

When Affordances Climb into your Mind: Advantages of Motor Simulation in a Memory Task Performed by Novice and Expert Rock Climbers

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Abstract

Does the sight of multiple climbing holds laid along a path activate motor simulation of climbing that path? One way of testing whether multiple affordances and their displacement influence the formation of a motor simulation is to study acquired motor skills. We used a behavioural task in which expert and novice rock climbers were shown three routes: an easy route, a route impossible to climb but perceptually salient, and a difficult route. After a distraction task, they were then given a recall test in which they had to write down the sequence of holds composing each route. We found no difference between experts and novices on the easy and impossible routes, whereas on the difficult route, the performance of experts was better than that of novices. This suggests that seeing a climbing wall activates a motor, embodied simulation, which relies not on perceptual salience, but on motor competence. More importantly, our results show that the capability to form this simulation is modulated by individuals' motor repertoire and expertise, and that this strongly impacts recall.

Keywords:

simulation, affordance, embodied cognition, grounded cognition, canonical neurons, mirror neurons, motor memory, memory for actions, motor chunks

1. Introduction

Humans are able to take advantage of the objects and entities displayed in their environment in order to achieve their goals. Many behavioural studies have shown that the vision of objects, such as cups and hammers, affords simple actions, such as reaching and grasping. As a result, the notion of *affordance*, originally proposed by (Gibson, 1979), has been given new life. Affordances can be defined as action patterns activated while observing objects. The underlying neural basis for affordances can be found in the discovery, in the F5 area of the ventral premotor cortex of the monkey, of canonical neurons (Murata et al., 1997). Visuomotor canonical neurons discharge in the presence of graspable objects, when no overt response is required—the majority of neurons responds selectively to specific kinds of grips (e.g., precision vs. full hand grips). Their function probably consists in representing objects in terms of potential action patterns. Evidence in humans confirms the existence of a parieto-premotor circuit active during the observation of manipulable objects (Grèzes et al., 2003). Brain activation results showed that the response of the left ventral premotor cortex was stronger for manipulable than for non-manipulable objects (Gerlach et al., 2002; Kellenbach et al., 2003). A number of studies with different brain activation techniques (fMRI, PET) have shown that the brain responds differently to tools compared to other objects which do not evoke actions, such as buildings, animals and faces (e.g., (Boronat et al., 2005; Chao and Martin, 2000; Creem-Regehr and Lee, 2005; Grèzes and Decety, 2002; Johnson-Frey, 2003;

Martin et al., 1996); for a review see (Martin, 2007)), and that the recall of actions associated with tools activates the left premotor cortex (Grafton et al., 1997). On the behavioural side, a variety of studies with compatibility paradigms have shown that the vision of objects activates a *motor simulation* and might even evoke overt reaching and grasping movements (Borghia, 2004; Borghia et al., 2007; Bub et al., 2003, 2008; Edwards et al., 2003; Fischer et al., 2008; Tipper et al., 2006; Tucker and Ellis, 1998, 2001; Vainio et al., 2008). Overall, both behavioural and brain imaging studies have shown that perceiving affordances activates in observers specific motor programs. This phenomenon can be interpreted as activation of a motor simulation, where ‘simulating’ means that the same sensorimotor systems that are activated during interaction with objects are activated off-line, during object observation, but without the execution of overt movements (Gallese, 2009; Jeannerod, 2006).

1.1. Affordances and motor simulations in rock climbing

Indoor rock climbing consists in reaching the top of a specially-designed wall, namely a climbing wall (see fig. 1, left), by grasping climbing holds with the hands and the feet. Climbing routes, which consist in carefully arranged sequences of climbing holds, vary in difficulties, depending on the slope of the climbing wall, the length of the route, as well as on the number, kind, and arrangement of the climbing holds. There are indeed countless artificial climbing holds that have been designed to be used in indoor rock climbing, which have different shapes, and afford different grip.

