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The role of action in perceiving and comparing functional relations

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Abstract

There is growing evidence that even the most abstract capacities of human cognition are not entirely amodal and disembodied. The present study presents two empirical studies which aim to demonstrate that relational reasoning is grounded in our sensory-motor experience. Experiment 1 shows that the affordances of tool-like objects have an effect on comparing functional relations. Experiment 2 makes sure that this finding can not be explained by an automatic activation of motor systems. The results are interpreted as evidence that at least certain functional relations are perceived by simulating interactions with the environment. It is also asserted that the process of comparing such relations is constrained by the properties of the human body such as hand-dominance.

Keywords: relations, situated cognition, embodiment, action, simulation, analogy

Introduction

Imagine you are asked to compare the relation between an axe and a wooden log with the relation between a meat chopper and a piece of meat. One way to solve this problem is to find out what relation holds in the first pair of objects, turn it into propositional form (e.g. 'is used to cut(axe, wood)'), do the same for the second pair of objects and than compare the two symbolic structures. This is what many models of relational reasoning do (Gentner, 1983; Falkenhainer*,* Forbus*, &* Gentner*,* 1989). Some models can also establish a correspondence between distinct relational symbols by measuring their semantic similarity (Holyoak & Thagard, 1989; Kokinov, 1994; Hummel & Holyoak, 1997, 2003). However all these models do not address the problem of where the relational meaning comes from (how the propositions are encoded) and they all assume that the process of comparing relations is amodal and disembodied in nature.

On the other hand, there is plenty of evidence that human cognition is inherently modal and constrained by the characteristics of the human body (Glenberg, 1997; Barsalou, 1999; 2008; Lakoff, 1999; Fisher & Zwaan, 2008). For example, it has been shown that the perception of a graspable object immediately activates a potential motor interaction with this object, even when it is task-irrelevant (Tucker & Ellis, 1998, 2004; Beauchamp, Lee, Haxby & Martin, 2002; Beauchamp & Martin, 2007; Buccino, Sato, Cattaneo, Rodà & Riggio, 2009). Proponents of the embodiment theory claim that this phenomenon is not a mere side effect of spreading activation, but that motor programs are part of the representation of objects. These motor programs are used to simulate potential interactions with an object and determine its function.

Similarly, the perception of a functional relation between two objects should require a mental simulation of the relevant interactions with the objects. For example, in order to comprehend the functional relation between an axe and a piece of wood, you would simulate grasping the axe and chopping the wood with it. And in order to compare two instances of functional relations you have to be able to compare the motor dynamics resulting from simulating the actions involved in each of the relations. Such an approach is justified by the study of Klatzky, Pellegrino, McClosky & Lederman (1993), which found that there is remarkable consistency in people's knowledge about the movements underlying functional interactions with objects. There is also evidence that sometimes people consciously try to detect the perceptual motor similarities of different situations in order to evaluate how analogous they are (Clement, 2009).

Figure 1: An example of the stimuli used by V&K. Participants had to compare the relation between the objects in the left part with the relation in the right part of the screen. The affordances of the objects were manipulated by making them easier to be grasped with the left or with the right hand. In this example, both affordances are right.

Recently, Vankov & Kokinov (2009) (henceforth V&K) proposed a model of grounding relational meaning in simulated interactions with the environment. According to the model, the motor dynamics resulting from these interactions is used not only to comprehend relations, but also to solve the role-filler binding problem (Hummel, 1999). The model makes two major predictions. First, it predicts relation-specific motor effects when relations are perceived, even if the task does not involve any motor activity. The second prediction is that relations are compared most efficiently when it is possible to simulate the underlying interactions simultaneously or in close temporal proximity.

