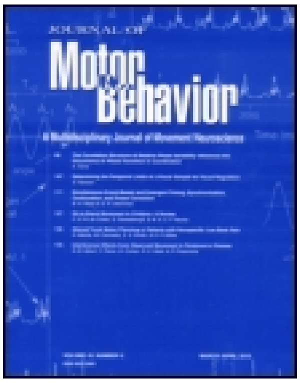

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Memory for the Functional Characteristics of Climbing Walls: Perceiving Affordances

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Memory for the Functional Characteristics of Climbing Walls: Perceiving Affordances

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ABSTRACT. In 2 experiments, differences in visual perception of climbing routes (route finding) between 7 expert climbers, 4 novices, and 9 inexperienced participants were studied. In both experiments, participants reproduced on a scale model the locations and orientations of 23 holds of a climbing wall. The results showed that the expert climbers recalled more information and recalled clusters of information and that they focused on the functional aspects of a climbing wall, whereas they neglected its structural features. Inexperienced participants did not recall such clustered information, and they reported almost exclusively the structural features of the holds. The perception of nested affordances and the expert climbers' neglect of details are discussed.

Key words: affordances, chunking, expertise, sport climbing, visual perception

For moderately difficult climbing walls, a sport climber must perceive (or interpret) a climbing wall and perceive (or deduce) possible climbing actions to find a good path to climb, executing a process called *route finding* (Cordier, Mendès France, Pailhous, & Bolon, 1994). During route finding, climbers are not yet climbing.[1] A climber has to perceive whether a hold is reachable from some position (Pijpers & Bakker, 1993, 1995; Pijpers, Bakker, & Holsheimer, 1997) and how a hold can be grasped or used as a foot support. In a preliminary survey,[2] climbers indicated that they used route finding predominantly to practice the order of climbing movements (revealing a kind of climbing choreography), to determine the best climbing path, to improve climbing performance (e.g., speed and efficiency), and to find spots on the climbing wall to rest. Furthermore, the climbers indicated that mistakes made during route finding are a major reason for falling during climbing. Those findings suggest that skill in sport climbing might be related to skill in route finding.

In the present study, we used the ecological approach to perception and action (see Gibson, 1979; Michaels & Beek, 1995; Reed, 1996) to describe the relation between skill and perception (and memory) in sport climbing. The ecological approach and the related dynamical systems approach have received increasing attention by human movement scientists and have led to new insights into perceiving and acting (see Beek, Peper, Daffertshofer, van Soest, & Meijer, 1998; Bootsma, 1998; Kelso, 1995; Michaels, 1998; Michaels & Beek, 1995; Reed, 1996; Whiting, Meijer, & van Wieringen, 1990). The mutuality between an organism and its environment is the fundamental starting point of the ecological approach. For sport climbing, such a mutual dependency between the climber and the climbing environment led us to wonder whether skilled climbers perceive and remember the action possibilities—affordances—of climbing walls and their constituents. That is, do expert climbers perceive climbing opportunities rather than structural features of the wall when they look at a climbing wall? Stoffregen (2000) reported that since Gibson's (1979) final presentation of the affordance concept, researchers have made relatively few efforts (e.g., Oudejans, 1996; Stins, 1998) to develop that concept. Our aim in the present study was, on the one hand, to examine whether experts' perception in sport climbing is characterized by the perception of climbing opportunities, thus providing evidence for the perception of affordances, and, on the other hand, to further develop or explicate the affordance concept.

Several studies on a variety of tasks have provided evidence that differences in motor skill might be caused, at least partially, by differences in visual perception (Aber-

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nethy, Neal, & Koning, 1994; Beltel, 1980; Ericsson & Lehmann, 1996; Paull & Glencross, 1997; Pijpers & Bakker, 1993; Vickers, 1988, 1996). For example, Abernethy et al. (1994) showed that expert snooker players can be distinguished from novice players by their superior ability to rapidly and accurately pick up the information relevant for the task. Similarly, Pijpers and Bakker (1993) showed that skilled sport climbers accurately perceive the maximum distance they can reach, whereas novices underestimate their reaching capacity.

The relation between visual perception (and memory) and skill level is usually explained in terms of "chunking" or "templating." Miller's (1956) original chunking concept was subsequently applied to skills by de Groot (1965) and by Chase and Simon (1973), who studied the extraordinary perception and memory skills of chess masters. Chase and Simon stated that "the most important processes underlying chess mastery are these *immediate visual-perceptual processes* rather than the subsequent logical-deductive thinking processes" (p. 215, italics added). Empirical findings demonstrated that chess masters are capable of reproducing a complicated meaningful chess position after an exposure of only 5 s (Chase & Simon, 1973; de Groot, 1946/1965; de Groot, Gobet, & Jongman, 1996), which seems inconsistent with the human short-term memory span that has beem reported in the information-processing literature. Chase and Simon thought that the finding that an individual can exceed the capacity of short-term memory implies that some kind of clustering of individual elements in memory into larger, meaningful units (chunking) takes place. In chess, perceived chunks (game configurations) contain information about visual properties (i.e., color of the pieces and spatial proximity) and chess functions (i.e., defense and identity of the pieces; attacks appeared to be less important).

The perceptual chunking model of Chase and Simon (1973) was eventually modified in two ways. First, experimental evidence suggested that clustering relies not so much on short-term memory encoding as on recognition of complex patterns (see Gobet & Simon, 1998; de Groot et al., 1996). Second, de Groot et al. (1996) showed that chess masters described positions at higher levels of abstraction than the patterns proposed in Chase and Simon's original account. Masters use labels like "the Averbach variation of the King's Indian." That finding led to the template model (see Gobet & Simon, 1998). Templates are complex retrieval structures in long-term memory. To rapidly store new information, the system creates slots at locations where there is substantial variation. Furthermore, templates have pointers to other templates and representations of plans, moves, and procedures (Gobet & Simon, 1998).

For cognitive skills (e.g., chess and verbal tasks), the chunking concept (and its related template model) is the widely accepted characterization of experts' perception and memory. Though sport climbing is quite different from chess, both involve perceptual tasks in which topographic constraints (i.e., the configuration of the pieces on a chess board and the holds on a climbing wall, respectively) determine the actions that might and might not be executed. In addition, in several studies (e.g., Abernethy et al., 1994; Allard & Burnett, 1985; Garland & Barry, 1991), a relationship has been found between expertise in sports and memory for perceived actions and game situations.