One common procedure for climbers, both during their training and during competitions, is simulating climbing routes before actually climbing them, especially when they have to

climb a route for the first time (see fig. 1, right). The simulation they build might include both information on specific affordances, i.e. the characteristics of the holds (shape, orientation, etc.), and information on their displacement, i.e. the way they are arranged on the climbing wall. Given that routes involve multiple climbing holds (see fig. 2), clearly any simulation of a part of the route changes the way the rest of the route is perceived. For example, simulating grasping a certain hold with the right hand makes some other holds affordable to be grasped with the left hand, and some other holds out of reach. At the same time, the necessity of reaching a certain ‘goal’ hold determine which holds are affordances retrospectively, and disrupts the affordances of some holds (e.g., far holds) in the climbing wall. For all these reasons, motor simulation in rock climbing should be considered an *affordance calculus* rather than a response to a sequence of individual affordances. Crucially, the motor competence of climbers also determines what constitutes an affordance. Experienced climbers can hold small holds that are difficult for weak climbers to grasp, and can simulate sequences of actions that are too complex to be picked up by novice climbers, much like how expert chess players ‘see’ complex strategies. In brief, not only expert climbers are better while climbing routes, but we hypothesize that they also understand them better, where understanding should be intended as proficiency in the affordance calculus.

1.2. Aims and hypotheses of the study

Our study addresses the role affordances play in the recall of routes by rock climbers. Although there is an increasing number of studies on how observing objects (or object pairs, e.g., Riddoch et al., 2003) activates the motor system, the role played by multiple

affordances for complex actions implying a sequence of movements has not been widely investigated. In addition, the majority of studies on simulation evoked by affordances do not take into account the observers' competence. An open issue in this field pertains to the extent to which affordances are elicited automatically, upon seeing objects, or are activated when a specific action goal is pursued. Studying recall in expert and novice climbers can contribute to showing to what extent the activation of affordances is modulated by observers' experience and competence. Finally, we still know very little on how affordances improve recall. Acquired motor skills offer a unique way to test this question.

In our study, novice and expert climbers were asked to observe and recall the position of holds of 3 routes that they never climbed: an easy route (ER), a difficult route (DR), and a (motorically) impossible but perceptually salient route (IPSR). We predicted that performance would not differ between the two groups for the ER because both groups would be able to perform a motor simulation. In addition, performance would not differ for the IPSR route, when for both groups it was impossible to form a motor simulation of climbing. If this is true, this would demonstrate that the simulation formed is a motor one, and would be activated only when participants have the motor competence necessary to perform the sequence of actions. Accordingly, the performance of experts should overcome that of non-experts in the DR, when the actions required to climb the route they are shown are part of their motor repertoire.

2. Materials and Methods

2.1. Participants

Participants were 18 climbers who attended to the “Lanciani Climb” arena (see fig. 1, left) in Rome¹. They all volunteered for research participation. Experts had between 5 and 10 years climbing experience, whereas novices had less than six months climbing experience. Experts and novices were balanced for gender (6 men and 3 women each group) and age. To balance the order in which the different routes were presented, as well as to avoid assigning the task to large groups, we divided the participants in 6 groups of 3 randomly selected participants: 3 groups composed by experts, and 3 by novices.

2.2. Materials

Two experimenters (both expert climbers) set up three novel routes (i.e., not known, partially or totally, to the participants) from a climbing wall containing 110 holds. Each route was composed of 10 holds (the typical average length for most training routes). Route difficulty depends on the configuration of the holds (their graspability²) and the configuration of the limbs in transition between the holds (Smyth and Waller, 1999). The Easy Route (ER) could be climbed without difficulty by both experts and novices because of the orientation and arrangement of the holds. Two further routes were set up. In order to control for

¹The participants recruited for this study were tested according to the ethical standards; human research subjects guidelines were followed. Each participant gave informed consent for the study.

²Note that in rock climbing there are several possible grips. Each hold has a specific grip, and climbers usually refer to numerous kinds of prehensions depending on how many fingers are used, what is the position of the fingers (plied or not), whether the thumb is used, what is the position of the hand (e.g., upward or downward), and so on. Therefore, the traditional distinction between precision grip and power grip is not enough here.

perceptual factors that might facilitate memorization, these two routes differed in perceptual salience. The Difficult Route (DR) was difficult to climb because the holds were not easily graspable due to their shape and orientation, and only expert climbers could benefit from their affordances. All holds in the ER and DR were grey- or dark-coloured and did not differ in size or other perceptual characteristics. The third route, (motorically) Impossible but Perceptually Salient Route (IPSR), was impossible to climb as a whole (but parts of it could be climbed). The difficulty of such route was not due to the fact that participants had to simulate biologically impossible movements (Costantini et al., 2005) but rather on the arrangement of the holds. Specifically, it was impossible to benefit from the affordances offered by the holds and to configure the limbs for a transition from one hold to the other³. To facilitate memorization, however, we rendered some of the holds perceptually salient: they were vividly coloured, compared to the standard grey- or dark-coloured holds.

