The influence of hold regularity on perceptual-motor behaviour in indoor climbing

BUTTON, Chris, SEIFERT, Ludovic, ORTH, D.O. and DAVIDS, Keith <http://orcid.org/0000-0003-1398-6123>

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Title: The influence of hold regularity on perceptual-motor behaviour in indoor climbing

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Chris Button[1], Dominic Orth[2], Keith Davids[3], Ludovic Seifert[4]

Affiliations:

[1] School of Physical Education, Sport and Exercise Sciences, University of Otago, Dunedin, New Zealand

[2] Faculty of Behavioral and Movement Sciences, Vrij Universiteit, Amsterdam, The Netherlands

[3] Centre for Sports Engineering Research, Sheffield Hallam University, Sheffield, United Kingdom

[4] CETAPS - EA 3832, Faculty of Sport Sciences, University of Rouen Normandy, Mont Saint Aignan, France

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Abstract

Climbers often train on indoor climbing walls, which are modifiable to simulate features of outdoor climbing environments at different levels of difficulty. The aim of this study was to evaluate the influence of regularity of climbing holds on perceptual-motor behaviour. Skilled climbers performed six repetitions of two topographically-similar routes on an indoor climbing wall. One route was composed of 18 different types of hand holds (irregular route) whereas the other route had only two types of hand holds (regular route). Preview and climbing durations as well as visual search behaviours were measured. Participants rated the regular route as more difficult to climb, requiring greater perceived effort to complete. The time spent previewing, and then climbing, the routes was reduced on average by 12 and 16% respectively in the irregular route compared to the regular route. There were more fixations made when climbing the regular route (281 vs. 222 fixations per trial). It seems the climbers were more careful and thorough in their gaze behaviours with the regular route because of the additional technical demands it presented, whereas the irregular route afforded a more superficial visual exploration with use of more frequent saccades between holds. The findings suggest how irregularity in the environment is exploited by skilled climbers, apparently making the practice context easier to perceive and act in.

Key words: environment, exploration, fixations, gaze behaviours, route preview, representative design

Introduction

For numerous reasons, sports practice environments are typically altered or simplified (i.e., designed to be more regular) in contrast to competition settings. Coaches often intentionally reduce environment regularity in practice drills to simplify the demands upon the learner and thereby promote skill execution and task achievement (Davids, Button, & Bennett, 2008). Furthermore, pragmatic factors such as cost, safety and unpredictable conditions (e.g., weather) signify that learners have little alternative but to train in quite different environments to those in which they normally compete. For example, learner rock-climbers often train on indoor climbing walls, which are modifiable to simulate features of outdoor climbing environments, as well as different levels of performance difficulty. Of major concern to the practitioner, is whether training conditions, modified in regularity to support a safer (or less intense) learning context, actually support the transfer of skill to a specific setting of interest (such as competition or an extreme environment (Seifert, Orth, Button, Brymer, & Davids, 2017)). In this study we sought to evaluate the influence of environmental regularity on climbing perceptual-motor behaviours. More specifically, we wanted to investigate the somewhat counterintuitive idea that *increasing* irregularity in the practice environment can actually facilitate performance.

The theoretical rationale for this study comes from two sources. First, it has been proposed that the introduction of environmental irregularity can help to develop movement adaptability that is otherwise not encouraged under highly repetitive and predictable conditions (Newell, Liu, & Mayer-Kress, 2005; Seifert, Komar, Araújo, & Davids, 2016). Second, the concept of *representative learning design*, predicated on Brunswik's (1956) notion of representative design, suggests that practice environments should aim to simulate performance conditions and affordances (invitations for action) that are available to be utilized in competition (R. A Pinder, Renshaw, & Davids, 2009). As the competition settings are often more irregular and less predictable than practice, simulating this irregularity in meaningful ways may be essential for enhancing the representativeness of a practice environment. The concept of introducing irregularity into practice environments to improve performance also has emerging support in the literature (Wymbs, Bastian, & Celnik, 2016). Seifert et al (2015) and Orth et al (2017) examined the impact of increasing the complexity of the route design in a climbing task. When ascending a route with dual-edge holds, climbers exhibited a lower climbing fluency (exhibited by a more complex hip trajectory captured by a spatial index of entropy) than when attempting a less complex route design (routes with holds graspable by using only one edge: either horizontal edge or vertical edge) (Orth et al., 2017). Furthemore, during the more complex route design, climbers also exhibited higher behavioural exploration, which was reflected by higher range of hip rolling motion on the route with dual-edge holds than on the route with horizontal edge holds (Seifert et al., 2015).

