# PERCEPTUAL-MOTOR SKILLS IN CLIMBING: EXPERTISE AND LEARNING

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**Abstract**

This talk presents an overview of the perceptual-motor skills used by climbers and how they could be learned and optimized. First, I highlight how motor skills in climbing, i.e. climb-abilities (such as reachability, graspability and usability) could be assessed, learned and optimized through a constraint-led approach. I propose four indicators to assess behavioral regulation during the climb: (i) Assessment of the climbing fluency using inertial measurement unit (IMU) or camera (from 2D to 3D; from single camera to multi-camera system); (ii) Differentiate exploratory versus performatory actions; (iii) Detection of 5 states of activity by IMU located on feet, wrists and pelvis: stationary (absence of limb and hip motion), hold exploration (absence of hip motion but at least one limb in motion), postural regulation (hip in motion but absence of limb motion), global motion (hip in motion and at least one limb in motion), transition between holds (when absence of hip motion but at least one limb in motion is followed by global motion) (iv) Detection of time spent on 1 to 4 supports by using instrumented holds system. Second, I present the visual-motor skills, and notably the visual search behaviors occurring during pre-ascent inspections of a route and during the climb. I emphasize how focusing on functional (*vs*. structural) features of the environment, i.e. useful informational variables for action, could help to optimize perceptual-motor skills and climbing performance.

**Keywords**: perception and action, gaze behavior, fluency, adaptive exploration, constraint-led approach

**Résumé**

Cette présentation donne une vue d'ensemble des compétences perceptivo-motrices utilisées par les grimpeurs et comment elles peuvent être apprises et optimisées. Tout d'abord, je présenterai comment les compétences motrices en escalade (telles que les capacités d'atteinte, de saisie et d'utilisation des prises) peuvent être évaluées, apprises et optimisées grâce à une approche par les contraintes. Je propose trois indicateurs pour évaluer la régulation du comportement pendant la grimpe: (i) Evaluer la fluidité du déplacement par l'utilisation d'une centrale inertielle ou des caméras (2D à 3D, et 1 à plusieurs caméras); (ii) Distinguer les actions exploratoires et exécutoires ; (iii) Détecter cinq états dans l'activité du grimpeur grâce à l'utilisation de 5 centrales inertielles (situées sur les pieds, les poignets et le bassin): stationnaire (absence de mouvement des membres et du bassin), au moins un membre en mouvement), régulation posturale (mouvement du bassin mais absence de mouvement des membres), traction (mouvement du bassin et au moins un membre en mouvement), exploration des membres (absence de mouvement des membres et au moins un membre en mouvement), et transition entre deux prises (absence de mouvement des membres et au moins un membre en mouvement, mais suivi d'une traction) ; (iv) Détecter le temps passé sur 1 à 4 supports par un système de prises instrumentées. Deuxièmement, je m'intéresserai aux compétences visuo-motrices, et notamment les stratégies de recherche visuelle qui se produisent lors de la prévisualisation d'une voie et lors de la grimpe. Je montrerai que les grimpeurs expérimentés semblent se focaliser sur les aspects fonctionnels (plutôt que structurels) de l'environnement, c'est-à-dire des variables informationnelles utiles pour agir et en particulier leur permettant d'enchainer les actions, ce qui pourrait aider à optimiser les compétences perceptivo-motrices et les performances en escalade.

**Mots clés**: perception et action, stratégie visuelle, fluidité, exploration, contrainte

**Introduction**

When climbing surfaces are viewed from the ground, before climbing, it is often impossible to ascertain the features of the holds and how they can be used, and consequently climbers have to adapt their behaviors to dynamically changing, interacting constraints that they perceive and encounter. Assuming that perceptual-motor skills (such as reachability, graspability, supportability and usability) emerge through the continuous and active exploration of environmental properties, the first focus of climbers is to reach holds. Successful reaching action is dependant upon the individual accurately perceiving the relationship between their action capabilities and the environmental properties, termed affordances (Gibson, 1979). In climbing, postural stability is challenged because the climber must cope against gravitational forces to move his/her body upward, using a quadrupedal locomotion and particularly the extremities of fingers and feet. Therefore, climb-abilities refer to the perception of a vertical surface and its layouts (holds for hand and feet) leading to reach, grasp, stand, and use holds as a support for quadrupedal locomotion.