2.3. Procedure

Two experimenters and the trainer were present in the Lanciani Climb arena. Before entering the arena, an experimenter read written instructions to each participant. “You will enter in the arena and your trainer will indicate twice a route composed of 10 holds. Try to memorize the route, as later you will have to perform an additional task.” Groups (of 3 participants) were then invited to enter and to sit in front of the climbing wall, which includes 110 holds with different size and orientation, placed uniformly to cover its entire surface. The trainer indicated twice the holds of each route with a stick. After this demonstration,

³Easy and Difficult routes had climbing grades 5c and 7b, respectively (French scale).

participants had to turn their backs to the wall and perform a distracting task, i.e. to pronounce the letters from A to L. The procedure was repeated three times, one for each different route. The presentation order of the routes (ER, DR and IPSR) was balanced across participants. Participants were given a folder containing three A3 sheets, each displaying a picture of the climbing wall (which included all the holds). After the first of the three routes had been shown, they were asked to extract the first sheet and to mark down as quickly as possible (with a time limit of 2 minutes) the sequence of holds composing the first route. The same procedure was repeated for the two remaining routes.

Participants were then required to fill in a post-experiment questionnaire in which they were asked to report (by responding yes or no) whether they mentally imaged climbing the wall while being shown the route and while recalling them, whether they believed that imagining the route might be helpful for them, and which route appeared to them the easiest to climb.

3. Results

All participants performed the task without difficulties, independent of their degree of expertise. The number of holds reported in a correct sequence for each route⁴ was computed for each participant, and submitted to a 3x2 mixed ANOVA with Route (ER, DR and IPSR) as within factor, Expertise (Expert vs. Novice) as between factor and participants as the random factor; see fig. 3. All analyses were conducted using a Type I error rate of .05.

⁴Note that we considered as valid only the holds that were reported in the right sequence, not just those belonging to the route. Due to the large number of climbing holds in the climbing wall, and to the 'design' of the routes, the task was difficult, as testified by our results (this was intentional, and necessary to obtain enough recall errors to analyze).

Expertise factor was not significant ($F(1, 16) = 1.35$; $MSe = 20.92$; $p = .26$), whereas Route factor was highly significant ($F(1, 32) = 15.45$; $MSe = 3.35$; $p < .0001$). Post-hoc Newman-Keuls showed this was due to the difference between the ER ($M = 6.44$) and the two other routes, DR and IPSR ($M = 3.72$; $M = 3.33$, respectively). As predicted, the ER led to a better performance compared to the two other routes, independently from the degree of expertise of participants. It is worth noting that the average number of remembered sequences was exactly the same for experts and novices ($M = 6.44$).

Crucially to our hypotheses, the interaction between Expertise and Route was significant ($F(1, 32) = 3.60$; $MSe = 3.35$; $p < .04$). Post-hoc Newman-Keuls confirmed that there was no difference between Novices and Experts on the Easy Route ($p = 1$). More importantly, the difference between Novices and Experts was not significant with the IPSR (Newman-Keuls, $p = .21$, respectively $M = 2.78$, $M = 3.89$), whereas the performance of Novices was significantly worse than that of Experts with the DR (Newman-Keuls, $p < .004$, respectively $M = 2.11$, $M = 5.33$). This suggests that the two groups did not differ in memory capabilities when for both of them it was impossible to mentally simulate the motor task, i.e. in the IPSR. This indicates that the impossibility to form a motor simulation clearly affects recall. The impact of motor simulation on recall is confirmed by results with the DR, where the difference between the two groups clearly emerged. Namely, in the DR, the capability to climb the wall was part of the experts' motor repertoire, thus they were able to build a motor simulation.

In the post-experimental questionnaire, Experts and Novices did not differ in responding

to whether they mentally imagined climbing the route while being shown it (5 out of 9 for both groups responded using imagination) and while recalling it (4 out of 9 for both groups responded positively). However, compared to novices, experts seem more aware of the effects of the simulation (2 out of 9 novices and 4 out of 9 experts reported that imagination helped), even though neither group seemed to believe that imaging was strategically important, as participants did not believe it helped them during recall (only 3 out of 9 athletes responded positively for both groups). Experts and Novices differed also in that Novices were less aware of the differences between the routes (5 out of 9 novices did not distinguish between them).