The design characteristics of a 'to-be-climbed' surface can provide numerous, nested affordances available to be discovered via visual exploration and motor simulation (Orth, Button, Davids, & Seifert, 2017; Pezzulo, Barca, Bocconi, & Borghi, 2010). Climbers can regulate their behaviours when traversing a surface by seeking information for affordances available in a performance environment. Therefore, exploratory activity in climbing may help the individual reduce uncertainty in how to use or pass between holds, to avoid falling and enhance postural stability, or to determine more efficient progress through a route to improve performance (Orth, Davids, & Seifert, 2017; Seifert, Cordier, Orth, Courtine, & Croft, 2017). For example, an exploratory route preview, which is an activity often undertaken prior to climbing involving visual inspection of the route, allows experienced climbers to climb routes with fewer rest points (Sanchez, Lambert, Jones, & Llewellyn, 2012). With respect to practice, Dupuy and Ripoll (1989) measured the eye movements of five skilled rock-climbers attempting the same outdoor route in three conditions: 1) on-sight, 2) after practice (i.e., on the 5th attempt), and 3), at maximal speed (to assess the influence of time pressure). Exploratory visual fixations were reduced under the latter conditions of repetition and temporal pressure, however fixations related to hand and leg movements were unaffected under these performance constraints. Hence, particularly during initial attempts to climb a route (i.e., during on-sight climbs), skilled climbers seemed to engage in a high proportion of exploratory visual search and planning. Dupuy and Ripoll (1989) suggested that prior experience of the route facilitates decision-making about which holds to use, and thus leads to a decrease in the amount of visual search activities (i.e., such as attempting to regulate current actions based on visual inspection of upcoming holds) and motor exploration (such as touching but not using holds) required. Also when speed climbing, several motor actions are performed at the same time, which is associated with less overall prospective exploration (at least evidenced by less distally-located visual search patterns). As visual-motor guidance was less affected by speed climbing and repetition, a tentative interpretation is that this process is optimized (i.e., learnt) during initial attempts and remains relatively stable despite other changes in task constraints (Dupuy & Ripoll, 1989).

An important consideration in relation to the design of practice environments concerns the opportunities for action (i.e., affordances) that are made available to a learner. On an indoor climbing wall, the array of support holds can be conceived of as comprising a rich landscape of affordances through which invites specific actions from a climber (Withagen, de Poel, Araújo, & Pepping, 2012). Certain characteristics of the affordance landscape, like hold shape and orientation, are particularly informative to climbers as these factors help them to anticipate how they may link different movements together and discover relevant affordances (Pezzulo et al., 2010). Indeed the edge depths on holds affects not only grasping techniques (Amca, Vigouroux, Aritan, & Berton, 2012), but also the level of mobility required to use them (at least in terms of velocity at the hip) (Fuss, Weizman, Burr, & Niegl, 2013). Seifert, Boulanger, Orth and Davids (2015) manipulated affordances (i.e. hold orientation and the number of available edges for grasping) to examine the adaptability of skilled indoor climbers. In a specially designed route where each hold had two edges available to use, more trunk rolling motions emerged from the climbers, as well as a greater overall number of exploratory movements, compared to routes with only a single-edge present at each hold (Seifert, Boulanger, Orth, & Davids, 2015).

Identifying nested affordances through visual and motor exploration seems to be a crucial component of skilled climbing behaviour (Seifert et al., 2013). Seifert et al. (2017) found that both experienced and inexperienced climbers showed high inter-individual variability in gaze behaviours when previewing a route. Whilst variable, the gaze behaviours were categorised into four visual strategies (i.e., ascending, fragmentary, zig-zagging, and sequencing), the use of which were not related to skill level but more associated with the duration of preview. Interestingly climbers who used shorter previews often climbed more fluidly as indicated by fewer rests. Hypothetically, a climbing route containing more variation in hold design contains a richer landscape of affordances for skilled climbers in contrast to one that has the same number and placement of holds but fewer variations in hold design With more affordances to choose from, the climber has greater potential to vary the way in which they climb a route. Indeed, less regularity in holds allows the climber to adapt their actions to a greater extent, which may help to prevent fatigue (Amca et al., 2012). However, hold irregularity may pose a challenge during route preview in identifying the various hold characteristics and the best ways to use them (Orth, Davids, et al., 2017). Consequently it is possible that a route with less regular holds would take longer to inspect and may lead to prolonged stoppages dedicated to exploratory behaviours either with the visual and/or motor systems (as suggested in Sanchez et al., 2012).