In this article, we describe phenomena associated with chunking and templating in terms of the action possibilities a climbing wall offers (i.e., the climbing affordances). Gibson (1979) stated that "if a terrestrial surface is nearly horizontal (instead of slanted), nearly flat (instead of convex or concave), and sufficiently extended (relative to the size of the animal) and if its substance is rigid (relative to the weight of the animal), then the surface affords support" (p. 127). In a similar way, if the upper surface of a hold on a climbing wall (see Figure 1) is nearly horizontal and is sufficiently extended (relative to the size of the foot of the climber) and if its substance is rigid (relative to the weight of the climber), then the hold affords support. A hold affords grasping if it is sufficiently concave or convex and extended (relative to the size of the climber's hands and to the climber's grip strength and grasping abilities). In addition, a hold can be reached only when it is not much more than one arm or leg length away. The claim that affordances can be perceived translates to the claim that such "reachableness," "graspableness," and "stand-on-ableness" of holds can be seen by climbers because there is available information that specifies the reaching, grasping, and standing possibilities for a climber. For climbers, various places on a climbing wall will thus afford climbing.

In line with Gibson (1979), Sanders (1997) stressed that affordances include opportunities as well as dangers for action. Those opportunities and dangers for climbing together yield climbing paths of various levels of work,

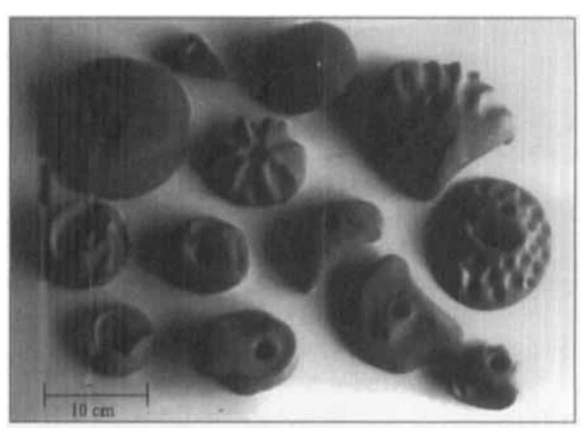

FIGURE 1. Some of the climbing holds that were used in the experiments. One attaches a hold to a climbing wall by placing its flat back side at the wall, putting a bolt through the hole of the hold, and tightening it onto a nut behind the wall.

danger, and length, for example. Consistent with the view that learning involves the education of attention to such information, expert climbers should focus on the climbing opportunities a wall offers. In this study, we predicted that an expert climber should be able to see and remember characteristics of the climbing paths, whereas it is less likely that an inexperienced person will perceive and remember such characteristics. Cordier, Mendès France, Bolon, and Pailhous (1993) claimed that by means of route finding, expert climbers are capable of "producing a series of well-formed movements which are linked together into actual 'sentences' and serve to structure the climber's motor behavior" (p. 371). Perceiving such a "climbing choreography" might be described as the perception of a chain of several meaningfully interrelated climbing opportunities.

According to the ecological approach, before and during the execution of movement actions, the action possibilities an environment specifies are perceived. Consequently, climbing routes ought to be remembered by climbers in terms of the movement actions they afford. Following that line of argumentation, one might expect that when expert climbers are asked to reproduce a climbing wall from memory on a scale model, their reproduction will reflect the perceived affordances. Thus, we expected that the superiority of experts would be found in their recall of climbing opportunities that they have perceived. In the present experiments, we addressed two questions: Is clustered information about affordances picked up during route finding in sport climbing, and what is the effect of expertise on that pick up?

EXPERIMENT 1

In Experiment 1, the pick up of information in sport climbing was examined in three steps. First, we asked whether skill in climbing, like skill in chess, is associated with better memory. We expected that the expert climbers would recall the holds of an actual climbing wall more rapidly and accurately than the novices and the inexperienced participants. Second, we assumed that the expert climbers, when applying route finding, would be able to perceive and memorize more individual items after a 5-s viewing period than would the novices and the inexperienced participants. In accordance with the affordance concept and the description of route finding as the building of a choreography, it is likely that such information is functional and meaningful. Our third prediction, therefore, was that the expert climbers would recall more functional aspects of a climbing wall than would the novices and the inexperienced participants.

Method

Participants

Sixteen participants (5 expert male climbers, aged 28.8 ± 7.05 years; 2 male and 2 female novices, aged 29.8 ± 6.24 years; and 5 male and 2 female inexperienced participants, aged 27.5 ± 4.17 years) took part in Experiment 1. The expert climbers were all professionally involved in climbing (route setters and a national coach) and spent 15 or more hours climbing per week; their climbing skill (assessed as the maximum climbable route) ranged from 7a to 7c+ French rating scale of difficulty (French RSD; see Delignières, Famose, Thépaut-Mathieu, & Fleurance, 1993, for a validation of that rating system). The climbing skill of the novices ranged from 4c to 5c French RSD. They had limited experience, were not professionally involved in climbing, and did not climb more than an average of 3 hr per week. The inexperienced participants had no climbing experience whatsoever. All participants voluntarily engaged in the experiment and were naive as to our objectives.

Apparatus

A vertically oriented, flat artificial indoor climbing wall with a height of 7.0 m and a width of 3.5 m was used (see Figure 2). The wall was situated in a large experimental room. On the left portion of the wall (a 7.0- × 2.4-m area), 23 holds of various shapes (see Figure 1) were placed by a professional setter of climbing routes, resulting in a climbing route of difficulty 5c/6a French RSD (corresponding to 5.9 on the Yosemite Decimal Rating System [YDS; used in the U.S.] and to 6–/6 on the rating scale of the Union Inter-

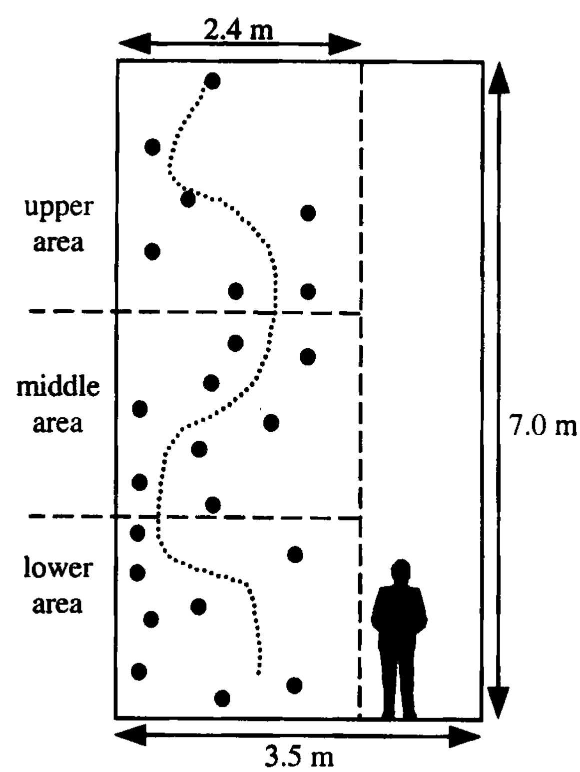

FIGURE 2. The climbing wall with its 23 holds (represented by black dots) and the rough climbing trajectory (dotted line). The rough climbing trajectory was not drawn on the climbing wall or on the scale model but was explained verbally by the experimenter.