4. Discussion

Our results support the hypothesis that visually perceiving affordances leads to the activation of a motor simulation. More importantly, they clearly show that performing this simulation, the activation of which depends on climbers' motor competence, improved recall. Multiple results allow us to converge on this conclusion.

As predicted, we found that both experts and non-experts performed equally well with the Easy Route. This suggests that, when participants possess the motor competence allowing them to climb a given route, they simply simulate doing it, and this very fact improves their recall of the route. More importantly, our results allow us to understand what happens with difficult routes, that is when, for some reason, it is difficult or impossible to construe a simulation. Specifically, the design we used allow us to distinguish situations in which participants could rely on perceptual salience for memorization and situations in which only a subset of participants might build a motor simulation grounded on previous climbing

experience.

Notice that in this study we do not consider the specificity of the climbing method experts and non-experts adopt; we simply focus on different climbing competence. A few studies have addressed and demonstrated that experts and novices might use different patterns of action. Boschker et al. (2002) found that, differently from inexperienced climbers, experts focused on the functional aspects of a climbing wall, whereas they did not consider its structural features. Boschker and Bakker (2002) showed inexperienced climbers a video of a model climbing the expert way, the novice way, and a control video. They found that participants who were shown a video of expert climbers learned to use experts modes of climbing, such as arm crossing, and climbed faster and with more fluent movements than the others.

Overall, our results fit well in the embodied cognition (Glenberg, 1997) literature and have implications, concerning both the role of affordances for simulation and for recall, as well as the relationship between motor competence and the capability to form and use motor simulations. First, they indicate that a simulation is evoked only when the holds have perceptual characteristics and also afford actions. Namely, no simulation is activated when climbers observe holds which are perceptually salient (i.e. having vivid colors) but not useful for climbing the route, that is when the holds do not represent good affordances. This result helps to qualify the kind of simulation evoked: holds (affordances) elicit an embodied, motor simulation, not a purely visual simulation.

In addition, this finding helps us comprehend the mechanisms on which memory of action relies (see for example Daprati et al., 2005). Overall, our study suggests that the ability to

benefit from objects' (holds') characteristics and from their arrangement can help a climber form *motor chunks*, i.e. chunks based on sequences of real action possibilities, which, in turn, leads to better recall of a given route⁵. Memory performance is better when climbers are allowed to form motor chunks, not when they use memory strategies relying on the visual saliency of some holds. This finding is also compatible with the idea that motor simulations elicit procedural memories (see Pezzulo, in press, for a discussion).

Second, our results suggest that the activation of a motor simulation is possible only when performing a given sequence of actions is part of participants' motor competence. The better recall of Experts compared to Novices is totally due to the fact that, given that they were able to climb the difficult route, they could mentally simulate climbing (do the 'affordances calculus') and, with the help of the affordances, they were able to recall the sequence of required movements. Novices were impeded from simulating because they did not possess the motor capability to climb the Difficult Route. This suggests that the ability to simulate is modulated by previous motor experiences, in keeping with ideomotor theories of perception and action.

⁵We suggested the idea of *motor chunks* in analogy with a study by Chase and Simon (1973), which investigates how competence influences recall of chess positions in novice and expert chess players. Expert chess players outperformed novices in the recall of meaningful chess positions, but not in non-meaningful positions. The authors suggest that the experts' larger set of 'chunks' of chess positions permits them to recognize complex patterns as individual units and therefore to recall them better. Our study adopts a similar procedure, but focuses on motor competence rather than on abstract problems like chess. Although it is unclear to what extent the recall mechanisms are the same in the two domains (see Pezzulo and Castelfranchi, 2009 for a discussion), competence influences recall in both. One hypothesis, then, is that a similar *motor chunking* mechanism could be in play when actions are simulated by re-enacting motor processes. It is worth noting, however, that unlike chess players, climbers see the routes for the first time, and they never experienced the same configuration of holds. Rather than retrieving a fixed set of chunks, then, climbers have to build (or reassemble) chunks on the fly; therefore, the putative motor chunking mechanism should go hand in hand with motor planning rather than being a purely memory retrieval process. This view is consistent with Glenberg's 1997 idea that simulations can be *meshed* with (episodic) memories.