The Current Study

The type of information manipulated in the current study was based on the concept of environmental regularity where it was assumed that, the more regular an environment is, the more predictable it is. The level of predictability was expected to exert a strong influence on: a) what information individuals ultimately use to guide action during performance, and b), their ability to locate and exploit information-movement couplings fluently (i.e., in a behaviourally-efficient manner, (Orth, Kerr, Davids, & Seifert, 2017)). We anticipated that by modifying the regularity in the hand holds available to climbers, we might induce meaningful changes in how climbers perceive the route (evidenced in their visual search behaviours observed on the climbing wall), as well as their climbing fluidity. As such, we required skilled climbers to attempt to traverse two similar topographical routes (see Figures 1 and 2) which differed in levels of environmental regularity (i.e., low regularity – 18 types of hold design; high regularity – 2 types of hold design). In principle, the different holds in the irregular route present a larger field of affordances for climbing actions (i.e., inviting different ways of supporting, grasping and moving between holds), than the regular route, and, therefore, should allow skilled climbers to move with more fluidity (Orth, Davids, et al., 2017).

Specifically, we predicted that in comparison to the irregular route, the regular climbing route would result in:

- reduced preview and climb durations

- increased perceived difficulty and more perceived effort to climb the route
- less exploratory visual search behaviour (i.e., fewer, longer fixations, decreased search rate) in preview and during climbing

Furthermore, we predicted that the differences listed above would dissipate with physical practice of the two routes as the importance of the route preview diminishes.

Methods

Participants

Twelve male indoor climbers volunteered to participate after responding to advertisements posted at a climbing club. Only intermediate to skilled climbers were recruited based upon their current, self-reported level of indoor climbing ability (corresponding to higher than 6b on the French sport climbing rating scale: see Draper et al., 2011). Exclusion criteria included no clinically diagnosed visual deficits, nor any recent acute musculoskeletal injury that might interfere with climbing ability. Of the 12 climbers, 3 fell more than once during testing due to fatigue and/or movement execution errors and they were excluded from further analysis. The remaining 9 participants possessed a range of indoor climbing experience from 6 to 18 years (Table 1).

Table 1. Participant details (Ew = Ewbank, Australian scale of climbing difficulty; kg = kilograms; m = metres; y = years)

	P1	P2	P3	P4	P5	P6	P7	P8	P9	Mean (SD)
Age (y)	22	28	30	24	25	24	22	21	27	24.7 (3.0)
Climbing experience (y)	10	6	7	18	10	8	14	9	18	11.1 (4.5)
Indoor on-sight rating (Ew)	27	23	22	27	25	26	23	23	26	24.7 (1.9)

French/sport scale	7c	6c	6b+	7c	7b	7b+	7a	7a	7b+	
Height (m)	1.75	1.81	1.74	1.84	1.74	1.63	1.76	1.78	1.81	1.76 (0.06)
Arm-span (m)	1.77	1.80	1.83	1.98	1.81	1.70	1.80	1.84	1.81	1.82 (0.07)
Body mass (kg)	66	70	61	77	62	50	60	70	63	64.3 (7.7)

Equipment

The performance analysis took place on an indoor climbing wall. The facility was part of an indoor climbing club run by a public sport and recreation facility. The venue had constant temperature and lighting and, for the duration of testing, the wall was restricted for use only by participants. The climbing wall itself (3.5 m wide x 10.7 m high) was made of multiple smooth wooden boards. The holds were attached firmly onto the wall with 50mm cap-screw bolts. The climbing holds were polyethylene moulded shapes with a rough textured exterior to simulate the frictional characteristics of rock. A range of different shapes and sizes of hold were used depending on the regularity of the route (see below). Standard climbing harnesses and rope were used both by participants and the belayer.

Figure 1. *Sample of holds making up the white, irregular route (left) and the two holds*

making up the yellow, regular route (right).

Participants wore an unobtrusive mobile eye movement registration system (MobileEye, Applied Science Laboratories, Bedford, MA). The system was used to determine the participants' monocular point of gaze as they previewed, and then climbed a route. The head mounted hardware device, similar to a pair of glasses, was positioned on the participant's face with adjustable straps to maintain a fixed position. Video footage was collected by two miniature cameras attached to the frame of the glasses. The video footage was transmitted to a digital video recorder, which was carried in a small backpack strapped around the participants' waist. The system was calibrated by having the participants visually fixate on a series of known points from a known position of reference. In between trials, participants were required to fixate on a series of known positions to provide for accuracy checks in the case of calibration drift. The system is reported to be accurate to 1° of visual angle with a 0.5° precision (https://imotions.com/portfolio-items/asl-glasses).