nationale des Associations d'Alpinisme [UIAA RSD]). The climbing route consisted of 16 handgrips and 7 foot supports, determined as such by the route setter and by 2 expert climbers.[3] The number of handgrips on the climbing wall was much higher than the number of foot supports, because handgrips could also be used to stand upon, whereas foot supports were too small or too smooth to grab. In addition, the climbing wall could be divided into three areas of about equal size: The upper area of the wall consisted of 7 holds, the middle area consisted of 8 holds, and the lower area consisted of 8 holds (see Figure 2). The shape and orientation of each hold was clearly visible to a participant standing on the floor. The holds on the climbing wall were oriented in one of eight directions: 0°, 45°, 90°, 135°, 180°, 225°, 270°, or 315°, relative to an imaginary vertical line on the surface of the wall.

We used as a scale model of the climbing wall a cardboard sheet with the same color as the wall and measuring 2.3 × 0.8 m (one third of the left portion of the climbing wall). The scale model was placed horizontally on the floor, and next to the scale model was a second set of 23 holds, identical to the ones used on the climbing wall. The locations of the holds on the scale model were indicated by 23 firmly attached orange dots (32 mm in diameter). During reproduction on the scale model, each hold of the second set had to be placed at the correct orange dot. We drew lines (10 cm long) on the scale model to indicate the 1.5-, 1.75-, and 2.0-m levels of the real wall. Furthermore, the real wall consisted of nine visible panels that were indicated by lines drawn on the scale model.

Procedure

After we told the participants what the experiment was about, we questioned them about their personal characteristics (e.g., name, age, gender, climbing experience). Subsequently, each participant was given about 1 min to examine the second set of holds placed next to the scale model. The instructions given during the experiment were standardized, and the participants were tested individually.

The participants were asked to study the holds on the climbing wall for 2.5 min and to then immediately try to reproduce the perceived climbing route on the scale model, that is, to place the correct hold at the correct orange dot on the scale model and with the correct orientation.[4] An opaque screen prevented vision of the climbing wall during reproduction. The participants were given as much time as they needed to reproduce the holds on the scale model and were allowed to change already placed holds. They informed the experimenter when they finished the reproduction. Then, the experimenter provided feedback by removing the wrongly placed holds from the scale model and by turning the wrongly oriented (but correctly placed) holds upside down. The orientation of the reproduced holds was determined with an accuracy of 45°: A deviation of more than 22.5° from the correct orientation was marked as a wrong orientation.

On the second and subsequent trials, the participants looked for only 5 s at the wall (as in the designs of the chess studies that were described earlier), and they then adjusted the wrongly placed or oriented holds, or both, on the scale model. The experimenter provided feedback, as before. That procedure was repeated until the entire route was correctly reproduced on the scale model, but with a maximum of 12 trials.

Assessments

The number of correctly placed (independent of orientation) holds and the number of correctly placed-plus-oriented (when both were correct) holds were assessed per participant and per trial. Those two variables revealed similar results; therefore, only the results of the number of correctly placed-plus-oriented holds are reported here. Two performance variables were calculated, in analogy with the chess studies: (a) the number of correctly reproduced holds at Trial 1, expressed as a percentage of the total number of holds (Correct Holds 1), and (b) the trial in which the task, the exact reproduction of the climbing wall on the scale model, was completed (Completed). If the task was not completed at Trial 12, then the Completed variable was given a score of 13.

To examine the extent of recalled clustered information, we determined the recall following the 5-s viewing trials (Trials 2–12). Placement and orientation were each characterized as one individual item, as in the chess research. (We took a rather conservative position: The recalled information had to consist at least of those two items, and possibly more.) The numbers of items recalled after each 5-s trial (Recall Score 2–12) were computed as the sum of the number of correctly placed holds per trial and the number of correctly oriented holds per trial (independent of place). Thus, the maximum Recall Score 2–12 was 46. The first trial was excluded from that analysis because we presumed that the viewing period (2.5 min) involved long-term memory processes. If the reproduction task was completed within 12 trials, then the last trial was also excluded from the analyses, because only a limited number of items could then be picked up during that final trial.

To measure the perceived functional aspects of the climbing wall, we assessed the recall at Trial 1 of the following two parameters: the number of correctly reproduced handgrips and foot supports (hold) and the number of correctly reproduced holds on the three different areas of the climbing wall (area). The route setter and 2 expert climbers indicated that from a functional point of view, the handgrips are more important to identify as such than the foot supports. That is, a climber will always find a spot to place his or her feet. In addition, all 3 climbing experts indicated that the most difficult passages of the route were located in the middle and upper areas of the wall, whereas the lower area was much easier to climb (see Figure 2). In the middle area, one has to climb a difficult traverse from the left to the right side of the route; and in the upper area, several handgrips were located at a rather large distance from each other, making it quite difficult to climb. In the lower area of the climbing wall, on the other hand, many holds were placed close to each other, making it climbable in relatively easy ways. When participants recall a greater number holds from a more difficult area of the wall than from a less difficult area, then they apparently have focused on the most relevant information, because the more difficult area is the part most important for successfully climbing the entire wall. Therefore, recall of holds from a more difficult area of the wall is especially indicative of the pick up of functional information.

Results and Discussion

An analysis of variance (ANOVA) was conducted on the number of correctly placed-plus-oriented holds on Trial 1 (Correct Holds 1), with skill (expert climbers, novices, and inexperienced participants) as a between-participants factor and hold (handgrips and foot supports) and area (upper, middle, and lower areas of the climbing wall) as within-participant factors. In addition, ANOVAs were conducted on the trial on which the recall task was completed (Completed) and on the mean number of items recalled during the 5-s trials (Recall Score 2–12), with skill (expert climbers, novices, and inexperienced participants) as a between-participants factor. Those results are plotted in Figures 3 and 4. A Student–Newman–Keuls test, with a level of significance of .05, was used for all post hoc analyses.