V&K reported an experiment which managed to provide support for both hypotheses. Participants were asked to compare the functional relations in two pairs of objects (Figure 1) by giving a verbal response – pronouncing 'yes' or 'no'. An effect of the affordances of the objects was found. Right-handed participants' response times were faster when the objects in the relation on the left were displayed in such a way, that it was easier to manipulate them with the left hand. The effect of the affordance of the object on the right was reversed in direction and much smaller in size. The very fact that an affordance effect was found is in support of the hypothesis that perceiving relations involves simulating actions. The bigger size of the effect of the affordance which was closer to the subjects' non-dominant hand implied that subjects tried to simultaneously simulate the actions involved in the two relations. A control study ruled out the possibility that this result was due to the mere perception of objects with varying affordances. However it is still possible the effect was due to presenting the two relations at once. Another valid point is that the overall reaction time could have been affected mostly by the affordance of the relation displayed near the subjects' non-dominant hand because it was harder to be simulated. Also the design of the experiment did not allow to control the sequence in which the subjects look at the two relations. Therefore it is possible that the effect of the relation which had been attended last was different (bigger or lesser) from the other one. A new experiment was designed and conducted in order to overcome these problems.

Experiment 1

The experiment used the same stimuli as V&K, but the relations were displayed one by one in the center of the screen in order to control the order in which they were perceived and isolate the effect of the presentation location.

The elimination of the factor of the presentation location served to set apart the effect of the affordances of the stimuli from any spatial compatibility effects. It is well known that people respond faster to stimuli which location is compatible to the response action (Simon & Rudell, 1967). Although the response action in V&K was verbal, it is possible that subjects' reaction times had been affected by the congruence of the presentation location and the affordances of the stimuli. For example, an interaction between objects with a left affordance could be easier to be simulated with the right hand if they are displayed in the right part of the screen.

The new design also allowed testing the effect of a stimulus – the relation which was presented first – which had to be retrieved from memory at the time of the comparison. If any affordance effect was found for the first relation, it would seriously question any disembodied view on relational comparison which assumes that relations are first encoded as symbols and then compared.

However, according to embodied view on relational reasoning, there must be an effect of both affordances because the sensory-motor dynamics of both relations is needed at the time of comparison. Moreover, the embodied view predicts that relations will be compared more efficiently when the underlying interactions with environment could be simulated in close temporal proximity. Therefore it is predicted that subjects will be faster when the affordances differ and they can employ both their hands in the simulations.

Method

Participants 36 right-handed participants (20 females) took part in the experiment for course credit or as volunteers. Their average age was 24.06 years (age range from 18 to 53, *SD* = 5.91).

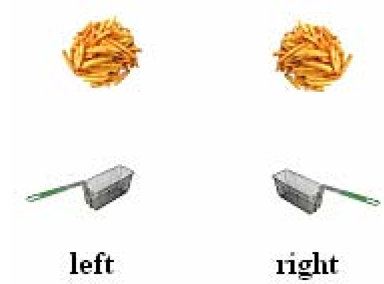

Figure 2a: A left and a right affordance of a pair of objects which make a functional relation.

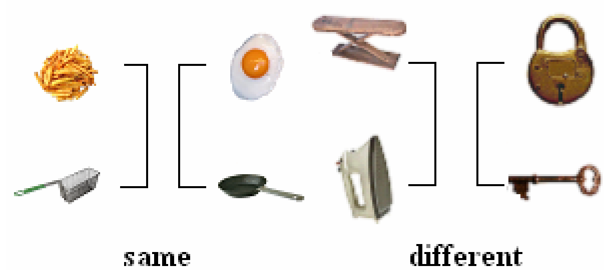

Figure 2b: Examples of the stimuli used in 'same' and 'different' trials.

Stimuli The stimulus set was the same one that was used in V&K. It consisted of 144 photos of various household objects. Each stimulus consisted of two pairs of objects. The objects in each pair participated in a certain functional relation, such as 'hammer' – 'nail', 'key' – 'lock', 'fork' – 'spaghetti', etc. In all pairs, it was possible to manipulate the affordance so that the interaction between the objects could be performed easier either with the left or the right hand

(Figure 2a). The relations in the two pairs were the same in half of the stimuli ('same' trials) and different in the others ('different' trials). A pre-test study was used to organize the objects pairs in such a way that there was maximal agreement among people whether the relations were same or different (Figure 2b). All images were resized to 400x400 pixels. In all pairs there was one tool-like, graspable object (axe, hammer, ironer, fork, etc) and it was always located at the bottom position.