Two climbing routes were designed by an experienced route setter (irregular: 18 types of hold, and regular: 2 types of hold). As indicated in Figure 2, the topographical positions of the holds were similar for the two routes. So that each route was clearly distinguishable, the irregular route was comprised solely of yellow coloured holds, the regular route used only white holds. Each route was composed of an initial horizontal traverse section from right to left (approximately 3.5m) and a vertical ascent section (approximately 10.7m) with 19 hand holds and 6 additional small footholds. The hand holds could be used either for the hands or feet but the footholds were only to be used by the feet. Hand holds 5-10 were configured to form a crux (see Figure 2). A 'crux' is a climbing term for a demanding region of the route where more advanced climbing actions may be required to progress. The relative difficulty of both routes was set at a grade ('6a' on the French rating scale) that had been previously achieved by the participant group of climbers (their abilities being above '6b').

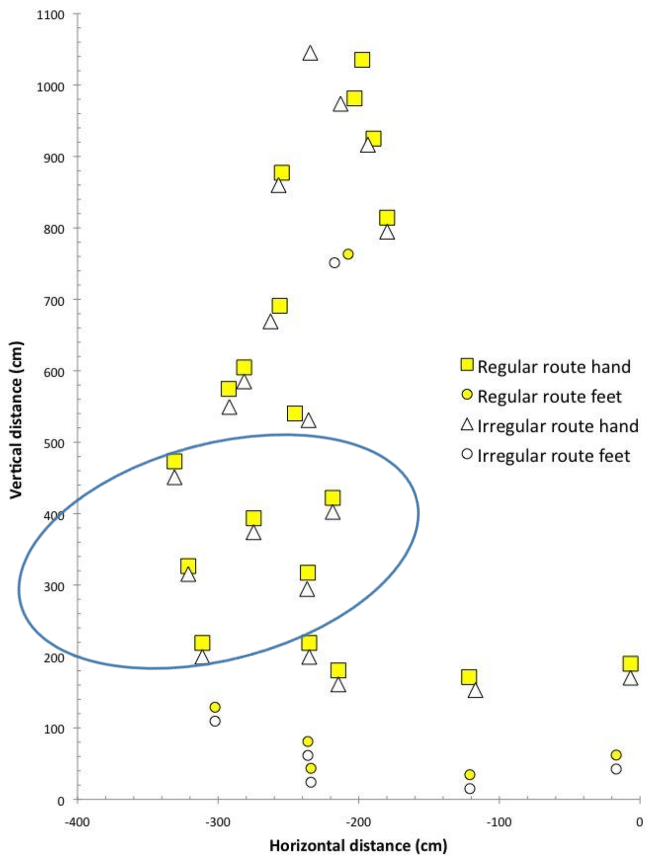

Figure 2. *The spatial coordinates of each hold for the two indoor routes. The crux region comprising hand holds 5-10 is highlighted by the blue ellipse.*

Climbing performance indicators, such as durations of preview and climb were determined from external video footage (Sony EX-View Super HAD, effective pixels: 768x520, 560 line resolution, 120° angle of view). The camera was mounted on a tripod approximately 5 m from the climbing wall, and the zoom, pan and tilt functions were utilised to ensure the climber remained central to the field of view at all times.

Procedure

Ethical approval for the following procedure was granted by the participating institution's ethics committee. Participants were tested on two occasions separated by at least 7 days. Each session required the climber to preview and then attempt 6 ascents on the assigned climbing route (yellow or white). Each testing session lasted for approximately 60 minutes.

Upon arrival at the climbing gym, participants first undertook a 10-15 minute climbing-specific warm-up consisting of their preferred stretches and light climbing activities. The participants then put on the eye movement registration system and carrying bag. To ensure the system was functioning accurately participants were requested to stand with their head still and fixate on a number of features in the climbing gym. When participants reported they were comfortable with the equipment they were escorted to the climbing wall and told which route they would be attempting to climb.

First, participants were given up to three minutes to preview the assigned route. The instructions given were: "*You will attempt to climb the (white or yellow) route.* Y*ou have three minutes to view the route*". If participants required less than 3 minutes inspection of the route they could terminate the preview when they wished. After the preview of trials 1, 2 and 5, participants verbally rated the perceived route difficulty using the standard French scale that they were most familiar with.