Recall Performance

ANOVAs conducted on the Correct Holds 1 and Completed variables revealed significant effects for skill, Fs(2, 13) = 38.34 and 47.46, respectively, ps < .001, observed power = 1.00. For Correct Holds 1, post hoc analyses revealed a significant difference between the expert climbers ($M_E = 42.1 \pm 6.20\%$) and the inexperienced participants ($M_I = 9.4 \pm 5.92\%$), as well as between the expert climbers and the novices ($M_N = 15.2 \pm 7.53\%$). For the Completed variable, significant differences between all skill levels were found ($M_E = 5.2 \pm 0.84$ trials, $M_N = 8.8 \pm 1.26$ trials, and $M_I = 11.7 \pm 1.25$ trials). Three of the participants (all inexperienced) did not complete the reproduction task within 12 trials. Figure 3 shows that at Trial 1, the performance of the expert climbers was much better than that of the novices and inexperienced participants. With every subsequent trial, the inexperienced participants recalled a small but consistent number of additional holds correctly. The numbers of additional holds correctly recalled by the novices and the expert climbers during the subsequent trials were somewhat higher (i.e., the lines of the expert climbers and novices were steeper than the line of the inexperienced participants). The novices completed the reproduction task sooner than the inexperienced participants did, whereas the expert climbers needed only a few trials to complete the reproduction task. Those results revealed that the expert climbers more accurately recalled the place and orientation of the holds of an indoor climbing wall than the novices and the inexperienced participants did and that the novices performed better than the inexperienced participants.

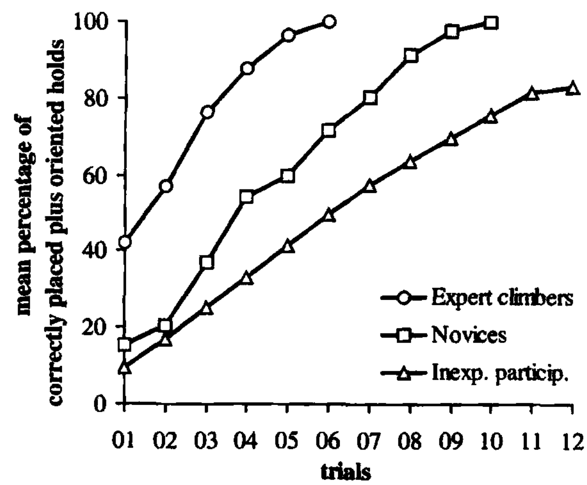

FIGURE 3. Performance on the reproduction task by the inexperienced participants (inexp. particip.), novices, and expert climbers. Reported are the mean percentage of correctly placed plus oriented holds on the scale model of the climbing wall per trial. Trial 1 was performed after participants had viewed the climbing wall for 2.5 min, Trials 2–12 were performed after they had viewed the wall for extra periods of 5 s.

Clustered Information

To examine whether the climbers picked up clustered information, we assessed the numbers of items recalled during the 5-s trials (Recall Score 2–12). Generally, researchers presume that participants have picked up clustered information if they recall more than nine items during a 5-s trial, thus exceeding short-term memory capacity (cf. Chase & Simon, 1973; de Groot, 1965; de Groot et al., 1996). The results showed that the expert climbers recalled more than nine items in 25.0% of the 5-s trials, the novices recalled more than nine in 14.8% of those trials, and the inexperienced participants more than nine in 5.9%. Only 2 of the 7 inexperienced participants ever recalled more than nine items: Both reported that they had used a recall strategy (focusing only on the place of the holds and applying the most common orientation to every hold). An ANOVA conducted on Recall Score 2–12 revealed a significant main effect of skill, $F(2, 13) = 7.68$, $p = .006$, observed power = .88. Post hoc analyses showed that the expert climbers ($M_E = 7.9 \pm 1.95$ items) and the novices ($M_N = 6.5 \pm 1.75$ items) recalled significantly ($p < .05$) more information than the inexperienced participants did ($M_I = 4.0 \pm 1.59$ items). Notice that Recall Score 2–12 for each group corresponded to the slope of their recall performance, as depicted in Figure 3.

The information picked up by all participants in the starting condition (after Trial 1) should have been the same. Compared with the expert climbers, however, the novices and the inexperienced participants performed more poorly on Trial 1, and they therefore had to recall many more items in the subsequent 5-s trials (Trials 2–12). That difference in the to-be-recalled items during the 5-s trials might have confounded the Recall Score 2–12. To circumvent the possible confounding, we conducted a subsequent ANOVA on Adjusted Recall Score 2–12, a variable that represented the number of items recalled per 5-s trial when all participants were left with an equal number of items to be perceived. The participant who recalled the most items correctly at Trial 1 set a limit (29 items, 63.0%); from that limit onward, the to-be-perceived number of items was the same for all participants.[5] Adjusted Recall Score 2–12 was calculated from that limit onward in the same way as Recall Score 2–12. The ANOVA conducted on Adjusted Recall Score 2–12 also revealed a significant main effect of skill, $F(2, 12) = 7.23$, $p = .009$, observed power = .86. Post hoc analyses showed that the expert climbers ($M_E = 7.8 \pm 1.95$ items) recalled significantly more items than both the novices ($M_N = 5.4 \pm 0.75$ items) and the inexperienced participants ($M_I = 4.4 \pm 1.46$ items) during the 5-s trials. The novices and the inexperienced participants did not differ from each other.

Those results confirmed our expectation that during route finding expert climbers would recall more items after a brief exposure than novices or inexperienced participants would. The large number of items recalled by the expert climbers during the 5-s trials was indicative of the perception of clustered information.

Functional Aspects

Our third prediction was that the expert climbers would focus on the functional aspects of the climbing wall, whereas the less skilled participants would not, or would do so to a lesser extent. To examine the functional aspects, we compared (a) the number of handgrips and foot supports and (b) the number of more difficult and less difficult passages that were correctly reproduced for the three skill levels.[6]

Handgrips Versus Foot Supports

The holds of a climbing route can be divided, on functional grounds, into handgrips and foot supports. As noted earlier, from a functional point of view handgrips are more important than foot supports because climbers can more easily find a spot to place their feet than a spot to grasp. A finding that a relatively large number of handgrips was reproduced (compared with the number of reproduced foot supports) would indicate that the climbers focused on the functional aspects of the climbing wall. To examine the number of correctly recalled handgrips and foot supports, we included the within-participant factor hold (handgrips and foot supports) in the ANOVA on Correct Holds 1. That analysis revealed a significant interaction between skill and hold, $F(2, 13) = 21.91$, $p < .001$, observed power = 1.00 (Figure 4A). Post hoc analyses revealed a significant difference between the percentage of handgrips correctly reproduced by the expert climbers ($M_{E\text{-}hg} = 55.0 \pm 12.02\%$) and the percentages in all the other cells (i.e., the percentage of handgrips correctly reproduced by the novices and the inexperienced participants, and the percentage of foot supports correctly reproduced by the expert climbers, novices, and inexperienced participants [$M < 21.4 \pm 14.29\%$]).