Design The experiment had a 2x2 within subject design. The two independent variables were:

First affordance – left or right, depending on the affordance of the first pair of objects.

Second affordance – left or right, depending on the affordance of the second pair of objects.

The dependent variable was the reaction time of participants' verbal responses ('yes'/'no').

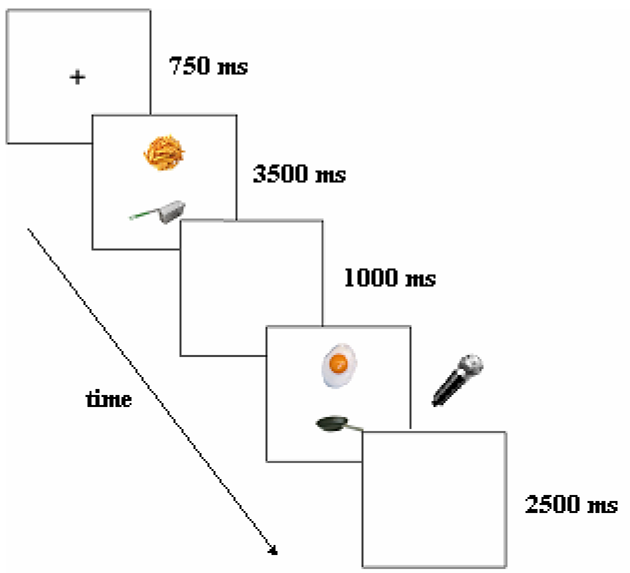

Figure 3: Experimental procedure. Reaction time was measured from the onset of the second relation until a verbal response was given.

Procedure Each stimulus was presented once to each subject. Affordance conditions and the order of presentation of the relations (first or second) were counterbalanced across subjects and it was made sure that the same combination of the affordance factors would not repeat more than 3 times in a row. Same/different trials were pseudo-randomized, so that a given correct response would not repeat more than 3 times. The trial sequence was fixed for all subjects, i.e. they saw the stimuli in the same order.

Participants were tested in a sound-proof booth. The stimuli were presented on 19" computer monitor with a resolution of 1280x1024 pixels. Before the actual experiment all participants went through a microphone training session in order to make sure that they would articulate their responses clearly enough. The experimental session started with 8 practice trials, none of which appeared in the experimental part. Each trial began with a centrally location fixation cross (750ms), followed by the onset of the first pair of objects. The objects were displayed one below the other in the centre of the screen. Subjects were instructed to perceive the relation between the objects without making any response. The first pair of objects was presented for 3500 ms and when it disappeared the screen stayed blank for 1000 ms. After that a second pair of objects was presented at the same position as the first one. The stimuli stayed on the screen for 5000ms or until a response was generated. Participants were instructed to respond by saying 'yes' if the relation between the objects in the second pair was the same as in the first pair and say 'no' otherwise. The subject's response time (RT) was measured since the onset of the second pair of objects till the moment a verbal response was detected. Stimulus presentation and response recordings were controlled by E-prime software (Schneider, Eschman, & Zuccolotto, 2002). The inter-trial interval was 2500 ms. The experiment took about 10 minutes. The total number of test trials for each subject was 36, including 18 'same' and 18 'different' trials.

Results

Trials in which subjects failed to respond or the response was incorrect were excluded from the analysis. An incorrect response was counted when a subject said 'yes' in a 'different' trial or 'no' in a 'same' trial. RT lying more than ±2.0 standard deviations from the mean 'same' and 'different' RT times were also removed. Thus a total of 82.10% of the originally collected RT data were included in the analysis.