The instructions issued to participants prior to climbing were: "*You will attempt to the climb this route six times, with 5 minutes rest between climbs. Self-pace your ascent, try to climb as fluently as possible (by minimizing stops and without falling) to get to the top*" ('getting to the top' was defined as grasping the final hold on the route). Participants were also made aware that they could only use the coloured holds corresponding to the route that they were attempting, although they did not have to use every hold. No prior information was provided to participants about the specific characteristics of the holds in either route. In all cases, climbs were top-roped (the climbers were supported in the event of a fall by an anchor rope managed by an experienced belayer).

Both the preview and climbing processes were repeated until six trials had been completed. If the participant fell without completing the route during any of the trials, that trial was not repeated. In between trials participants were given five minutes seated rest at a position beyond the visual field of the wall. These rest periods were also used to recheck the accuracy of the eye movement registration system by requiring participants to fixate on known objects in their field of view.

Data Analysis

The study involved a single group, repeated measures design with three factors: condition (preview and climbing); route (regular and irregular); and trial (1 to 6). Several variables were recorded and included how long climbers spent previewing and climbing the route. The climber's self-rated perception of route difficulty (both in terms of route grade - French Rating Scale of Difficulty), immediately after trials 1, 2 and 5, was noted. Furthermore, relative perceived exertion (RPE scale designed by Borg from 6 to 20 on Likert scale) was reported by the climbers after each trial. Gaze behaviour data were collected during both the preview and climbing parts of each trial, which included three commonly reported fixation variables i.e., average fixation duration as a percentage of trial duration, number of fixations, and search rate (the number of fixations divided by the total fixation time per trial). Fixations were automatically coded by custom written Matlab® routines (1994-2014, The MathWorks, Inc.) using the x and y coordinates provided by the MobileEye system. A fixation was coded when the point of gaze dwelt for at least 80 ms within a region of no greater than 58 pixels.

Missing data points and outliers (> ± 2SD) were replaced with the average from that participant's associated series of data points. Checks of normality and sphericity were performed for the repeated measures variables and, where necessary, Greenhouse-Geisser corrections were applied to the statistical tests. The numerical data described above were further analysed with 3 factor repeated measures ANOVA. In the event of significant main effects or interactions, post-hoc paired sample t-tests were employed. The level of statistical significance was set at $p<0.05$. Effect sizes (η^2) were calculated using partial eta squared which describes the proportion of total variability attributable to a factor.

Results

Of the 12 participants, three fell at least once during testing and their data are not reported here. The remaining nine participants completed the six ascents successfully in both conditions. The quality of the remaining eye tracking data was manually checked and it was confirmed that data from 84% of trials were captured successfully (comparable to the quality reported by Seifert et al., 2017).

Preview and climb duration

Contrary to our first hypothesis, the durations of the route previews and climbs were less for the irregular (white) route than the regular (yellow) route. A significant main effect of route confirmed this observation ($F(1,8)=7.42$, $p<.03$, $\eta^2=.48$). A main effect of trial was in line with expectations, where durations of both previews and climbs decreased as a function of trial ($F(5,40)=28.19$, $p<.001$, $\eta^2=.78$). There were no other significant main effects or interactions for preview duration. Post-hoc t-tests revealed that, by trial 6, the differences between conditions were no longer significant (p's>0.05). Regardless of which route was being attempted, the time taken for the previews and climbs were similar throughout the study (mean difference = 9.4 ± 6s, maximum difference = 21 s) and followed similar trends (see Figure 3).

