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Exploring in a climbing task during a learning protocol: a complex sense-making process

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Abstract

A large body of literature has highlighted the role of exploration in skill acquisition, with much of it showing that variable practice conditions encourage exploration. However, how learners make sense as they explore contrasting learning conditions remains unclear. Our study, rooted in the enactive approach tested a twofold hypothesis: (1) exploration takes different forms specified by the general dimensions of sense-making activity and (2) the specification of these general dimensions is related to the practice conditions.

Our study focused on a climbing task over a 10-session learning protocol. Twelve sports sciences students participated under variable and constant practice conditions. First, two steps were drawn from the course-of-action research program: (1) documenting the climbers' lived experience during previews and climbs with video recordings of their activity and self-confrontation interviews and (2) identifying the general dimensions of intentions, perceptions and actions using thematic analysis. On this basis, a quantitative analysis was then conducted to identify phenomenological clusters (PhC) through a hierarchical cluster analysis of the general dimensions. Last, the distributions of these PhC for the first and last sessions of the learning protocol were compared.

Our results showed singular distributions of the four PhC identified in both previews and climbs between the first and last learning sessions. This supports our first hypothesis by highlighting the four PhC, two for the preview and two for the climb. Our results did not support the second hypothesis, however, of a link between PhC and practice conditions in that no condition-specific PhC were identified.

Introduction

In radical embodied cognitive science (Newen et al., 2018; Seifert et al., 2020), learning new sporting skills is characterized as learners changing their interactions with their performance environment, thereby affecting their ability to deal with novel performance environments (Hacques et al., 2021a). These changes are mostly investigated using a behavioural approach to examine learner-environment interactions from the perspective of the experimenters (Button et al., 2020). In the current article, we present the main results revealed by this perspective and then describe how a phenomenological account can enrich our understanding of the processes at stake when learning. We then present an investigation of how learners make sense of their performance environment over the course of practice and show how different practice conditions can affect this sense-making process.

Studying exploration in motor learning: the major contribution of the ecological dynamics framework

Ecological psychology places interactions between an individual and his/her environment at the centre of action/perception/cognition through the concept of exploration (E. Gibson, 1988; J. Gibson, 1966). From this viewpoint, exploration is defined as the active process of revealing and picking up information to adaptively move in the environment.

In line with this conceptualization of exploration, a series of studies in climbing has analysed how the exploratory activity of climbers changes with practice or expertise in terms of modality and temporal organization and how these changes support skill transfer to new climbing routes (Seifert et al., 2014, 2015, 2018; Orth et al., 2018; Hacques et al., 2021a).

A study by Orth et al. (2018) showed that less experienced climbers always present intense exploratory activity by touching the handholds as they search to determine how best to grasp and/or use them, and at the hip level to regulate their body posture. In contrast, expert climbers explore only at the hip level, suggesting that visual information is sufficient for them to determine which actions need to be performed without the need for haptic information. In line with these results, Hacques et al. (2021b) showed that haptic exploration (i.e., touching the holds) and visual exploration (i.e., number of visual fixations) decreased with learning, and the entropy of the learners' gaze path decreased. According to these works, these changes do not imply that perceptual-motor exploration disappears with skill acquisition, but that exploration is reorganized to better specify the opportunities for action offered by the environment (i.e., the hold grasp-ability and use-ability, Seifert et al., 2018).

The reorganization of exploratory activity also affects how performers transfer their skills to a new performance environment. For example, the study of Orth et al. (2018) suggested that, with practice, less experienced climbers were able to transfer their skills to new routes when they developed the ability to explore the handholds haptically while maintaining their balance. This exploratory behaviour enabled them to achieve a performance score (i.e., measure of climbing fluency) on a transfer test similar to that of the skilled climbers, although the skilled climbers displayed different behaviour with fewer exploratory touches of the handholds (Orth et al., 2018). Thus, improving skill transfer does not necessarily require the development of a specific form of exploratory activity, but it instead requires practice conditions that foster learners' attunement to the affordances of their performance environment (Seifert et al., 2018; Hacques et al., 2021a).

Indeed, practice conditions were shown to affect perceptual-motor learning and transfer, notably when they induce variability in the task constraints. Ranganathan and Newell (2013) proposed to classify externally induced variability (i.e., by an experimenter) in two categories: (1) variability at the execution redundancy level and (2) variability at the task goal level (i.e., structured or randomized). First, variability induced at the execution redundancy level enables the development of exploration by allowing learners to explore similar movement patterns for the same goal (Ranganathan & Newell, 2013; Pacheco et al., 2021). Second, structured variability at the task goal level enables the exploration of new types of movements that can be generalized to new contexts. It can be induced by one or a few parameters (e.g., the shape of the hold in climbing), whereas randomized variability at the task goal level enables the exploration of new types of movements to find the optimal movement pattern that can achieve the task goal (i.e., to perform in the task). In contrast, it is argued that externally induced conditions of practice may "force" the exploration of the learning environment in the sense that these conditions prescribe the direction for exploration. Another study (Hacques et al., 2021b) examined the effect of autonomy (i.e., self-controlled practice) on visual-motor exploration during a learning

protocol in climbing. The results revealed that with a self-controlled practice schedule, novelty stimulates the learner's commitment at the beginning of the learning process and that at the end of the process, the possibilities of transferring to new climbing routes remain low. In any case, the way in which learners make sense of exploration under these practice conditions remains unresolved.

