Perceptual motor skills in climbing: expertise and learning

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1. Performance in climbing

• Speed Climbing:
  Route completion,
  Climbing time for route completion.

• Lead Climbing:
  Route completion,
  When a route is not completed, scoring relates to the last controlled or used hold:
  IFSC rule: 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”.

• Bouldering:
  The number of attempts required to complete the route,
  When a route is not completed, scoring relates to the number of attempts required to gain a zone point.
With the combined climbing events at the Tokyo Olympic Games, another view about LEARNING & EXPERTISE is needed:

1. Understanding expertise goes beyond the "how fast can you climb", "how hard can you climb" or "how accurate can you climb", "how fluent can you climb" questions


3. What perceptual-motor adaptability tells us about learning & expertise?

4. Adaptability means adapted and adaptive behaviors:
   - adapted behavior to a set of constraints reveals stability against perturbations,
   - adaptive behavior reflects flexibility to guarantee functional solution to constraints that dynamically interact.

2. BACKGROUND

2.1. Expertise / Adaptability / Degeneracy

- **Adaptability** = stability (i.e., robustness of some functionalities to external disturbances) when it’s needed and flexibility (i.e., functional variability) when it’s needed (Seifert, Button, Davids, 2013 Sport Med; Warren, 2006).

- Degeneracy - Multi-stability is described as many structures-one function relationship

  ... Structural variability is adaptive when it leads to stability in the performance outcome.

- Pluri-potentiality - Multi-functionality is referred to a one structure-many functions relationship

- More than multi-stability, experts are able to exhibit creativity or innovation i.e., exploitation of new opportunities = multi-functionality (Kelso, 2012).
2.2. The Ecological Dynamics framework to examine adaptability

How a set of interacting and dynamical constraints makes emerge movement coordination?

In indoor climbing, route setter can manipulate constraints such as orientation, shape, size of holds, distance between holds, to understand how climbers adapt.

More generally, adaptability could be assessed when transfer of skills is required between:

- indoor speed, bouldering and lead climbing
- indoor and outdoor rock climbing,
- rock, ice climbing and mixed routes.

Training adaptability means to PROHIBIT the behaviour we don’t want to see anymore (i.e. by manipulating constraints to set action boundaries) rather than to PRESCRIBE an expected behaviour. The constraint-led approach promotes EXPLORATION, PROBLEM-solving and SEARCH strategies.

Figure 5. Representation of coordination emerging from the interaction of constraints through perception-action coupling (Davids et al., 2008).
Adaptability is tested by manipulating task constraint:

3. How do climbers adapt to hold orientation?

Orientation and number of edges easy to grasp are changed to induce shift in grasping patterns and movement coordination:
Hypothesis:

Novice climbers mostly use ‘face’ body position, horizontal hold grasping and a small range of hand and foot patterns (‘duck’-like),

Experts are able to experience a variety of body, hand and foot positions, using mainly ‘side’ body position like ‘Cleopatra’ and both internal and external side of the climbing shoes.
Orth D, Davids K, Chow J-Y, Brymer E

Repertoire Influences the Rate and Nature of Learning in Climbing: and Seifert L (2018) Behavioral Movement Science and Sport. This article was submitted to

Costantino Balestra, *Correspondence:*

26 November 2017


12 June 2018

Extreme climbing where participants perform while knowing

Change in coordination repertoire has been observed in bi-manual dy configuration patterns. To explain these individual differences different coordination patterns have been identified qualitatively reorganizing movement system components—the movement system component can be identified qualitatively as either a poorly integrated system component or an effective system component (or coordination abilities). Extreme environments requires a skill set normally acquired in non-extreme environments. In extreme climbing is common for an individual to experience difficulties or coordination limitations. Such environments can be categorised into two types:

- climbing without informational constraint;
- climbing by mostly ‘facing’ the wall;
- climbing by rolling the body ‘side’ to ‘side’.
3.2. Experimental design to test hold orientation