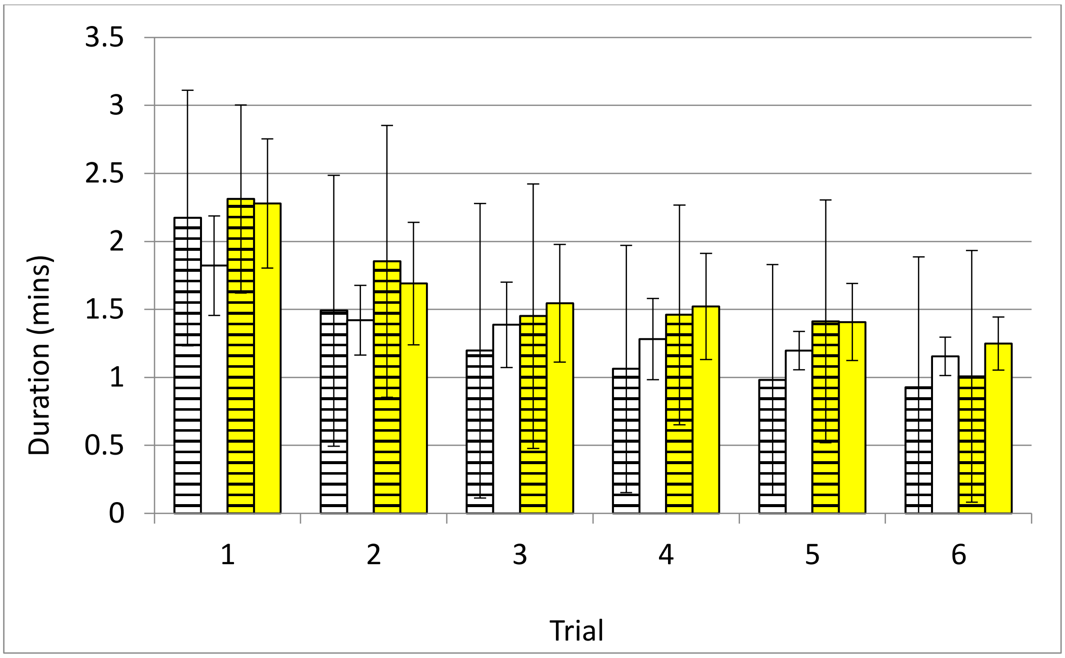

Figure 3. Duration of previews and climbs for the different routes as a function of trial. Note: the white bars are the irregular route, the yellow bars are the regular route. The bars with horizontal lines are previews and the open bars are climbs.

Perceived difficulty and physical exertion

Participants judged the regular route as more difficult to climb than the irregular route and this difference was stable across trials (see Figure 4). For perceived difficulty there was a main effect of route ($F(1,8)=13.98$, $p<.007$, $\eta^2=.64$), but no main effect of trial, nor an interaction. The regular route difficulty was graded at 6b+ (2.08 ± 0.03 Ewbank scale) whereas the irregular route was graded at 6a+ (1.67 ±.03 Ew).

After completing each climb participants provided a rating of perceived exertion. Reflecting the ratings of perceived difficulty, participants also rated the regular route as more demanding (mean = 14 ± 2: “Somewhat Hard (heavy)”) than the irregular route (mean = 12 ± 2: “Between Light and Somewhat Hard”). As with perceived difficulty, the route main effect was significant ($F(1,8)=13.1$ $p<.008$, $\eta^2 =.62$), but there was no effect of trial.

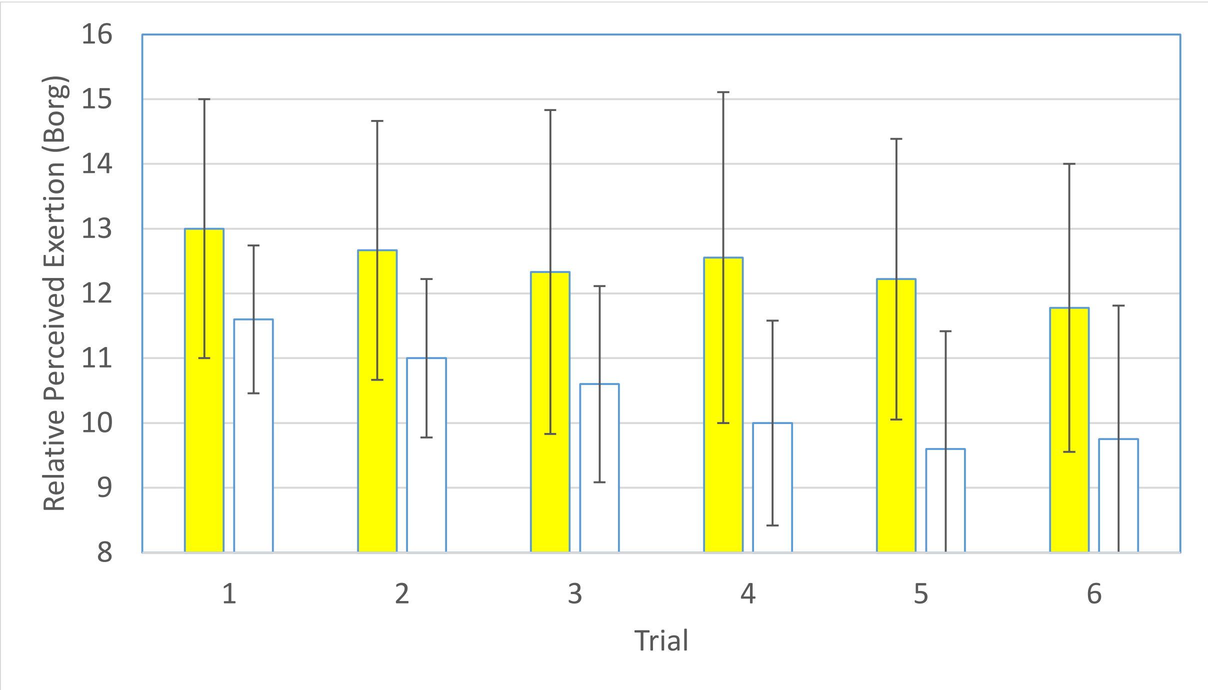

Figure 4. Relative perceived exertion after climbing as a function of trial and regularity condition (yellow bars – regular route, white bars – irregular route). Error bars are standard deviations.