Overall, the research that has analysed perceptual-motor exploration from behavioural variables has made a major contribution to the literature by highlighting the role of behavioural (e.g., in locomotor tasks, visual-haptic behaviour) variability to characterize exploration in the learning process. The enrichment of this work has been pursued by studies to identify the meanings that actors construct as they explore the environment with which they are interacting. This line of research seems to be heuristic regarding the work done from the phenomenological approach for skill acquisition (Dreyfus, 2002; Ravn, 2022; Ravn & Høffding, 2022; Høffding & Schiavio, 2021), including the enactive framework (Varela, 1979; Maturana & Varela, 1987; Varela et al., 1991).

A heuristic approach for the study of exploration in motor learning: the enactive and phenomenological framework

The enactive approach is grounded in phenomenological philosophy and the cognitive sciences (Varela et al., 1991; Stewart et al., 2010; Di Paolo et al., 2017; Poizat et al., 2022). This framework is designed to examine agents' sense-making as it emerges from their structural coupling with the environment (Di Paolo et al., 2017). In the enactive framework, exploration can be defined as "a fundamental way of making sense of oneself as coupled with the world" (Høffding & Schiavio, 2021, p. 811). More precisely, exploration is conceived as an autonomous active regulation that ensures the enactment of meaningful interactions with the world during the dynamics of activity (e.g., a learning activity) (Buhmann & Di Paolo, 2017; Di Paolo et al., 2017). Research from within this framework has investigated exploration in motor learning (Bermejo et al., 2020). For example, research on the knowledge construction of elite table tennis players during a match highlighted the role of exploration as the players built knowledge about their coupling with the environment (Sève et al., 2005). The results showed that the exploration activity consisted of a process of investigating the opponent's activity in relation to the game score and game events. This study identified some of the elements that structured the players' exploratory activity (e.g., the score) during a match. It thus opened the way to research on the emergence of forms of exploration over a longer period and in varied conditions of practice, as can be found during a motor learning sequence.

The first experimental study in a learning context focused on sense-making in the search for fluidity in climbing from the identification of learners' intentions, perceptions and actions (Rochat et al., 2020). These participants described how they lived their climbing fluency from a phenomenological synthesis of intentions, perceptions and actions in a variable practice condition. Thus, the results showed that, from the learners' perspective, climbing fluency consisted in searching for new hand/foot chainings to construct a new climbing situation in response to challenges to their activity. Exploration in this sense is lived as a new manner to interpret the environment. The results also showed that a part of exploring is becoming sensitive to new sensations in the interactions with the environment and that sensations are refined in the course of these interactions. Overall, this research pointed to the importance of considering the subjectivity of learners when they learn a new skill. Rochat et al. (2020) described learning as "enacting significations". (p. 19)

The current study

On the basis of these studies of the effects of practice on perceptual-motor exploration, this study rooted in the enactive approach aimed to enrich the definition of exploration. More precisely, we seek to characterize the exploration from a phenomenological point of view in order to extract phenomenological clusters that can reveal exploration macro-formats. The earlier work that investigated the learning dynamics at a phenomenological level showed that by determining learners' intentions, perceptions and actions, we are able to gain insight into how and why these learners transform their interactions with their practice environment (Rochat et al., 2020). In this vein, the present study further investigates the effect of different practice schedules (constant, variable and self-regulated) on how actors make sense when exploring their learning environment. But this study takes a step forward: it characterizes the exploration sense making from a phenomenological synthesis of the intentions, perceptions and actions through a Hierarchical Clustering Analysis (HCA).

Method

Participants

Twelve undergraduate students (9 males and 3 females; *mean* age = 19.6 ± 1.2 years) volunteered to participate in this study. All were enrolled in the Sports Sciences School of Rouen Normandy University and had no prior experience in climbing. They were thus considered to have the lowest grade skill level according to the International Rock-Climbing Research Association scale (Draper et al., 2015).

Protocol

The participants were randomly assigned to one of three groups. The protocol included 10 sessions divided into two weekly sessions for 5 weeks. In the first group, called "constant group (C)", participants systematically climbed the same "control route", which was 525 cm high with 20 holds (i.e., 13 handholds and 7 footholds, Fig. 1). The second group was called "imposed novelty (IN)". In each session, these participants climbed three times on the control route and three (in sessions 1 and 10) to six (in sessions 2 to 9) times on variant routes prescribed by the experimenter. In sessions 2 to 9, they were confronted each time with a novel variant route. Nine variant routes – which differed from the control route – were designed on a 480-cm high wall. Each variant route was composed of 20 holds and differed from the others such that only the spatial layout of the handholds was manipulated without affecting the difficulty of the routes. The size and shape of the hand- and footholds were the same for all the routes. The last group, called "chosen novelty (CN)", followed the same practice schedule

as the IN group except that the participants had to choose at the end of each session whether they wanted to keep the same variant routes or have a novel variant route for their next session.

For all groups, the very first and very last trials of the protocol were performed on a “transfer” route. The transfer route was 495 cm high and also had 20 holds (Fig. 1). Like the variants, the transfer route was designed by changing the spatial layout of the handholds without manipulating the difficulty of the route.

Before each climbing session, participants had a 10-min warm-up on easy boulder routes in the bouldering area of the climbing gym. Before each climb, they had a 30-s preview that could be used completely or not. Then, the experimenter gave the following instructions:

Use all the handholds in a bottom-up order, do not to use holds with both hands or both feet at the same time. In addition, find a way to climb the route as fluently as possible: that is, avoiding pauses and jerky movements.

Data collection

This research mobilized the methodological framework of the course-of-action research program (Theureau, 2003; Poizat et al., 2022) rooted in the enactive approach. In keeping with the pre-reflective consciousness hypothesis and semiotic hypothesis (Poizat et al., 2022), two types of data were collected: (1) audiovisual recordings of the participants while they were previewing and climbing each route and (2) phenomenological data concerning the lived experience of the participants during their preview and climb.

