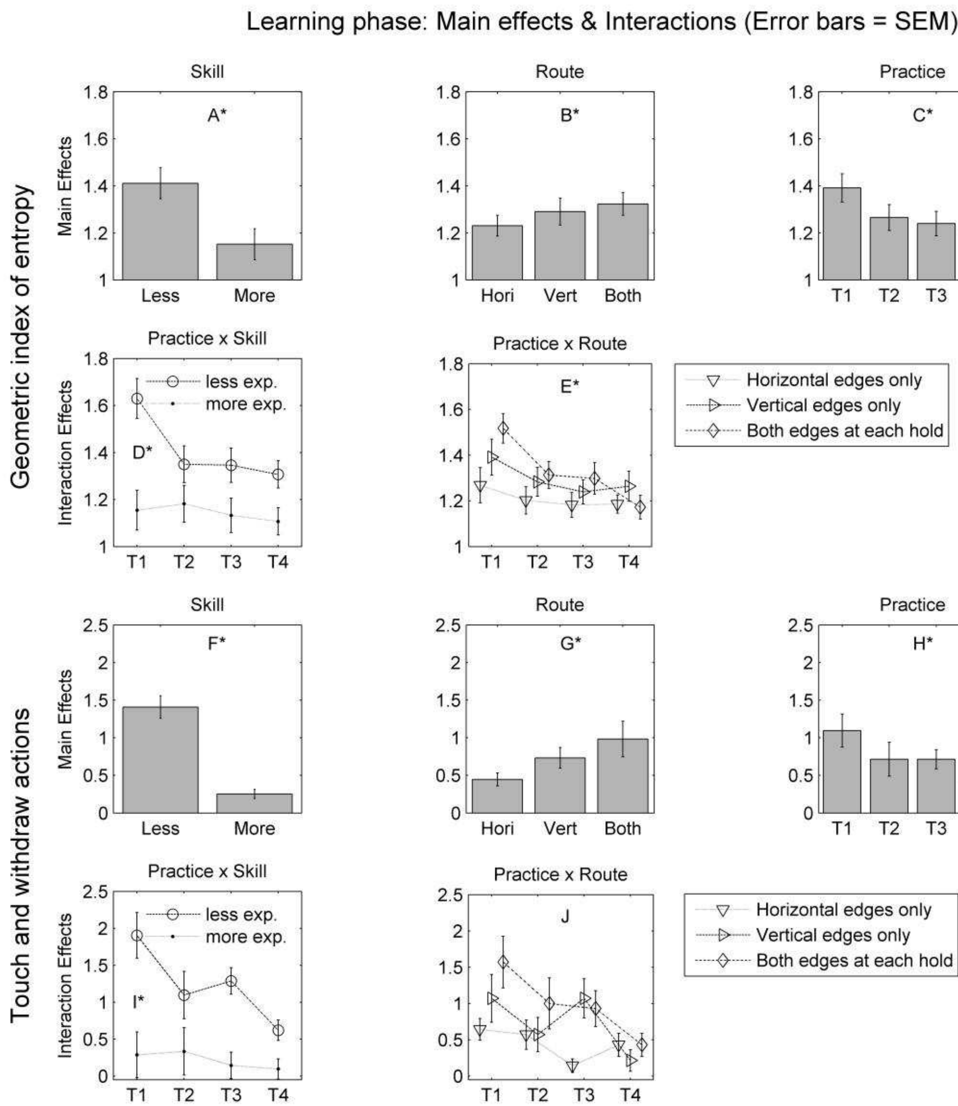

Figure 2. The main and interaction effects across the two main dependent variables, entropy (Graphs A-E) and hold exploration (Graphs F-J). **Note: Both** = Double edged route; **exp.** = experience; **Hori** = Horizontal route; **SEM** = standard error of the mean; **T** = Trial; **Vert** = Vertical route; ***** = significant main or interaction effect.

Figure 3

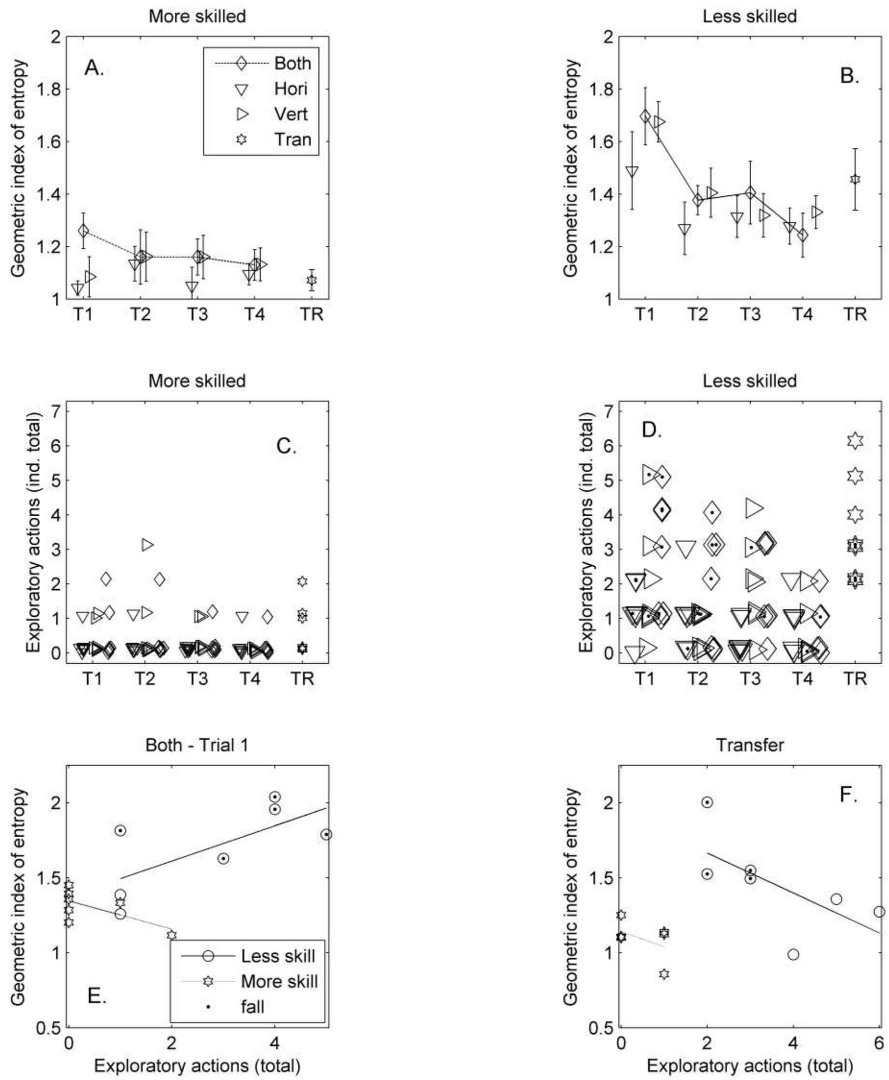

Figure 3. The entropy and hand hold exploration across each condition, over practice and under transfer for the more experienced group (Graph A and C) and the less experienced group (Graph B and D). Also indicated are instances of falls (filled in shapes in figure D). Graphs E and F highlight the change in relationship between exploration and entropy in trial 1 of the double edged route and the transfer test. **Note: Hori** = Horizontal route; **SEM** = standard error of the mean; **Tran** = Transfer route; **T** = trial; **Vert** = Vertical edged route.