Number of fixations

There were a total of 47,944 fixations made across the 9 participants with an overall mean of 268 ± 130 per trial. There were main effects for regularity ($F(1,8) = 7.34$, $p <.03$, $\eta^2 =.48$) and trial ($F(5,40) = 25.2$, $p <.001$, $\eta^2 =.76$). Post-hoc comparisons confirmed there were more fixations made in the regular hold route in both the preview and the climb conditions. There were fewer fixations made as a function of trial repetitions (T1<T2, T3<T4, T5<T6: *p*’s <.03).

There was also a condition by trial interaction ($F(5,40) = 3.06$, $p <.02$, $\eta^2 =.28$) with the overall number of fixations initially higher in preview but converging following practice (see Table 2).

Table 2. Mean number of fixations (SD) as a function of condition and route

	Preview		Climb	
Trial	Irregular	Regular	Irregular	Regular
1	378 (162)	411 (149)	307 (69)	395 (120)
2	260 (137)	324 (156)	223 (60)	317 (84)
3	268 (170)	326 (184)	200 (46)	249 (44)
4	193 (107)	256 (140)	213 (63)	261 (104)
5	204 (165)	278 (168)	204 (67)	236 (79)
6	168 (112)	180 (184)	187 (50)	226 (101)
Mean	245 (76)	296 (20)	222 (43)	281 (65)

Relative duration of fixations

There was a main effect for the relative duration of fixations in terms of the preview and climbing conditions ($F(1,8)=534.9$, $p <.001$, $\eta^2 =.99$), with longer relative fixation durations in the preview condition (see Table 3). There was also a main effect of regularity ($F(1,8)=6.4$, $p<.04$, , $\eta^2 =.45$) where relatively more time was spent fixating in the regular route.

Search rate

Search rate was significantly higher in the climbing condition compared to the preview ($F(1,8)=225.7$, $p<.001$, $\eta^2=.97$), and also higher for the irregular route compared to the regular route ($F(1,8)=9.0$, $p<.02$, $\eta^2=.53$, see Table 3).

*Table 3. Relative fixation duration and search rate by condition and route*Variable	Preview		Climbing	
	Irregular	Regular	Irregular	Regular
Relative fixation duration (%)	65.6 (9.7)	70.9 (7.8)	36.5 (5.9)	37.4 (8.3)
Search rate (fixations per sec)	4.6 (0.2)	4.3 (0.3)	7.4 (0.1)	7.1 (0.1)

Discussion

The aim of this study was to determine whether the level of regularity in hold design influenced the behaviours and perceptions of skilled climbers. We also wanted to identify whether repetition of a route caused such changes to dissipate, as this would suggest that (ir)regularity can influence learning rate.

Reduced preview and climb duration in the irregular hold route

Our prediction that the regular hold route would result in reduced preview and climb durations was not supported by the data. In fact, the time spent previewing, and then climbing, was reduced on average by 12 and 16% respectively in the irregular route compared to the regular route (see Figure 2). In other words, the route in which only two types of holds were present took more time to preview and to climb, in comparison to the route in which 18 different shapes of hold were present. Our interpretation of this somewhat counter-intuitive finding is that participants spent longer, both considering how to climb the regular route in preview, and then actually climbing it, due to the relative lack of variation in grasping opportunities (affordances) offered by the regular route. As fewer climbing solutions (i.e., grasping patterns: i.e., pinch and crimp for the squared hold, slope and crimp for the rounded hold) are invited with just two types of hold, the participants spent longer attempting to perceive how these might be efficiently grasped and/or used. Furthermore, the duration of both conditions also reduced with repetition of the route, reaching a plateau by trial 6. By the sixth repetition of the routes, participants had seemingly found effective solutions to climb each route and, therefore, initial differences in previewing and climbing duration were diminished. The lack of interaction between condition and trial suggests that both routes supported learning at similar rates with route repetition.