Audiovisual data collection

Audiovisual data were collected for each climb by recording the activity of each participant. Ascents were filmed using a wide-angle standing camera to see the participant during the preview and the climb.

Phenomenological data collection

Phenomenological data were collected immediately after each session with self-confrontation interviews (Theureau, 2003; Rochat et al., 2020) based on the video recordings of each preview and climb. These video recordings were used as past-activity traces to help the climbers re-enact their experience (Theureau, 2003). This means that they were invited to chronologically relive their meaningful experience throughout the climbing trials. Based on these video traces, the interviews consisted of asking them to comment on their activity during each preview and climb while avoiding retrospective judgments and generalizations. The interview prompts were especially aimed to document (1) the climbers’ intentions (“What are you trying to do?”), (2) their actions (“What are you doing? ”), and (3) their perceptions (“What is drawing your attention?”; “What are you feeling?”). The interviews were conducted by two trained researchers who were experienced in conducting self-confrontation interviews with athletes from different sports. For all participants and all sessions and trials, a total of 120 self-confrontations were performed. Each interview lasted 45 minutes on average.

Data processing

Given the study objectives, the analysis focused particularly on the trials common to the three learning groups for sessions 1 and 10 in order to detect potential transformations in the emergence of the phenomenological dimensions of exploration between the beginning and the end of the learning protocol (i.e., trials on the “control route” and the “transfer route”). Thus, eight trials per participant were analysed (i.e., four in session 1 and four in session 10; 96 trials for the 12 participants).

The data were processed in three steps. The first two steps followed the methodology of Rochat et al. (2020). First, the participants’ courses of experience were reconstructed by identifying their actions, perceptions, and intentions. Second, a thematic analysis of the course of experience identified the general dimensions of the participants’ experience. The third step consisted in identifying phenomenological clusters of exploration by applying a hierarchical cluster analysis to the general dimensions across trials. This last step aims at revealing macro-level exploration formats that could help practitioners’ intervention.

Reconstruction of the course of experience

The first step was to restore the course of experience of each participant and each climb. From the verbalizations in the self-confrontation interviews and the climbing activity recorded on the videos, this consisted of a semiotic labelling of (1) intentions, reported in response to the question: “What is expected?”; (2) perceptions, reported in response to the question: “What is meaningful?”; and (3) actions, reported in response to the question: “What am I doing?” (e.g., as already done in Rochat et al., 2020, and Seifert et al., 2017b).

Identification of general dimensions in the courses of experience

The second step consisted of a thematic analysis to identify the general dimensions of intentions, perceptions, and actions (Rochat et al., 2020). We conducted this analysis to inductively find similarities in the climbers’ intentions, actions, and perceptions (Braun & Clarke, 2006; Braun et al., 2016; Vaismoradi et al., 2013) in order to characterize the general dimensions that made up their courses of experience. The raw data of the intentions, actions, and

perceptions were examined in detail and the detection of similarities among them helped identify the first-order themes, which were merged into second-order themes and then into general dimensions (third-order themes).

For example, "aligned holds", "snake shape" and "zigzags" as first-order themes from the reconstruction of the learners' courses of experience were grouped into a second-order theme called "spatial arrangement of holds", which in turn was grouped into the general dimension of "physical characteristics".

These steps were jointly performed by the first, second and last authors, who were all trained in performing this type of phenomenological data processing. In cases of disagreement, the researchers re-watched the video recordings of the self-confrontation interviews and the audiovisual recordings and discussed what they had seen and heard until a consensus was found.

Identification of phenomenological clusters of exploration: a hierarchical cluster analysis (HCA)

The third step, a hierarchical cluster analysis (HCA), was used to classify all the analyzed trials. The objectives were to identify association patterns between the general dimensions (i.e., intentions, perceptions, actions). The methodology of the HCA had four steps. First, trials were classified as follows: a value of 1 was indicated when the general dimension was present during the trial and a value of 0 when the general dimension was not present. Second, the dissimilarity matrix was obtained with the computation of binary distances between trials. Third, the Ward method was applied to aggregate trials into clusters by minimizing the total within-cluster variance (Ward, 1963). Fourth, the optimal number of clusters was assessed using the Caliński and Harabasz (1974) criterion. This criterion is a penalized ratio of the between-cluster dispersion and the within-cluster dispersion of the trials. Thus, the maximum value of this criterion indicates the optimal number of clusters. The criterion was computed for two to 15 clusters.

Last, an analysis of the distribution (in percentage) of the general dimension of intentions, perceptions and actions for all clusters obtained in preview and climb was applied (see Table 1 and Table 2). This analysis was used to label and define the phenomenological clusters. All treatments were performed with the NbClust 3.0 package under RStudio (Rstudio© 2021.09.1 build 372 that used R version 4.1.2., Boston, MA, USA).

Statistical analysis

Chi-square tests were performed to compare the distributions of the phenomenological clusters from previews and climbs between (1) the three groups of practice, (2) the first session of learning (i.e., session 1) and the last session of practice (i.e., session 10), and (3) the control route and the transfer route. The level of statistical significance was set at $p < .05$. The chi-square tests were performed on JASP software (JASP© 0.13.1, Amsterdam, The Netherlands).

Results

Identification of the general dimensions of exploration

This section of the results describes the general dimensions in preview and climb obtained from the thematic analysis carried out for the three constituent dimensions of the participants' experience (for more details see online resource in the online resource supplementary materials). The general dimensions are illustrated by a few verbatims extracted from the participants' courses of experience.