**Climbing Motor Skills**

To assess climb-abilities, a first indicator could be how 'fluent' is the climber. As non-expert climbers exhibit more stationary than motion (assessed by hip displacement) during performance, the whole climbing time related to stationary/motion could be a *temporal* indicator of fluency. For instance, Billat et al. (1995) reported that advanced climbers spent 63% a route duration stationary and 37% ascending, and non-experts were immobile for even longer. A *spatial* indicator of climbing fluency such as the geometric entropy index value from the hip displacement is regularly (Cordier, Mendès-France, Bolon, & Pailhous, 1993; Sibella, Frosio, Schena, & Borghese, 2007). The geometric index of entropy ($H$) has been calculated by recording the path distance covered by the hips ($L$) and the perimeter of the convex hull around that path ($c$): $H = \text{logn}2L/c$ (Cordier et al., 1993). $H$ reveal the amount of fluency/curvature of a curve: the higher the entropy, the higher the disorder of the system (Cordier et al., 1993). A low entropy value is associated with low energy expenditure and greater climbing fluency. $H$ remains a spatial measure of body motion that does not consider the displacement of the hips over time (i.e., when a climber pauses), only the projection of the path. Thus, it is necessary to get an index of climbing fluency that integrates both *spatial* and *temporal* measurements into a single outcome, such as velocity and acceleration and jerk (Seifert et al., 2014). Analyses of the jerk coefficient of hip trajectory and orientation, that is, third time derivative of position or the rate of change of acceleration, indicating trajectory smoothness, have revealed decreases of jerk coefficients with practice, providing a useful indicator of climbing fluency (Seifert et al., 2014).

As climbing holds can take many forms and offer a variety of different functional characteristics, different types of reaching expertise may exist; therefore focus should be paid onto the specific reach, touch and grasp patterns used to interact with a climbing hold. During indoor wall climbing, Pijpers et al. (2006) distinguished exploratory and performatory movements of potential holds on a rock surface by holds that were used or not used as support during the ascent. Calculating the ratio between 'touched/grasped' and 'used' holds to move upward could indicate how climbers explore environmental properties by using adaptively perception and action systems. The distinction between touched, grasped, and used holds is also used in lead climbing competition to assess achievement when a competitor falls before reaching the top. The IFSC rules indicate that "*a hold shall be considered as "controlled" where a competitor has made use of the hold to achieve a stable or controlled position, whereas a hold from which a competitor has made a controlled climbing movement in the interest of progressing along the route shall be* *considered as "used"*. To help the judges make their decision, the IFSC rules indicate that "*a controlled climbing movement may be either "static" or "dynamic" in nature and in general will be evidenced by (i) a significant positive change in position of the competitor's center of mass; and (ii) the movement of at least one hand in order to reach either the next hold along the line of the route*". These rules reinforce the idea that repetitive exploratory movements may lead to early fatigue, stoppages, and falls. This also places into perspective why skilled climbers try to minimize their exploratory actions during climbing, for example the 'three-holds-rule', a commonly used training constraint (Sibella et al., 2007), limits touching to fewer than three surface holds before grasping a functional one. With learning and expertise, the number of exploratory and performatory actions was found to decrease, as exploration became more functional (Orth, Kerr, Davids, & Seifert, 2017; Seifert, Boulanger, Orth, & Davids, 2015). Capturing climbing fluency from a single point (i.e. hip) is limited because the same hip path can be obtained from various limb movements and coordination patterns when kinematic, kinetic and muscular levels are considered. Concerning kinematics, Boulanger et al. (2016) have presented an application of a machine learning method to automatically detect and classify five climbing states using inertial measurement units (IMUs) attached to feet, wrists and pelvis: stationary (absence of limb and hip motion), hold exploration (absence of hip motion but at least one limb in motion), postural regulation (hip in motion but absence of limb motion), global motion (hip in motion and at least one limb in motion), transition between holds (when absence of hip motion but at least one limb in motion is followed by global motion) the wrists, feet and pelvis of the climber. Seifert et al., (2018) manipulated the hold orientations to understand how it can influence exploration and facilitate the acquisition of new behavioural pattern. Three routes were designed: a horizontal-edge route afforded horizontal hold grasping, a vertical-edge route afforded vertical hold grasping, and a double-edge route afforded both horizontal and vertical hold grasping. The results showed that with practice, the learners decreased the relative duration of hold exploration, suggesting that they improved affordance perception of hold grasp-ability. The number of performatory movements also decreased as performance increased during learning sessions, confirming that participants' climbing efficacy improved as a function of practice. Last, the results were more marked for the 'horizontal' route, while the 'dual-edge' route led to longer relative stationary duration and a shorter relative duration of performatory states. Together, these findings emphasized the benefit of manipulating task constraints to promote safe exploration during learning (Seifert et al., 2018). A last indicator to assess climb-abilities could be to look at time spent into 1 to 4 supports. Recent technological development allows getting accurate time of contact with the holds for each support (Luxov©, France).