3 routes randomly distributed

Route properties:
10.4 m height
20 hand holds
F-RSD = Level 5b

Task goal:
Climb as fluent as possible, i.e. minimizing stops and saccades
**Data collection:** Worn sensor (IMU)

- **Controller unit**
- **Laptop or desktop for data management** (MotionDevTool version 3.1.1)
- **Motion Pod3 de MOVEA**
  - inertial measurement unit combining 3D accelerometer, 3D gyroscope, 3D magnetometer
  (www.movea.com, France)
3.2.1. Effect of route design and learning on jerk

Jerk corresponds to the third derivative of position and indicates the smoothness of hip or CoM trajectory.

Jerk decreases with learning and hold design complexity.
3.2.2. Effect of route design, learning and SKILL on geometric index of entropy

H1(blue) = \ln(2*PL1/c)
H2(orange) = \ln(2*PL2/c)

since PL1 > PL2
H1 > H2
for the same height HTot
3.2.3. Effect of route design and learning on exploratory-performatory movement and body roll

1. **Number of performatory movements**, defined as the number of movements during which a hold is released and contact is made with another hold, which is then used as support.

2. **Number of exploratory movements**, defined as the number of times a hold was touched without it being used as support. [Pipers et al. (2006) Ecol Psychol]

<table>
<thead>
<tr>
<th>Route Type</th>
<th>Performatory movements</th>
<th>Exploratory movements</th>
<th>Ascent duration (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal-edge route</td>
<td>20.7 ± 0.4</td>
<td>0.2 ± 0.1</td>
<td>74.6 ± 9.0</td>
</tr>
<tr>
<td>Vertical-edge route</td>
<td>22.3* ± 0.4</td>
<td>0.6* ± 0.1</td>
<td>114.2* ± 16.2</td>
</tr>
<tr>
<td>Double-edge route</td>
<td>22.2* ± 0.4</td>
<td>0.5* ± 0.1</td>
<td>118.1* ± 15.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Session</th>
<th>Performatory movements</th>
<th>Exploratory movements</th>
<th>Ascent duration (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>22.2 ± 0.2</td>
<td>0.4 ± 0.1</td>
<td>115.9 ± 9.0</td>
</tr>
<tr>
<td>2</td>
<td>21.8* ± 0.4</td>
<td>0.3 ± 0.1</td>
<td>103.2 ± 18.4</td>
</tr>
<tr>
<td>3</td>
<td>21.4* ± 0.4</td>
<td>0.3 ± 0.1</td>
<td>96.5* ± 13.7</td>
</tr>
<tr>
<td>4</td>
<td>21.4* ± 0.4</td>
<td>0.1* ± 0.1</td>
<td>93.4* ± 14.1</td>
</tr>
</tbody>
</table>
### 3.2.4. Five states of activity in climbing


**Table: Full body state**

<table>
<thead>
<tr>
<th>Limb immob</th>
<th>Limb (1+) mov</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immobility</td>
<td>Hold interaction</td>
</tr>
<tr>
<td>Regulation</td>
<td>Traction</td>
</tr>
</tbody>
</table>

**Decision tree**

- **Multiple sensor**
- **Detection layers**
  1. Immobility, Motion
  2. Regulation, Traction, Hold interaction
  3. Change hold, Exploration

**Threshold to decide immobility:**

\[ \omega_T = 0.15 \text{ rad/s} \text{ for the hands and feet and } \omega_T = 0.12 \text{ rad/s} \text{ for the pelvis} \]
5 inertial measurement unit combining 3D accelerometer, 3D gyroscope, 3D magnetometer (www.movea.com, France)
Validation with manual video annotation obtained from blind process (cross of 2 operators analysis). Accuracy between 70% (pelvis) to 90% (hands & feet).
Ex of full-body analysis