Preview

The thematic analysis of the preview highlighted four general dimensions for intentions: (1) designing sequences of actions, (2) "reproducing sequences of actions", (3) "climbing fluently", and (4) "respecting the instructions". The general dimensions are detailed in the online resource supplementary materials.

The general dimension of "designing sequences of actions" refers to the participants' intentions to organize optimal discrete actions such as handhold or foothold positioning. As an illustration, they tried to avoid crossing their hands to ensure the design of an optimal handhold position:

I try to do the preview from the bottom up so I can find a sequence that will avoid ending up with poor placement for this group of holds; I want to finish with my right hand here and then chain with the left hand so that I can grab this hold with the right hand without crossing hands (Participant from CR group, Session 1, Trial 1, Transfer route).

This general dimension was also related to the design of action sequences like same-hand grabbing of the next handhold or alternating movements. An example would be when they tried to avoid movement chainings like hand crossings in favour of grabbing two consecutive holds with the same hand or when they designed hand-foot coordination sequences: "I have to find a way to put one foot off-centred to the right so I can take the left hand off-centred" (Participant from CR group, Session 1, Trial 1, Control route).

The general dimension of "reproducing sequences of actions" refers to the participants' intentions to reproduce actions performed during previous climbs that they considered to be efficient. In this case, they tried to reproduce hand and foot sequences that felt fluid to them on either part of the route or the whole route: "I plan to start again in the same way as on my first try and thus show that my earlier sequence was valid" (Participant from the CN group, Session 1, Trial 2, Control route); "I'll do the same start as before with a left hand raise and then a cross, which worked well" (Participant from the CN group, Session 1, Trial 2, Control route).

The general dimension of "climbing fluently" refers to the participants' intentions to improve the fluency of their climbs. For example, to be more fluent, they tried to limit stops and avoid losing balance, rushing or being dynamic on the holds:

Now I'm trying to climb like a cat, so I tell myself to go slowly, to be much more delicate on the foot holds, the rhythm is not going to be the same – it's a good technique to improve fluidity (Participant from the IN group, Session 10, Trial 2, Control route).

The general dimension of "respecting the instructions" refers to the participants' intentions to remain in line with the requirements that defined the task: "I have to find a sequence on this route that takes the instructions into account, especially the one about starting with both hands on the same handhold" (Participant from the CR group, Session 1, Trial 1, Transfer route).

The thematic analysis of the climbers' perceptions during the preview revealed three general dimensions: (1) "physical characteristics", (2) "functional characteristics", and (3) "previous climbs". The general dimensions are detailed in the online resource supplementary materials.

The general dimension of "physical characteristics" reflects the participants' perceptions of the environment, particularly the physical characteristics of the route. For example, they were sensitive to the distance between holds, the layout of the holds, and even the shape evoked by the spatial arrangement of the holds: "There's a certain pattern that is repeated on the route. There are small ladders of three holds that go up to the left, three that go up to the right, and so on" (Participant from the CR group, Session 1, Trial 1, Transfer route).

The general dimension of "functional characteristics" reflects the participants' perceptions of the possibilities for action sequences offered by the spatial arrangement of the holds. For example, the learners sometimes recognized the spatial arrangement of the holds as helpful for their future climbs and thus had more positive perceptions of the climb. On the contrary, they could perceive the route negatively, assuming that the spatial arrangement of the holds would make for particular difficulties:

When I see the route, I think I'll have to do a lot of hand-crossings, but for me it's problematic, especially since there aren't many footholds and the holds are generally spaced out (Participant from the CN group, Session 1, Trial 1, Transfer route).

The general dimension of "previous climbs" refers to the participants' memories of previous ascents related to the physical characteristics of the route or the sequences of actions. To illustrate, this general dimension was at times related to the perception of previous unpleasant stops "I remember perfectly the three places on the route where I stopped; each time it was at the moment of relaunching to the top" (Participant from the CR group, Session 10, Trial 1, Control route).

The thematic analysis of the climbers' actions revealed four general dimensions: (1) "miming one part of the route", (2) "miming the complete ascent", (3) "focusing on one part of the route", and (4) "scanning the route".

The general dimension of "miming one part of the route" refers to the participants' simulating themselves grasping sequences of handholds. These actions were mainly directed at the beginning or end of the route: "I mime the start sequence by including the places where I think I will make crossings" (Participant from the IN group, Session 1, Trial 1, Transfer route).

The general dimension of "miming the entire ascent" refers to the participants' actions as they simulated hands sequences from the bottom to the top of the route to test the possibilities of sequences:

I start directly by miming with my hands to try to find the easiest sequence and see if it's feasible or not; So, I keep miming the rest of the route and try to do a preview up to the top (Participant from the CR group, Session 1, Trial 1, Transfer route).

The general dimension of "focusing on one part of the route" refers to the participants' actions as they concentrated on sections of the route considered difficult, especially hand- or footholds: "This time I do my preview focusing on one of the two center holds and I think of several possibilities at that spot, but I don't choose one" (Participant from the IN group, Session 1, Trial 2, Control route).

The general dimension of "scanning the route" refers to the participants' actions when they looked at the whole route from top to bottom and from bottom to top, once and several times: "I looked at the route from bottom to top and scanned it several times" (Participant from the IN group, Session 1, Trial 1, Transfer route).

Climb

The thematic analysis of the participants' intentions during the climb revealed four general dimensions: (1) "ensuring the correct execution of action chaining", (2) "improving the timing of the climb", (3) "maintaining balance while climbing", and (4) "respecting the instructions". The general dimensions are detailed in the online resource supplementary materials.

The general dimension of "ensuring the correct execution of action chaining" refers to the participants' intentions to reproduce the hand and/or foot sequences planned during the preview. For example, they focused on avoiding mistakes and performing a known sequence of hand actions: "Now I'm doing what I'd planned, right then left, then right hand. It goes well" (Participant from the CR group, Session 1, Trial 3, Control route).