**Visual-motor skills**

Information that specifies action is sometimes hidden and climbers can pick up misinformation information during the climb. "*If misinformation is picked up, misperception results*" (p.142) (Gibson, 1979). Once a climber has started a route it can be difficult to climb down or to change his/her path. Visual inspection of the route before the climb may help to pick up certain features of the climbing route (such as position and orientation of holds) and reproduce them. Expert climbers typically focus on *functional* features the wall supported (such as hold grasping and sequences of movements). Since more than one hold is generally required to perform climbing actions this presumably facilitated the recall of more clusters of information (multiple holds associated with action(s)). Whereas, the inexperienced climbers did not recall such clustered information, mostly reporting the *structural* features of the holds (such as their orientation and shape) (Boschker, Bakker, & Michaels, 2002). In these respects, there is good evidence that route previewing enhances climbing performance by giving the climber the opportunity to perceive affordances offered by the surface and its layout (which is associated with more effective recall; Boschker et al., 2002), and thus to minimize misperception (Seifert, Cordier, Orth, Courtine, & Croft, 2017). Four visual strategies are used by skilled climbers during route previewing (Grushko & Leonov, 2014; Seifert et al., 2017): *Ascending* (looking from the bottom upwards), *fragmentary* (the climber jumps parts of a route), *zigzagging* (moving gaze from side to side, e.g. hand holds to foot holds), and *sequence-of-blocks* (blocks of two to four hand holds, with particular attention being focused on crux points). Sequence-of-blocks and zigzagging strategies would be associated with deep visual inspection, probably because the informational variables (e.g. hold shape, orientation, size, etc) of the route don't clearly specify action (Seifert et al., 2017). Conversely, ascending and fragmentary strategies would be associated with superficial visual inspection, probably because the climber can perceive the functional features of the holds and the sequence of movements that are required (Seifert et al., 2017).

Visual search during climbing is predominantly focussed upon determining potential hand-holds in preparation for action. In comparison, much less time is spent looking at other features of the climbing surface or the climber's own body. Once the relevant hold has been identified the climber rapidly shifts their gaze (known as a '*saccade*') to the next potential hand (or foot) hold. Presumably, the climber uses their awareness of reaching length to facilitate visual guidance of their limbs towards anchorage points as performatory fixations (visual fixations associated to limbs or body movement) are generally much shorter than exploratory fixations (visual fixations when the climber is stationary). Climbers generally execute two to three times as many exploratory fixations as performatory fixations. Hence, the primary changes to visual search as a function of skill and experience appear to be in terms of improved economy of visual search with fewer, shorter fixations and a decreased search rate.

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