<table>
<thead>
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<th>Limb immob</th>
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<td>Regulation</td>
<td>Traction</td>
</tr>
</tbody>
</table>

- Immobility: 25%
- Regulation: 5%
- Hold interaction: 43%
- Traction: 27%
Affordance Realization in Climbing: Learning and Transfer

Ludovic Seifert*, Dominic Orth*, Bruno Mantel², Jérémie Boulanger³, Romain Hérault* and Matt Dicks*#

No interaction between route design and practice effects

With practice:
- Performance
- Number of immobility period
- Number of performatory movements
- Relative duration of exploratory movement

Using dual-grasping holds help to achieve effective exploration, as climbers still explore while maintaining level of performance (climbing time and fluency) : Adaptive flexible behaviour

<table>
<thead>
<tr>
<th>Trial</th>
<th>Number of falls</th>
<th>Ascent duration (s)</th>
<th>Jerk coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.1 ± 1.5</td>
<td>120.8 ± 13.8</td>
<td>3.07 × 10^{13} ± 1.28 × 10^{12}</td>
</tr>
<tr>
<td>2</td>
<td>2.7 ± 1.1</td>
<td>100.9 ± 10.2</td>
<td>1.73 × 10^{13} ± 9.71 × 10^{11}</td>
</tr>
<tr>
<td>3</td>
<td>1.4 ± 0.9*</td>
<td>87.4 ± 8.8*</td>
<td>9.94 × 10^{12} ± 4.71 × 10^{11}</td>
</tr>
<tr>
<td>4</td>
<td>0* p = 0.01</td>
<td>84.6 ± 6.3*</td>
<td>4.21 × 10^{12} ± 2.78 × 10^{11}</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial</th>
<th>Number</th>
<th>Relative duration (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMMOBILITY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>27.9 ± 5.7</td>
<td>31.6 ± 4.5</td>
</tr>
<tr>
<td>2</td>
<td>28.4 ± 5.6</td>
<td>28.2 ± 4.8</td>
</tr>
<tr>
<td>3</td>
<td>22.5 ± 4.6</td>
<td>32.0 ± 5.0</td>
</tr>
<tr>
<td>4</td>
<td>21.3 ± 3.7* p = 0.028</td>
<td>30.3 ± 5.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HOLD EXPLORATORY MOVEMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
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</tr>
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<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>PERFORMATORY MOVEMENTS</th>
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<tbody>
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</tr>
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<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
</tbody>
</table>

Climbers skill level: 5c
4. How do climbers adapt their motor coordination to hold location?
New device to collect hand and feet motions

Instrumented hold Luxov ® Touch: http://www.luxov-connect.com/produits/#touch
5. How do climbers perceive their action capabilities according to task-goal complexity?

Task complexity varies according to the involved **degrees of freedom**:

**Estimate** the **maximal distance** that the hold can be (i) **reached**, (ii) **grasped**, (iii) **grasped** by one hand while the other hand **releases** the starting hand-hold, (iv) **grasped to then be used to grasp** the highest possible hold on the wooden board.
4 tasks: 4 trials in each task

**Reaching**
the center of
the hold for 3s
by one hand
without falling

**Grasping**
the hold for 3s
by one hand
without falling

**Grasping & Release:**
*Grasping* the
hold for 3s by
one hand while
the other hand
*releases* the
starting hand-
hold, without falling

**Using:**
*Use the foot and hand holds to grasp* the
highest possible hold on the
wooden board
for three seconds
without falling
- Advanced climbers performed closer to their maximal (especially at the 1st or 2nd trials).

- They rarely overestimated their capability.

- Conversely, intermediate climbers often underestimated their capability at the 1st and 2nd trials.

- At trials 3 and 4, they tended to overestimate their capability and failed (fall).
Experienced climbers estimate and can act close to their maximal, by exploring and creating new motor solutions, such as moving foot first and hand in a second time.
As a result, some climbers can grasp hold at higher distance in « using » (186cm) than in « grasping » (173cm) task.