The general dimension "improving the timing of climbing" refers to the participants' intentions to be efficient in their climbing. For example, they tried to keep their hands or feet on the holds for as short a time as possible or to avoid jerks or stops during the climb:

I want to have my pelvis moving all the time, I want my arms and legs to work together, to be able to pull with my arms and push with my legs at the same time to shorten the downtime (Participant from the CR group, Session 10, Trial 1, Control route).

The general dimension of "maintaining balance while climbing" refers to the participants' intentions to maintain a stable, well-oriented body while climbing to perform well. They used their feet to remain stable and focused on maintaining the orientation of the body along a vertical axis:

I try to keep my pelvis from moving to the sides as much as possible even though the track goes to the right and to the left; I try to keep it in the center when I climb even if it goes to the right at the beginning (Participant from the IN group, Session 10, Trial 1, Transfer route).

As in the preview, the general dimension of "respecting the instructions" refers to the participants' intentions to meet the task requirements, such as to be efficient and avoid putting both hands on the same holds: "When I arrive to take this hold, I tell myself that I shouldn't take it with both hands because it's prohibited in the instructions" (Participant from the IN group, Session 10, Trial 1, Transfer route).

The thematic analysis of the participants' perceptions during the climb revealed four general dimensions (see online resource supplementary material): (1) "sensation of being unbalanced", (2) "sensation of being balanced", (3) "sensation of efficient timing", and (4) "sensation of perturbed timing". The general dimensions are detailed in the online resource supplementary materials.

The general dimension of "sensation of being unbalanced" refers to the participants' negative perceptions of, for example, a fall, discomfort, or a loss of body stability. They were also sensitive to hand-crossings or to unreliable footholds or discomfort:

From the start I feel an imbalance towards the back and a feeling of discomfort in my feet [...]. Then, when I have to let go of my right hand in the middle of the track, I feel very unbalanced and uncomfortable on my feet (Participant from the CN group, Session 1, Trial 1, Transfer route).

The general dimension of "sensation of being balanced" refers to their positive perceptions during the climbs. For example, these positive sensations could be felt in a specific way through the reliability of hand or foot support or in a global way in the sensation of a well-aligned body: "It's the best trial of the session! My hips didn't move too much towards either side, except a little to the right at the beginning, I had the impression that the red light pretty much stayed in the middle" (Participant from the IN group, Session 10, Trial 1, Transfer route).

The general dimension of "sensation of efficient timing" refers to body markers experienced as positive during the climbs. These markers were perceived either in the movement of the whole body or in certain sequences of hand-foot actions such as the feeling of power between the hands and feet: "I feel that I put the tip of my feet on the holds and that helps me go fast [...]. My arms and legs are working at the same time to help me move quickly" (Participant from the CR group, Session 10, Trial 2, Control route).

The general dimension of "sensation of perturbed timing" refers to the negative perceptions of the participants regarding efficiency during climbing. These feelings of inefficiency were perceived, for example, through the sensations of stops or jerky movements or through the selected holds that impeded the synchronization of the hand-foot actions:

I really have the feeling that I'm not moving forward, that my feet are preventing me from moving forward, that in fact it's as if I were climbing only with my hands; I have the impression that everything is complicated and it's taking forever (Participant from the CR group, Session 10, Trial 1, Transfer route).

The thematic analysis of the climbers' actions revealed four general dimensions: (1) "making errors", (2) "carrying out the planned actions", (3) "improvising actions", and (4) "modifying the planned actions". The general dimensions are detailed in the online resource supplementary materials.

The general dimension of "making errors" refers to unplanned actions experienced by the participants as errors. These significant errors concerned both footholds and handholds: "I'm making a mistake here because I put a right hand on the handhold that is completely to the left and it makes me unbalanced" (Participant from the CR group, Session 10, Trial 1, Transfer route).

The general dimension of "carrying out the planned actions" refers to the actions of the participants corresponding to the movements they had planned during the preview. These actions concerned the chains of both hand actions and hand-foot actions:

I start as planned and continue kind of automatically until I finish without any problems. In fact, I do the same sequence as in the previous trial because it was good; so once again I put my knee against the wall and think that all I need to do is repeat what I did before to improve the fluidity (Participant from the CR group, Session 1, Trial 3, Control route).

The general dimension of "improvising actions" refers to actions not planned by the participants during their preview. This dimension therefore refers to participants' actions that emerged during the climb without having been considered beforehand. These actions concerned either the hand or the foot chaining: "Well, here, I'm climbing as best as best can because I don't have my feet! So, I make a jump to get my feet up and then I just finish however I can, it's crazy what I did there" (Participant from the CR group, Session 10, Trial 1, Transfer route).

The general dimension of "modifying the planned actions" refers to the modifications in hand and foot actions that the participants made during the climbs. These modifications were intended to improve or disrupt their climbing fluency. For example, they used a hold with the other hand:

I don't do what I had planned because I wanted to put my right hand to the right but instead, I put it to the left and got unbalanced, so I swing a bit like a pendulum to restart on the next hold (Participant from the CR group, Session 1, Trial 1, Transfer route).

These modifications could also disrupt their climbing fluency:

I don't feel comfortable enough to start up again how I had planned, so I modified it to do a cross, except that I find myself in a very uncomfortable position... nevertheless I think that I didn't do so bad (Participant from the IN group, Session 1, Trial 1, control route).