Difficult Passages

Reproduction of more holds from the difficult upper and middle areas than from the easier lower area would also imply that the participants focused on the functional aspects

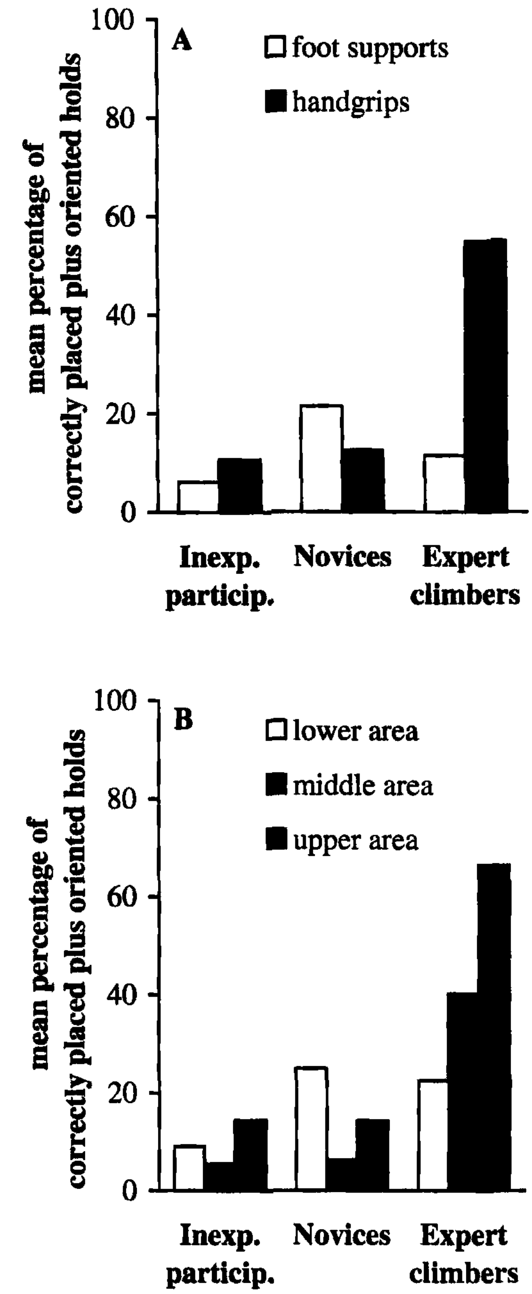

FIGURE 4. Differences between the inexperienced participants (Inexp. particip.), novices, and expert climbers in mean percentages of correctly placed plus oriented holds on Trial 1 (**A**) for handgrips versus foot supports and (**B**) for the three areas of the climbing wall.

of the wall. To examine the number of correctly recalled holds on the most difficult passages of the climbing wall, we included the within-participant factor area (upper, middle, and lower areas of the climbing wall) in the ANOVA on Correct Holds 1. That analysis revealed a significant interaction between skill and area, $F(4, 26) = 5.27$, $p = .003$, observed power = .94 (Figure 4B). Post hoc analyses revealed that the expert climbers reproduced significantly more holds correctly from the upper area ($M_{\text{E-up}} = 65.7 \pm 16.29\%$) than from the lower area ($M_{\text{E-low}} = 22.5 \pm 13.69\%$); they had an intermediate score for the middle area ($M_{\text{E-mid}} = 40.7 \pm 12.78\%$). For the novices and the inexperienced participants, no differences were found between the three areas of the climbing wall ($M < 25.0 \pm 20.20\%$). Furthermore, the expert climbers reproduced significantly more holds correctly from the upper area as well as from the middle area of the climbing wall than did the novices and the inexperienced participants. For the lower area of the wall, no differences between the three skill groups were found.

To summarize, the results of Experiment 1 revealed that the expert climbers more accurately recalled the place and orientation of the holds of an indoor climbing wall than the less skilled participants did. Their superiority could be seen both on the first trial and on the 5-s trials. In addition, the results of the analysis of the functional aspects of the climbing wall supported the hypothesis that expert climbers direct their attention toward the functionally important aspects of a climbing wall. During 2.5 min of route finding, the expert climbers, unlike the novices and the inexperienced participants, focused predominantly on the handgrips and the difficult passages at the upper and middle areas of the climbing wall.

The results of Experiment 1 indicated that the expert climbers recalled a large amount of information that reflected relevant features for climbing; that finding might point to an ability of expert climbers to perceive and memorize functional chains of holds (i.e., clusters of climbing opportunities). According to Chase and Simon (1973), clustered information in chess consists of visual properties and chess functions. In a similar vein, chunks in climbing might also consist of visual properties and functions. In sport climbing, the visual properties will obviously correspond to the structural features of the climbing wall, that is, the form, shape, size, location, and orientation of the holds as well as specific elements of a hold (such as holes and rims). The functions might refer to perceived possibilities for climbing (i.e., climbing opportunities) such as reaching, grasping, and standing opportunities, and opportunities for specific climbing moves. Many specific moves have been identified in climbing (e.g., a gaston, a hand or finger jam, a heel hook, and a drop knee) in which more than one hold is involved and at which several reaching and grasping or standing possibilities are perceived as one (clustered) climbing opportunity. In addition, climbers claim (see Note 2) that they perceive and memorize the order of possible climbing movements when applying route finding. That is, skilled climbers appear to perceive or construct a kind of climbing choreography that chains several successive action possibilities together.

Such climbing opportunities presumably correspond to the functional aspects, as measured in Experiment 1. The difference between handgrips and foot supports reflects the difference between grasping and standing possibilities, and the different areas of the wall exhibit aspects of the perceived climbing trajectory and choreography. However, a more qualitative analysis should (a) reveal the validity of the presupposition that the climbing opportunities correspond to the functional aspects, as measured in Experiment 1; (b) indicate which climbing opportunities are being perceived; and (c) examine differences in the perception of structural features and climbing opportunities by the expert climbers and the inexperienced participants. In addition, such a qualitative analysis might reveal whether functional chains of holds are being perceived and remembered.

EXPERIMENT 2

In Experiment 2, the nature of the perceived characteristics during route finding in sport climbing was investigated (i.e., what is perceived). Do those characteristics embody structural features, climbing opportunities, or both? In line with the ecological approach to perception and action (Gibson, 1979) and the results of Experiment 1, we presumed that the information that is picked up by expert climbers consists primarily of information about climbing opportunities, that is, the graspable, reachable, and "stand-on-able" properties of holds, and the climbing moves that they afford. Inexperienced participants, on the other hand, may not be able to perceive climbing opportunities (or climbing affordances). We predicted that an analysis of the expert climbers' route-finding capability would provide support for the notion that such climbers are able to perceive climbing opportunities, whereas the analysis would reveal that inexperienced participants notice primarily the structural features of a climbing wall. The perceptual difference between experts and inexperienced persons should be reflected in the verbal reports during recall.