It supports the idea that exploration still exists in expert and might lead to increase maximal action capabilities, affordances boundaries.

Ex of 8b climber
6. Visual motor skill in climbing

Integration of gaze and motor behaviours

Gaze behaviour using glasses equipped with camera filming eyes and scene camera
Gaze tracking: Eye positions mapped to the wall plane.
6.1. Expertise effect according to reachability

Integration of gaze-hip tracking data relative to the reachability

**Horizontal reachability** = Arm span

**Vertical reachability**

= Shoulder height + Arm length

Orth et al. (2014)
Experienced

Less experienced
6.2. Influence of hold regularity on visual motor skill

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

CHRIS BUTTON¹, DOMINIC ORTH²,³, KEITH DAVIDS ⁴, & LUDOVIC SEIFERT

European Journal of Sport Science, 2018
https://doi.org/10.1080/17461391.2018.1472812

ORIGINAl ARTICLE

Reduced preview and climb duration in the irregular hold route,
Less exploratory visual search behaviour in the irregular route.

Table I. Mean number and route

<table>
<thead>
<tr>
<th>Trial</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>378 (162)</td>
</tr>
<tr>
<td>2</td>
<td>260 (137)</td>
</tr>
<tr>
<td>3</td>
<td>268 (170)</td>
</tr>
<tr>
<td>4</td>
<td>193 (107)</td>
</tr>
<tr>
<td>5</td>
<td>204 (165)</td>
</tr>
<tr>
<td>6</td>
<td>168 (112)</td>
</tr>
<tr>
<td>Mean</td>
<td>245 (76)</td>
</tr>
</tbody>
</table>

The lack of variation in grasping opportunities (affordances) offered by the regular route may lead to prolonged stoppages and/or used.

Route difficulty: 6a
Climbers skill level: 7a-7c
6.3. Skill effect on route previewing and climbing
Role of route previewing strategies on climbing fluency and exploratory movements

Ludovic Seifert1*, Romain Cordier1, Dominic Orth3, Yoan Courtine3, James L. Croft2

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Initial Fixation

- Next fixation $d > 150$ cm
  - YES: Downward
  - NO: Upward

**New SCAN path**
3 next fixations go downward for $d > 300$ cm

**FRAGMENTARY strategy**
Maximal distance between 2 fixations (taken in a set of 10 fixations) with $d < 150$ cm

- NO
- YES: Maximum 2 next fixations go downward

**Sequence of BLOCKS**

**ZIGZAGGING strategy** with $d < 300$ cm

**ASCENDING strategy** with $d < 30$ cm between those 2 fixations

Visual strategies of scan path 1

**Horizontal axis (cm)**

**Vertical axis (cm)**

- Block 1
- Block 2
- Block 3
- Block 4
- Block 5
- ZZ 1
- ZZ 2
- Ascending
- Fragmentary
Climbers with longer preview and longer visual exploration are also those with longer climbing duration, immobility and hold exploration.

Those climbers might perceive hold independently, i.e. one by one.

Conversely faster climbers might perceive holds as a sequence.
7. Conclusion

Ecological dynamics framework shows how by using constraint-led approach, perceptual-motor skills can be assessed, trained without prescribing solutions but by promoting individual search strategy.

Core concept of this approach is ‘adaptability’, reflecting adaptive flexibility in order to efficiently explore and to increase action system boundaries.
THANK YOU FOR YOUR ATTENTION

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Special thanks to:

Jérémie Boulanger (France)
Chris Button (NZ)
Jean François Coeurjolly (France)
James Croft (Australia)
Keith Davids (UK)
Matt Dicks (UK)
Guillaume Hacques (France)
Romain Hérault (France)
John Komar (France)
Bruno Mantel (France)
Dominic Orth (The Netherlands)
Andrew Walsh (Australia)
Peter Wolf (Switzerland)