Identification of phenomenological clusters

Preview

The largest Calinski-Harabasz score was obtained for a model with two clusters (CH = [39.9283, 29.7254, 24.6477, 21.7715, 20.7126, 19.9426, 18.5771, 18.1587, 17.9546, 17.6186, 17.2156, 17.3879, 16.9393, 16.7423]). Based on the distribution of the general dimensions in the two phenomenological clusters (Table 1), we respectively named the clusters Construction-directed exploration (CE) and Re-construction-directed exploration (RC).

Table 1 Distribution (%) of the general dimensions of intentions, perceptions and actions between the two clusters of previews.

Phenomenological Clusters	General dimensions of Intentions				General dimensions of Perceptions			General dimensions of Actions		
	Designing sequences of actions	Reproducing sequences of actions	Performing	Respecting the instructions	Physical characteristics	Functional characteristics	Previous climbs	Miming one part of the route	Miming the entire route	Focusing on one of the routes
Construction-directed exploration (CE)	86,8	2,6	26,3	26,3	78,9	63,2	15,8	13,2	18,4	55,3
Re-construction-directed exploration (RC)	25,9	55,2	86,2	5,2	0	10,3	100	5,2	13,8	51,7

The CE cluster was defined as activities aimed at defining the orientation of actions based on the perception of the physical characteristics of the environment. CE was mainly characterized by the intention of “designing sequences of actions” (86.8%), the perception of “physical characteristics” (78.9%), and the action of “scanning the route” (71%).

The RC cluster was defined as activities to “re-construct” past actions by scanning the environment or fixing parts of the environment in order to perform well. RC was mainly characterized by the intention of “performing” (86.2%), the perception of “previous climbs” (100%), and actions of “looking at part of the route” (51.7%) or “scanning the route” (50%).

Climb

The largest Calinski-Harabasz score was obtained for a model with two clusters (CH = [20.9178, 16.9683, 15.1017, 13.5427, 12.3476, 12.2384, 12.1809, 11.6694, 11.7302, 11.4922, 11.2077, 10.7656, 10.4740, 10.2745]). Based on the distribution of the general dimensions in the two phenomenological clusters (Table 2), we respectively named the clusters Refined exploration (RE) and Performance-directed exploration (PE).

Table 2 Distribution (%) of the general dimensions of intentions, perceptions and actions between the two clusters of the climb.

Phenomenological clusters	General Dimensions of intentions				General dimensions of perceptions				General dimensions of actions	
	Ensuring the correct execution of actions chainings	Improving the timing of the climb	Maintaining balance while climbing	Respecting the instructions	Sensation of being balanced	Sensation of being unbalanced	Sensation of efficient timing	Sensation of perturbed timing	Improving actions	Modifying the planned actions
Refined exploration (RE)	95,8	35,4	33,3	20,8	25,0	58,3	20,8	68,8	47,9	95,8
Performance-directed exploration (PE)	47,9	70,8	4,2	8,3	20,8	10,4	83,3	45,8	29,2	22,9

The RE cluster included activities aimed at confirming the known direction of some of the actions and defining, during action, the direction of other potentially disruptive actions. It was mainly characterized by the intention of “ensuring the correct execution of action chainings” (95.8%), the perception of “sensation of perturbed timing” (68.8%), and the action of “modifying the planned actions” (95.8%).

The PE cluster included activities that confirmed the direction of actions known to be effective. PE was mainly characterized by the intention of “improving the timing of the climb” (70.8%), the perception of “sensation of efficient timing” (83.3%), and the action of “carrying out the planned actions” (97.9%).

Distribution of the phenomenological clusters for the preview and the climb

Preview

Overall, 39.6% of the trials belonged to the CE phenomenological cluster and 60.4% to the RE phenomenological cluster. No significant difference in the distribution of the phenomenological clusters was observed between the three learning groups [$\chi^2(2; N = 96) = 0.348, p = 0.840$]. This suggests that the emergence of the two phenomenological clusters was not related to the conditions of practice.

A significant difference between session 1 and session 10 in the distribution of the phenomenological clusters was observed [$\chi^2(1, N = 96) = 8.537, p = 0.003$], which indicated an effect of practice. More precisely, the CE cluster represented 54.2% of the trials in session 1 and dropped to 25% in session 10, whereas the RC cluster representation increased from 45.8% in session 1 to 75% in session 10.

The two phenomenological clusters were also distributed differently in the trials performed on the control route and the transfer route, [$\chi^2(1, N = 96) = 42.338, p < .001$]. This result indicates an effect of the route. Almost all the trials performed on the transfer route belonged to the CE cluster (95.8%), whereas on the control route, 20.8% of the trials belonged to this cluster and 79.2% belonged to the RC cluster.

Climb

Overall, the two phenomenological clusters were equally distributed across trials (50% for each). No significant difference in the distribution of the phenomenological clusters was observed between the three learning groups [$\chi^2(2; N = 96) = 0.750, p = 0.687$].

A significant difference between session 1 and session 10 in the distribution of the phenomenological clusters was observed [$\chi^2(1, N = 96) = 20.167, p < .001$], indicating an effect of practice. In session 1, 72.9% of the trials belonged to the RE cluster and this dropped to 27.1% in session 10, whereas 27.1% of the trials belonged to the PE cluster in session 1 and this increased to 72.9% in session 10.

A significant difference in the distribution of the phenomenological clusters between the control route and the transfer route was observed [$\chi^2(1, N = 96) = 42.338, p < .001$]. This result indicated an effect of the route. Almost all the trials performed on the transfer route belonged to the RE cluster (95.8%), whereas on the control route, 34.7% of the trials belonged to this cluster and 65.3% belonged to the PE cluster.