Method

Participants

Two graduate students who had no climbing experience (I1, a 24-year-old woman, and I2, a 26-year-old man) and 2 expert climbers (E1 and E2, a 31- and a 30-year-old man) took part in Experiment 2. E1 and E2 had more than 7 years of climbing experience and spent an average of 9.5 hr climbing per week; their climbing skills (assessed as the maximum climbable route) were 7c and 7a+ French RSD, respectively. All participants volunteered to participate in the experiment and were naive to our objectives; none had participated in Experiment 1.

Apparatus and Procedure

The artificial indoor climbing wall, climbing route, and scale model from Experiment 1 were again used. In addition, audio and video recordings were made of the verbal reports and climbing gestures of the participants as they reproduced the holds on the scale model.

The procedure of Experiment 1 was used, except that the participants were also instructed to think aloud during the reproduction task, that is, to verbally report everything they thought about, especially what was perceived when looking at the climbing wall and why they reproduced the holds in the way they did (with respect to place and orientation). The participants were allowed free recall of their thoughts. When verbal recall flagged or showed hitches, the participants were prompted to explain why they had reproduced the holds in a certain way and what they had perceived during route finding. When participants used specific climbing terms, they were asked to explain them.

Assessments

The number of correctly placed plus oriented holds of each participant at Trial 1 (Correct Holds 1) and the trial on which the reproduction task was completed (Completed) were determined as in Experiment 1. The tape recordings of the participants' verbalizations were transcribed. Statements about structural features (i.e., size and shape of a hold, its orientation, and its place at the wall) and climbing opportunities (i.e., reaching, grasping, and standing possibilities) were identified on the transcripts and scored as correct or wrong, compared with the actual climbing wall. Similarly, for each correctly reproduced hold the statements were identified as structural features or climbing opportunities and correct or wrong. In addition, to examine whether the participants perceived a kind of climbing choreography, we counted the number of statements that revealed an order of possible climbing actions, as well as the number of performed climbing gestures or movements during the reproduction task. Furthermore, one can differentiate between, on the one hand, a climbing opportunity deduced from memorized structural features and, on the other hand, structural features deduced from a memorized climbing opportunity. The second deduction is indicative of the immediate (or direct) perception of climbing opportunities and of the memorization of perceived possibilities for climbing actions. To assess that deduction, we counted the number of statements about climbing opportunities that directly determined one or more reported structural features or led to the modification of a structural element (i.e., an already-placed or -oriented hold, or both).

Results and Discussion

Experts' Perception

To examine whether the expert climbers again recalled the holds of a climbing wall more accurately than the inexperienced participants, we analyzed the Correct Holds 1 and Completed variables. On both variables, the expert climbers were considerably better than the inexperienced participants, and the performances of the participants in Experiment 2 mimicked those of the participants in Experiment 1. E1 recalled 47.8% at Trial 1 and completed the reproduction task at Trial 3, E2 recalled 30.4% at Trial 1 and completed the task at Trial 9. I1 recalled only 13.0% at Trial 1 and completed the task at Trial 12, and I2 recalled 8.7% at Trial 1 and had not completed the reproduction task by Trial 12.

Structural Features and Climbing Opportunities

To obtain an indication of the reliability of the assessed variables, we gave a second assessor written instructions and two already analyzed verbal reports (of Participants I2 and E2) as examples, and he then assessed the verbal reports of Participants I1 and E1. According to the second assessor, I1 mentioned 129 statements, of which 91.5% referred to structural features and 8.5% referred to climbing opportunities (the same percentages found by the first assessor, see Table 1); and E1 mentioned 130 statements, of which 36.2% referred to structural features and 63.8% referred to climbing opportunities (nearly the same percentages noted by the first assessor). Comparison of the analyzed verbal reports of both assessors showed that for I1, they classified 121 statements identically (112 structural features and 9 climbing opportunities), and for E1, they classified 109 statements identically (38 structural features and 71 climbing opportunities), which resulted in an overall correspondence of 84.9%.

To test the hypothesis that expert climbers recall the climbing opportunities of climbing wall and that inexperienced participants recall only structural features, we compared the number of statements about structural features and climbing opportunities (see Table 1). The (literally translated) transcripts presented next provide an idea of the kind of statements reported. First, we show a part of the transcript of Participant I1. The number of each hold is in parentheses, the statements referring to structural features are italicized, and the statements referring to climbing opportunities are in boldface type.

> That one (22) had a somewhat *irregular shape*. And that one, somewhat more *round*, just *more smooth* was that (18) one. And then came again a somewhat more *irregular shape* (11). So I looked at the *shape* and at the *order*. Here were quite a lot *little ones*. Let's see, that one (17) had the *shape of a moon*. Let's see, that over there, roughly like this. There *above* lay a *large* one. This one (23) I believe, that lay *right at the top*. Let's see, that one probably. **In this way I think it is most easy to grasp** .... Well, this (5) was such a *small, a bit irregular shape*, with a *flat side*, yes I call it a *flat side* because with such a ... eh ... **such a side that you can easily grasp, upwards**. Over here, that *small triangle* (1) I have just remembered it *qua shape*. And this one (6) that was with those *two flattened sides*. This (2) was also a *kind of triangle* with a *flattened side*.

Notice that only two out of all of the statements of the inexperienced participant referred to climbing opportunities (both were incorrect). First, the way in which Hold 23 seemed easy to grasp was not the correct orientation. Second, Hold 5 was placed just above the floor and was used as a foot support; its "flat side" was actually very difficult to grasp, and it was seldom used as a handgrip.

The next example shows a part of the transcript of Participant E1. This transcript is quite different from that of the inexperienced participant, and it reveals predominantly climbing opportunities, all of which were correct.