Differently from other sports, like dance, in rock climbing both the simulation elicited by action observation (of another rock climber) and the simulation elicited by affordances (simply observing a rock or climbing wall) can be studied. Therefore, our research extends also the results showing that a motor resonance phenomenon occurs when we observe others performing complex movements, such as dancing and playing basketball (e.g., Cross et al., 2006). This phenomenon has its neural basis in the mirror neuron system, which, differently from canonical neurons, are activated both during performance of an action (say, grasping, manipulating and holding objects), and during observation of others performing the same action (Gallese et al., 1996). In line with our results, this motor resonance is stronger when participants observe actors sharing their motor repertoire. In fMRI studies by Calvo-Merino et al. (2005), when capoeira dancers saw others dancing capoeira, their mirror neuron areas were more activated than when they observed classical ballet dancers. This effect was not due to dancers' higher familiarity with a kind of movement, but to a real motor simulation. In a control-study, Calvo-Merino et al. (2006) showed that the motor resonance effect was larger when classical ballet dancers observed movements performed by other classical ballet dancers of their own gender, even if sequences of movements of both genders were equally familiar to them. In the same vein, Aglioti et al. (2008) demonstrated with a psychophysical study that elite basketball players predicted the success of free shots at a basket earlier and better than expert observers and novice players. The experts' advantage was due mainly to their higher capability to predict by reading body kinematics in the early movement phases. A transcranial magnetic stimulation (TMS) study showed a time-specific motor activation

while observing videos of errors. The results of the combined physiological and TMS studies reveal that fine-grained motor resonance occurs after motor practice and that motor expertise specifically contributes to anticipating the actions of others.

Whereas the studies by Calvo-Merino et al. (2005, 2006) focus on the motor resonance generated while observing others performing an action, our research investigates the motor simulation elicited by multiple affordances that might help evoke and enhance previously developed sensorimotor association patterns. In addition, rather than investigating brain or behavioural responses to affordances, we analysed the impact of motor simulation induced by affordances on the memory of actions. Studying a special case, that of rock climbers, our behavioural study showed for the first time that multiple affordances activate a motor simulation, and that this strongly impacts recall, which is then modulated by participants' motor expertise and motor repertoire. Further studies are needed to better understand the neural underpinnings of the complex mechanisms of recall based on affordances and embodied simulation.

Our results could be explained in different ways. One alternative explanation is that experts might be better in fitting visual images of climbers' postures, and thus they could use visual imagery rather than motor simulations. Although our study cannot rule out this possibility, there are reasons to believe that this is not the case. First, while this hypothesis explains the advantage of experts in the DR, it does not explain the good performance of novices in the ER. To explain why novices are better in recalling the ER than the DR, one should say that visual imagery is specifically modulated by one's own (motoric) climbing

competence. Second, the exclusive use of visual imagery could hardly help solving our task. Namely, climbers experience the routes for the first time, and cannot see other climbers, so any visual simulation they build has to be done anew. However, spatial and configurational information (position of limbs in space) is not enough to determine which are the climbing positions one should remember, since valid climbing positions also depend on which affordances are offered by the holds, and which are the past and future movements. In other terms, although climbers could use visual imagery as part of their strategies, at least some of the processing required to recall climbing positions is better understood in motoric than purely visual terms.

Another possibility is that experts are more experienced with some patterns of holds, much like chess players are supposed to be. However, unlike chess players, climbers see the climbing routes for the first time, and there is an immense variety of combinations of holds, orientations, inclinations of the climbing walls, etc. Although the climbers could still pick up abstract similarities between old and new patterns of holds, our results indicate that this ability is competence-specific. This suggests that (at least part of) the ability to see novel patterns of holds as similar to old patterns consists in matching the current situation to one's own motor repertoire and current affordances, not (only) to spatial similarities. Again, although we could assume that recall of patterns could be part of the strategy, it is hard to imagine how such a highly specific and situated operation could be done in purely abstract terms, without accessing one's own motoric information. This is why we suggested that *motor chunks* should be built anew as part of the motor planning.

Before concluding, it is worth mentioning that several studies distinguish between two kinds of motor simulations: conscious and unconscious (see Jeannerod, 2006 for a discussion). Most of the afore-mentioned studies address unconscious motor simulations; in this context, the idea is that seeing a climbing wall automatically activates specific motor processes in climbers. There is, however, another kind of motor simulation, a conscious one, that can be performed by climbers, and is indeed routinely done as part of the athletes' training, and before the start of competitions (see fig. 1, right). Jeannerod (2006) suggests that the *representational content* of conscious and unconscious simulations are the same, with different time constraints determining their level of access (e.g., most unconscious motor images arise for the demands of immediate action and simply do not have the time to become conscious). In this study, the climbers were not explicitly instructed to mentally simulate. However, the procedure adopted in this study, and in the afore-mentioned ones, does not permit us to discriminate whether or not participants used a conscious strategy. Further studies are necessary to shed light on the differences between conscious and unconscious mental simulations, and their respective roles in motor planning.