Discussion

In this study, we sought to (1) enrich the definition of enactive exploration in learning environments, (2) assess the fruitfulness of our methodology to characterize enactive exploration, and (3) propose three learning conditions to enhance exploration in an enactivist approach to intervention.

Enrich an enactive definition of exploration in motor learning

In our introduction, we started from a minimal enactive definition of exploration. As a reminder, Høffding and Schiavio (2021) defined exploration as “a fundamental way of making sense of oneself as coupled with the world” (p. 811). Our results enriched this definition on two points.

First, our work identified four generic forms of exploration characterized from the four clusters. These forms reflected singular combinatory relations between intentions, perceptions and actions. From these combinatory relations, a sense-making process emerged from the learner's interactions with the environment. As an illustration, exploring in the preview was defined as scanning the route (action) to identify the physical characteristics of the environment (perceptions), which could then be used to perform hand and foot action sequences (intentions).

Second, our work showed that these forms of exploration were linked to the learning conditions. Notably, it appeared that the practice period and familiarity with the environment structured the exploration (i.e., repetition of the same route). At the beginning of learning, exploration consisted in a process of “inquiry” (Dewey, 1938), which we might call “exploration-inquiry”. During the preview, this meant investigating with particular sensitivity to the physical characteristics of the environment (e.g., hold sizes or spatial design) to define the options for hand-foot action chaining. During the climb, inquiry continued to validate or modify the options chosen. The “exploration-inquiry” process indicates how learners “adopt” the environment, essentially from its physical characteristics. At the end of the learning process, exploration reflected the learner's incorporation of the environment, which we labelled “exploration-incorporation”. During the preview, the physical characteristics of the route became transparent, and the climber's activity was structured by past experiences (Rochat et al., 2020). During the climb, the hand-foot action sequences were replaced by perceptual judgments of fluidity (i.e., effective climbing timing) from past experiences. Thus, “exploration-inquiry” and “exploration-incorporation” reflected an interdependence, with a co-definition between the preview and the climb. In this sense, the climb helped structure the following preview and reciprocally. In the enactive literature on skill acquisition, the role of the preview and its relation to the climb is a source of theorizing (Rucińska, 2021). For Rucińska, the preview is a form of “enactive planning” whereby the actor visualizes and marks the bodily actions that will be carried out during the following climb by a process of corporeal imaginings or spatial simulation. In this context, the climb refined the preview in the sense that the climbing activity consisted in an enactive re-planning that confirmed or rejected actions planned during the previous preview. In the same way, this interdependence between the preview and the climb was linked to the observation that exploration is a permanent process of “sense-making/actualization of this sense-making” between actors and the environment in and from which they interact. Moreover, our results indicated that the repetition of the same practice conditions (i.e., effect of practice) enhanced the actualization of the same forms of exploration for the preview (i.e., RC phenomenological cluster) and the climb (i.e., PE phenomenological cluster). In this case, this familiarity within the actor/environment coupling favored the emergence of an “exploration-incorporation” process. This was reflected by the learner's recognition of similarities in the environment. On the other hand, a lack of familiarity with the environment kept the learner in an “exploration-inquiry” mode, as shown by our results on the transfer route.

Overall, exploration as a continuous process of sense-making/actualization of this sense-making is both a pathway and a goal in learning activity. It is a pathway because it allows the emergence of a reality for the actor (i.e., his/her own world), and it is also a goal because it can also reflect the learner's

engagement or intention. This can be illustrated when a learner designs action sequences during the preview (CE phenomenological cluster).

Methodological contributions to the enactive approach

First, our results converge with those obtained by Rochat et al. (2020) in the general dimensions of intentions, perceptions and actions. These similarities between the two studies suggest the reliability of our common methodology: thematic analysis (Braun & Clarke, 2006), which was mobilized to identify the general dimensions of intentions, perceptions, and actions. This methodology highlights the stability in the results obtained for the general dimensions, supporting its reliability.

Moreover, our methodology goes beyond the methodology proposed by Rochat et al. (2020). First, we aimed to characterize a phenomenological synthesis of exploration from the general dimensions of intentions, perceptions and actions, without partitioning these general dimensions, as was done by Rochat et al. (2020). On the assumption that doing so might limit the impact of the results, we used hierarchical cluster analysis to connect the general phenomenological dimensions. However, although our clustering-based method was an opportunity to identify macro-level exploration formats, it did not allow us to distinguish variations within clusters. Indeed, a cluster remains a representation of a reality that hides a diversity of realities at a finer level. Yet, this level of representation might be useful to professionals as a way to help them better identify generic forms of exploration in the learner. Second, our study seems to be distinct from those usually conducted within an enactive phenomenological framework in the sense that it brought together many participants (12 participants), a variety of practice conditions (3 practice conditions), and a large quantity of practice (86 trials). These characteristics enabled us to conduct a quantitative analysis using the hierarchical clustering method, based on current works studying motor learning from behavioural analysis (Seifert et al., 2017a; Komar et al., 2019). This step follows a first methodological step traditionally used in research involving the enactive framework and mobilizing reduced samples data (Sève et al., 2005; R'Kiouak et al., 2016; Adé et al., 2017; Rochat et al. 2018, 2020; Terrien et al., 2022). This opportunity offers a new way of extracting new meaning from phenomenological data, especially by preserving the experiential globality (by combining the general phenomenological dimensions). Thus, tendencies in the distribution of forms of enacted exploration can be identified between learning sessions, groups, and conditions of practice.