> Well, this one (18) I knew, that's the one *most to the right*, that's the **first hold that you grasp**. This one (12) **went sidewards**. That *large ear* (21) I didn't remember but it remains . . . in my opinion was that one *on a row of three* (5, 21, and 3), so *next to each other* with a **foot support** (3) *beneath it*. But this one (21) was **very, very low really, very strangely low**. It was, I think, a bit . . . that you must **load it "gaston"** [a climbing technique that involves side-pulling with an elbow pointed outward]. This (13) is a **punch-grip**, also a *bit slantwise*. Two grips (8 and 4) that you also **load a bit side-wards** [he shows the climbing movement]. And then that **finger-hole** (19), that **two-finger grip**. That one (11) was *placed beneath it*, but actually **it would be of no use to me. I wouldn't use it at all**. And then *at the top*, I knew that there were **no foot supports but only clear handgrips** . . . . Well, **the movement that are in there are crossing movements; when you cross over each other** [he shows the movement by crossing his right arm over his left arm]. Well **that one you can do in two ways**, that's what I'm thinking about. At this part. That one (12) you might **grasp it so or so or so**, but you can also **grasp it so** and then first *in-between*, **but that is unnecessary** . . . . At a moment you will **turn into**, from that hold and **move your body in that way**. It is simply a matter of **turning into at this point** . . . let's see . . . one . . . two . . . three . . . yes, **three-four times turning into different directions** with your body **to load that grip properly**.

TABLE 1
Differences in the Verbal Reports of the 2 Inexperienced Participants and 2 Expert Climbers During the Reproduction of the Holds on the Scale Model of the Climbing Wall

	Inexperienced participants		Expert climbers	
Variable	I1	I2	E1	E2
Total number of statements	142	189	141	207
Type of statements				
Structural feature	91.5%	99.5%	31.9%	31.4%
Correct	88.0%	87.3%	26.9%	27.5%
Wrong	3.5%	12.2%	5.0%	3.9%
Climbing opportunities	8.5%	0.5%	68.1%	68.6%
Correct	5.7%	0.0%	66.0%	64.7%
Wrong	2.8%	0.5%	2.1%	3.9%
Type of statements per hold (n = 23)				
Structural feature	21	22	15	11
Climbing opportunities[a]	1	1	21	15
Structure deduced from climbing opportunities	0	0	6	5
Reported order of climbing actions	0	0	8	7
Performed climbing gestures	0	0	7	7

[a]Both inexperienced participants and expert E1 reported one wrong climbing opportunity; all statements about structural features were correct.

The structural features mentioned were, for example, the location of a hold at the wall, the place of a hold in relation to another hold, the size of a hold, the shape of a hold (e.g., smooth, irregular, round, moon-like, triangular, pancake-like, or fist-like), and the direction in which striking structural elements (e.g., all kinds of concavities, convexities, rims, notches, tips, and grooves) were pointing.

Reported statements about climbing opportunities concerned good or bad reaching opportunities, different grasping opportunities (e.g., the hand used for grasping; the direction in which a hold could be loaded or grasped; and different types of grips, such as a bucket, a mono or one-finger grip, a two-finger grip, a pinch-grip, a side pull, a left-grip, a right-grip, or an undercling), standing opportunities (e.g., the foot used for support), and specific climbing moves (e.g., a gaston, turning of legs, a turn-into of a leg, a cross through of the arms or legs, a resting position, a stretching movement), as well as a sequence of movements.

The results presented in Table 1 show that the verbal reports of the 2 inexperienced participants consisted almost exclusively of statements referring to structural features of the climbing wall. For Participant I1, approximately one third of the very few statements about climbing opportunities were wrong, whereas Participant I2 mentioned only one wrong climbing opportunity. A reported climbing opportunity was wrong when the reported function did not correspond to the actual function, for instance, if the participant said that a hold could be grasped when in fact it could be used only as a foot support. The absence of real climbing opportunities was also apparent in the types of statements per hold (see Table 1): For, respectively, 21 and 22 of the 23 holds, the 2 inexperienced participants referred to structural features, whereas all climbing opportunities mentioned were wrong. Those verbal reports corroborated the claim that inexperienced participants do not perceive climbing opportunities but instead rely solely upon the structural features of the climbing wall.

The verbal reports of the 2 expert climbers contained entirely different proportions of structural features and climbing opportunities. About one third of their statements referred to structural features, whereas more than two thirds of their statements referred to perceived climbing opportunities. Of the reported climbing opportunities, almost all statements (an average of 95.6%) were correct. Per correctly reproduced hold, the data revealed a similar proportion, indicating that the expert climbers perceived many opportunities for action when looking at a climbing wall.

In addition, we performed a t test to compare the percentages of climbing opportunities reported (percentage of structural features = 100% – percentage of climbing opportunities) by the participants in the two skill groups. The t test showed a significant difference between the expert climbers and the inexperienced participants, $t(2) = 15.931$, $p = .004$, indicating that the mean percentage of climbing opportunities mentioned was significantly larger for the expert climbers than for the inexperienced participants.

It is interesting to note that the numbers of structural features mentioned by the expert climbers were only one third of those mentioned by the inexperienced participants. That finding suggests that expert climbers partly disregard the structural features or physical details of the climbing wall. Climber E2 referred to route finding as a "rough" perception of the climbing wall when he explicitly mentioned that for him specific structural features and precise location of holds were not important; the only thing that mattered was whether a hold was or was not good (i.e., whether or not a hold was graspable, reachable, or stand-on-able). Both expert climbers spontaneously mentioned that they looked at possible climbing movements, and they reported on several occasions a memorized climbing opportunity and deduced from it one or more structural features (see Table 1).

Finally, both expert climbers made statements reflecting an order of climbing actions and performed several climbing gestures or moves, but such responses were completely absent in the inexperienced participants' statements (see Table 1). Although the number of such sequential or chained climbing actions reported by the 2 expert climbers was very low (compared with the total number of statements), obviously such climbing actions spanned a number of holds (minimally, five holds: two foot supports, two handgrips, and the next hold to grasp). Therefore, the number of reported chained climbing actions did reveal a substantial percentage of the total available information. That finding provides further evidence for perceived clusters of climbing opportunities. Like masters in chess, it appears that by perceiving the functional or meaningful aspects of the wall, expert climbers can reproduce a large amount of detailed information.

GENERAL DISCUSSION

The results of the two experiments revealed that the expert climbers recalled more information than did the inexperienced participants, the novices showed an intermediate recall performance, and the expert climbers focused on the functional (meaningful) aspects of a climbing wall. In addition, our findings indicated that the expert climbers recalled functional chains of holds. The inexperienced participants, on the other hand, reported almost exclusively structural features of a climbing wall.