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Figure 1: Left: (part of) the climbing wall of the “Lanciani Climb” arena, in which the experiments were conducted. The wall includes climbing holds of different forms and affording different grip (prehension depends also on where holds are placed on the climbing wall, and on their orientation). Right: athletes ‘studying’ a climbing route (not shown) before a competition. Note that some of them perform overt hand movements.

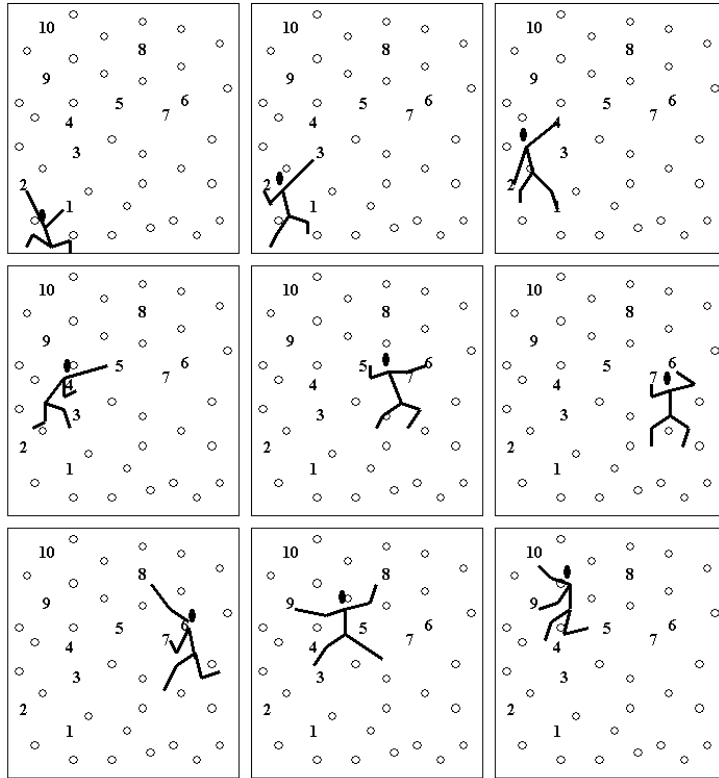


Figure 2: A sample sequence of 9 movements that compose a climbing route (from top-left to bottom-right corner). Each frame shows one movement, from the starting hold (1) to the final hold (10). Holds belonging to the sequence are numbered (1-10); holds for feet are not shown. Circles represent climbing holds that do not belong to the route. The holds' affordances are not shown, but consider that each hold can only be grasped in certain ways; for example, with only two fingers of the left hand. Note that the sequence of holds is not particularly meaningful or salient on a purely perceptual basis. Instead, it becomes much more significant in motor terms, or when the (simulated) climbing movements become part of the route representation. Note also that this sample climbing route is not composed of a simple sequence of right-hand and left-hand movements. For example, in both frames 2 and 3 the climber uses the right hand to reach holds 3 and 4, respectively. In many cases, a longer sequence (2-3-4) is preferred to a shorter one (2-4) if the movement required by the shorter sequence (2-4) is too difficult.

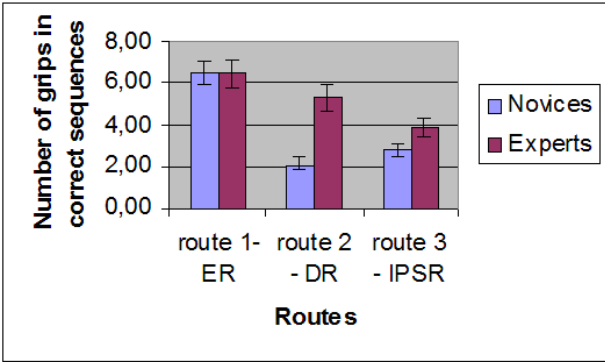


Figure 3: Results of the task. Number of grips in the correct sequences for each route (Easy Route, ER, Difficult Route, DR, Impossible but Perceptually Salient Route, IPSR).