Easier perceived difficulty and less perceived effort to climb the irregular route

The regular route was deemed by participants as more difficult to climb (6b+ or 2.08 ± 0.03 Ew) than the irregular route (6a+ or 1.67 ±.03 Ew). Furthermore, participants also rated the regular route as more physically demanding (“Somewhat Hard (heavy)”) than the irregular route (“Between Light and Somewhat Hard”). As the two routes were almost identical, topographically in terms of the locations of holds, this difference may be attributed to the relative challenge posed by the restricted number of hold types within the regular route. Presumably, participants were aware that the regular route would require more awkward grasps to be held for longer periods (in comparison to the irregular route) and thus perceived the two routes quite differently in terms of the technical and physical demands. Indeed, it is likely that the restricted number of hold grasping patterns led the climber to acquire earlier muscle fatigue, in comparison to the regular route where variable grasping patterns and body positions were afforded (Watts, Newbury, & Sulentic, 1996). After completing both routes, the climbers self-reported through an informal questionnaire that the regular hold route was perceived as more demanding as the lack of variety in holds restricted the number of grasp patterns they could use to climb fluidly. Overall, these findings suggest that the physical effects of route regularity on the key performance variables of muscle fatigue and perceived exertion may have originated in the narrow field of affordances (two holds only) used in the landscape by the participants.

Less exploratory visual search behaviour in the irregular route

Overall, periods of preview and climbing duration were reduced in the irregular route, which may indicate less exploratory visual search behaviour, particularly for the preview condition. There were also fewer, briefer fixations made in the irregular route. Perhaps the most sensitive measure of exploratory search behaviour is the search rate, and participants utilised a higher search rate whilst scanning the irregular route in comparison to the regular route. The irregular features of the holds in the white route were less predictable and they elicited more exploratory scanning during preview and climbing than the regular route. It seems likely that the irregular route invited a more superficial, broader inspection of the route whereas the regular route demanded a “deeper” visual inspection of the individual holds, with climbers paying particular attention to how subsequent movements might be chained together to climb fluidly. In other words, the climbers were more careful and deliberate in their gaze behaviours with the regular route because of the additional technical demands it presented, whereas the irregular route afforded a more superficial visual exploration with more frequent saccades between holds (Seifert et al., 2017). The results also appear to confirm Dupuy and Ripoll’s (1989) finding from outdoor rock climbing that the number of fixations decreases with experience of a route.

To summarise, this study contributes new knowledge about how changes in intensity of practice alters perceptual-motor behaviours in indoor climbing, as relatively few studies have measured gaze directly during climbing activities (although see Dupuy and Ripoll, 1989). As a function of skill level and experience of a route, climbers develop more economic visual search patterns in which the overall number of fixations decreases with practice on a route. Furthermore, the amount of regularity presented in the environment also impacts upon climbers' perceptions. Our study has revealed that routes offering restricted opportunity for different grasping patterns (where flexibility in climbing movement patterns is discouraged) may alter intensity of practice since they are perceived as more difficult and requiring more effort to climb fluidly than irregular routes. Climbers adopt more deliberate, structured gaze behaviours in such instances, whereas for routes that invite various ways using holds a larger range of scanning behaviours may be encouraged.

These results may provide useful insights for route design in climbing practice. For example, irregularity in hold design may be manipulated to modify the challenge point appropriately for learners and, thereby, provide optimal practice conditions depending upon skill level (Guadagnoli & Lee, 2004). Additionally, increased regularity in hold design may be rationalised from a strength and conditioning perspective, due to inducing higher levels of perceived exertion and muscle fatigue. However, decisions about learning design pertaining to environmental regularity need to be balanced with the potential injury risk induced, particularly in climbing where repetitive overuse injury to the fingers are the most frequent (Jones, Asghar, & Llewellyn, 2008; Woollings, McKay, Kang, Meeuwisse, & Emery, 2014).

Also, in many sports a common practice strategy is to reduce environmental irregularity whilst a movement pattern is refined and rehearsed to control for extraneous factors that might interfere with motor control (e.g., in cricket batting to use a ball-projection machine rather than a real bowler in springboard diving to decompose the whole task into separate components for practice). Our findings, however, suggest that irregularity can be exploited by skilled climbers. This study supports recent reminders in the literature cautioning against pedagogical strategies that reduce the representativeness of the practice environment which might alter the perceptual-motor behaviours of the learner in an unintended manner (R.A. Pinder, Davids, Renshaw, & Araújo, 2011). At this early stage, we recommend caution before applying the results of this indoor climbing study to outdoor climbing environments. Nevertheless, as indoor (or sport) climbing enters a new era of increasing popularity and visibility as an Olympic sport for 2020, we hope that the findings of this study and the implications will stimulate a more nuanced approach to the design of practice environments.

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