Many of the present findings have parallels in the motor control and perception literature. Allard and Burnett (1985) and Garland and Barry (1991) provided evidence for recall of clustered information in the reproduction of schematic drawings of motor tasks. We reported, on the basis of a quite different method of measurement, that the number of items recalled during the 5-s trials, the recall of functional properties, and the reported order of climbing actions all indicated the recall of clustered functional information in sport climbing. In agreement with research on experts' perception in motor tasks (see Abernethy et al., 1994; Beltel, 1980; Paull & Glencross, 1997; Pijpers & Bakker, 1993; Vickers, 1988, 1996), our findings showed that differences in skill level suggest corresponding differences in visual perception and memory. The striking difference found in Experiment 2 between the expert climbers and the inexperienced participants, together with the remarkable uniformity of the verbalization among the expert climbers as well as among the inexperienced participants, suggests a fundamental difference in the recall abilities of skilled and unskilled climbers. Expert performance in climbing seems to be characterized by the ability to immediately and accurately pick up functional information for action. Such functional information captures the action opportunities that a climbing wall offers a climber (i.e., the affordances of the climbing wall). That information, we argue, can reveal affordances of different grain. Fine-grained affordances consist of climbing opportunities of individual holds, such as reaching, grasping, or standing possibilities, whereas coarse-grained affordances consist of clustered functional information of multiple holds, such as a sequence of action opportunities that constitutes a kind of climbing choreography. Our thesis is that one can perceive affordances of different grains or, in other words, that meaning is directly picked up by expert climbers as units of information that may vary in scale. Affordances of coarse grain may be regarded as emerging from and constrained by affordances of finer grain, suggesting a nested structure (hierarchy) of perceived action possibilities. One should not assume that the relation between affordances of different grains is deterministic or causal. Presumably, that relation is emergent in nature; that is, higher level affordances emerge from lower ones.

We presume that the earlier-mentioned different scales of affordances (coarse and fine) are not fixed. Intermediate scales might be perceived by climbers (e.g., three or four holds might specify an affordance between coarse and fine grains, such as a standing or rest position) as well as affordances of very coarse grain (e.g., a rough glance at a climbing wall might reveal the difficulty of that wall for a specific climber, who might then decide to climb it or not) or even finer grain (e.g., detailed optical information about occluding edges, surface shape, surface slant, and textural grain of a hold, or the sides of a hold with magnesium on it may specify different ways of grasping a hold). The scale on which affordances will be perceived depends upon the interests, needs, and desires of the climber. In addition, during route finding a climber might switch from one scale to another and back again. For example, at first sight a climber might look at the difficulty of a route to estimate how difficult (or easy) it will be to climb. The climber might then switch to affordances of finer grain (difficult passages or individual holds). Finally, the climber might look at the rough climbing trajectory again and adjust his or her idea about its climbing difficulty. For route finding in sport climbing, the concept of nested affordances seems suitable as well as elegant in its simplicity for explaining at least some aspects of the phenomena associated with chunking.

In the reported experiments and because of the task requirements, the expert climbers appeared to use the functional information that was picked up as a basis for recalling structural features (the place and orientation of the holds). By remembering the affordances, a climber can detect a single, meaningful whole (which can be otherwise described as a collection of several separate items), enabling the retrieval of more information in a relevant, easy-to-remember way. We term such information *relevant* and *easy* because it (climbing opportunities or clustered functional information) reveals the properties of the environment–actor system (see Bootsma, 1998); that is, it reveals which actions might be performed by an actor in a certain environment. In a similar situation, another actor might perceive different affordances. Compared with climbing opportunities, the structural features of a climbing wall are more arbitrary and obscure in nature. They are properties chosen by an indifferent measurer, independent from an actor and independent from an action, and might, thus, include unimportant properties for the actor as well.

Sport climbing is illustrative of complex perceptual-motor tasks with imperative environmental constraints, a wide range of action possibilities, and a high degree of variability during the execution of the motor task. The findings of the present study might be generalized to motor actions and self-paced sports where "the quantity of uncertainty is *closed*" (Ripoll, 1991, p. 232), that is, to motor tasks with a relatively stable environment during performance. Thus, affordances might be similarly perceived by experts in sports in which a route or a trajectory can be reconnoitered before the race (or performance), often during a limited amount of time. Those sports would include skiing, auto and motorcycle racing, skating, cross-country running, horse jumping, whitewater canoeing, sailing, and (wind-) surfing, to name a few. If experts' perception in those sports is also characterized by the perception of (nested) affordances, then training of inexperienced persons might benefit from a focus on the various action possibilities of different grain that the sport environments offer.

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NOTES

1. During route finding, a climber will usually make climbing gestures and walk around to view the climbing wall from different angles. During climbing, climbers continue to search for the best climbable trajectory, although that kind of route finding was not studied in the present experiments.

2. To investigate the use of route finding in sport climbing, we administered a pencil-and-paper survey to 50 climbers of various skill levels (Boschker, 2001). General statements about the use of route finding as well as about differences between experienced and less experienced climbers were derived from that survey. Interested readers may contact the first author for a full description of the survey and its results.

3. Only for one hold did some discussion arise. That hold was somewhat hard to grasp, and participants did not have to use it at all when climbing the route, although we usually applied the hold as a handgrip and defined it as such.

4. During sport climbing competitions, climbers are allowed to look at the climbing wall for a maximum of 6 min before climbing it. A competition climbing route usually consists of 50 to 60 holds placed on a wall 14 m or more high. Our climbing wall was 7 m high and consisted of 23 holds; therefore, the initial perception time (for the first trial) was reduced to 2.5 min.

5. For Adjusted Recall Score 2–12, the data of 1 inexperienced participant were excluded from the analysis because of his extremely low recall performance, which did not exceed the limit of 29 items.

6. As a further test of the functionality of recalled routes, at the end of the experiment we examined whether the correctly placed holds on the scale model represented a climbable chain of holds, that is, a climbable route. For the first trial of each participant, the wrongly placed holds on the scale model were removed from the actual climbing wall, and the other holds (which were correctly placed but wrongly oriented on the scale model) were oriented as the reproduced holds on the scale model. An expert climber (with a climbing skill of 8a French RSD) tried to climb those routes. We recorded climbing (including displacement of a marker placed at the participant's back at waist level) with a standard VHS video camera (25 Hz) placed 15 m in front of the wall. Despite the fact that the expert participants recalled only 42.1% of the holds correctly at the first trial, the expert climber managed to reach the top of the wall on two of those routes, whereas on the other three routes he managed to climb 92.0%, 87.9%, and 59.7% of the wall. That finding suggests that the expert participants recalled climbable routes. A one-way ANOVA on the climbed vertical distance, with skill (expert climbers, novices, and inexperienced participants) as a between-participants factor, revealed a significant effect for skill, $F(2, 14) = 5.10$, $p = .022$. Post hoc analysis revealed a significant difference between the "climbability" of the routes reproduced by the expert climbers ($M_E = 4.52 \pm 0.855$ m) and those reproduced by novices ($M_N = 1.62 \pm 2.082$ m) and inexperienced participants ($M_I = 2.02 \pm 1.613$ m). After a vertical climbing distance of 5.14 m, the top of the wall was reached.

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