Learning conditions and climbers' enacted exploration

Our findings open discussion on both the effects of learning conditions on exploration and proposals for ways that practitioners can foster learning on how to explore through an enactivist intervention (Gallagher, 2017). Indeed, if you must explore to learn, it seems important to learn to explore. As our results show, exploration is learning in the sense that it is a dual process of sense-making/actualization of this sense-making that implies transformations in the learner's intentions, perceptions, and actions that are stimulated by the interactions with the environment. Three ideas are defended here: (1) learning to explore is learning by situating oneself, (2) learning to explore is learning to adopt the environment as a partner, and (3) learning to explore is learning to re-cognize.

First, our results characterized exploration as a change in the intentions, perceptions and actions over the learning period, whatever the conditions of practice. Therefore, facilitating the learning of exploration assumes that the learner's sense-making is at the heart of the practitioner's intervention. For the learner, learning to explore means learning to situate oneself, which means that the practitioner needs to be aware of what makes sense for the learner. For practitioners, this necessarily implies an investigation into the learner's exploration activity to gain insight into the "earner's own world". For example, "situated questioning" based on past activity traces (e.g., from video recordings) can help learners put into words their intentions (e.g., "When you start, what are you looking to do?"), perceptions (e.g., "Here, when you arrive at the middle of the route, what are you looking at?"), and actions (e.g., "Here, what are you doing to go to the next hold?") in the course of their activity.

Second, our results showed that the repetition of the same practice conditions can promote the development of exploration to an "exploration-incorporation" process. For practitioners, this requires the design of learning environments that encourage learners to seize opportunities for potentially effective actions that are likely to enrich their action plans. Essentially, rather than having learners solve problems, practitioners should adopt an intervention strategy that aims at encouraging them to find meaningful solutions based on what is significant for them in the environment. As an illustration, when learners are instructed to climb a route without using "prohibited" holds, the practitioner engages them in solving the problem of the prohibition. A more challenging approach would be to ask the learners to climb the same route but with only seven handholds allowed. In this case, the learners become engaged in exploring the environment to grasp opportunities for efficient actions. In sum, learning to explore is "learning to adopt the environment as a partner", which constantly offers new opportunities for action to improve efficiency.

Third, our results highlight the lack of changes in the lived experiences of exploration on the transfer route between the first and last trials of the learning protocol. This indicates that all of the learners had little or no reinvestment of the skills acquired during the learning process. However, the aim of learning is, in part, to reinvest skills in new environments (Seifert et al., 2015; Pacheco & Newell, 2015; Pacheco et al., 2018). For the practitioner, this suggests the need to design affording and connecting environments. An affording environment is one that has been materially, spatially and temporally designed to be meaningful and is able to engage learners in those actions intended by the practitioner while dissuading them from actions that are not intended for learning. This type of environment seems able to foster the recognition of similarities and analogies between intentions, perceptions and actions that have already been experienced. As an illustration, in climbing, to assess the learner's ability to reinvest skills acquired in a learning environment, it would be interesting to develop a new environment where the learner can recognize spatial dispositions of holds or hold orientations shared in part with the learning environment (Orth et al., 2018). We hypothesize that this connection was insufficiently fostered in our study because of the lack of similarity perceived by the learners between the control route, which they repeated 30 times, and the transfer route, which they experienced two times. Overall, learning to explore is learning to recognize structures in the learners' coupling with their environment.

Conclusion

Our study, conducted from an enactive and phenomenological approach, has provided new findings into how learners explore a learning environment from their lived experiences. The results have enriched the enactive definition of exploration, now conceptualized as a dual process of sense-making/actualization of this sense-making. Thus, exploration is seen as nested intentions, perceptions and actions that enact general tendencies of exploration. Our investigation of learners' lived experiences has enriched previous works that investigated exploration at a behavioural level. Notably, it highlights two key points: (1) learners' exploration evolves with practice and (2) there are no differences between variable and constant practice conditions in the enactment of exploration.

Although our study allowed us to identify the distribution of the general dimensions of intentions, perceptions and actions between the beginning and the end of the learning process, it did not allow us to identify the dynamics of their transformation over the 10 sessions of the learning protocol. In the future, our goal will be to track the dynamics of emergence and changes in the intentions, perceptions and actions during exploration over 10 sessions of a learning protocol in order to identify general tendencies in the changes from the general dimensions of enacted exploration.

Declarations

Ethics declaration

Conflict of interest statement

The authors report there are no competing interests to declare.

Ethics Statement

The protocol followed the guidelines of the Declaration of Helsinki. Participants were informed of the procedures and then gave their written consent to participate.

Informed consents

Informed consent was obtained from all individual participants included in the study. They consent that their anonymized data can be used for scientific publication.

Additional information

Data availability statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Supplemental online material

The online version contains supplementary information.

Author contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Clément Ganachaud, Caroline Ganière, Guillaume Hacques, Nadège Rochat, Ludovic Seifert and David Adé. The first draft of the manuscript was written by Clément Ganachaud and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Figures

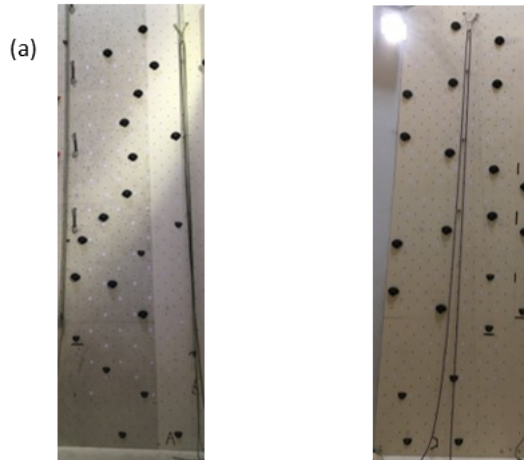


Figure 1

Illustration of the climbing routes designed for the learning protocol: (a) the control route and (b) the transfer route

Supplementary Files

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