Same and different trials were analysed separately. A 2x2 repeated measures ANOVA was performed on subject RT means in 'same' trials (Figure 4) and revealed a significant main effect of the affordance of the first relation ($F(1, 35) = 7.12$, $p < .05$, $\eta^2 = .17$). There was no effect of the affordance of the second relation ($F(1, 35) = 2.02$, $p = .16$, $\eta^2 = .06$). The interaction between the two affordance factors was not significant ($F(1, 35) = .20$, $p = .66$, $\eta^2 = .01$).

An analysis of mean item response times also found a main effect of the first affordance of 'same' items ($F(1, 17) = 9.05$, $p < .01$, $\eta^2 = .35$). The effect of the second affordance ($F(1, 17) = 2.69$, $p = .12$, $\eta^2 = .14$) and the interaction ($F(1, 17) = 2.15$, $p = .16$, $\eta^2 = .11$) were not significant .

Analyses of 'different' trials and items revealed similar patterns of results, but none of the effects reached significance.

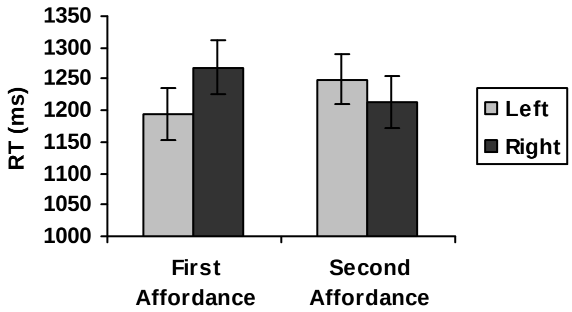

Figure 4: Experiment 1 results for same trials. Subjects' responses were significantly faster when the affordance of the first relation was left although all subjects were right-handed. The tendency for the affordance of the second relation was reversed. Error bars represent standard errors.

Discussion

The results replicated the findings of V&K (2009) as long as an effect of left/right affordances on comparing functional relations was found. Also, the shortest reaction times were in the condition when one of the affordances was left and the other one was right. Another similarity was that the effect size of the first affordance effect was bigger than the effect size of the second affordance.

The major result of Experiment 1 was that the subjects, all of which were right-handed, were faster to respond when the first affordance was left. This result can not be explained by presentation location as all stimuli were presented in the center of the screen. At first glance, there is no reasonable explanation why participants would be faster when one of the stimuli is easier to process by their non-dominant hand. However the results start to seem logical if we assume that subjects tried to run the two simulations of functional interactions simultaneously in order to compare the resulting motor dynamics. It is reasonable to assume that subjects always engaged their dominant right hand in simulating the functional interactions of the visually available second relation, event when the affordance of the objects was congruent to their left hand. Thus, when they had to compare the two relations by running two simulations at once they could use only their non-dominant hand for recalling and simulating the first relation.

The pattern of results of Experiment 1 is inconsistent with any classical encode-and-compare account. If relations are first turned into propositions and then compared, then there would not be any effect of the first affordance. The first relation would have already been encoded by the time the second relation is presented and the response is given. If the effect is due just to the activation of the visual image of the first relation then the direction of affordance effect should be the same for both relations. Yet, we conducted a control study to make sure that main results of Experiment 1 are specific to the relation comparison task.

Experiment 2

Several researchers have shown that mere looking at manipulable objects activates regions of the brain related to action (Beauchamp et al., 2002; Beauchamp & Martin, 2007; Buccino et al., 2009). The goal of this experiment was to make sure that the main findings of Experiment 1 are not due to such kind of automatic motor activation. In particular we wanted to check whether if two objects with varying affordances are presented sequentially and the task is to compare them for some reason, the reaction times will be shorter when the affordance of first object is congruent with the non-dominant hand of the subjects.

Method

Participants 24 right-handed participants (17 females) took part in the experiment for course credit or as volunteers. Their average age was 22.79 years (age range from 17 to 32, *SD* = 3.13).

Stimuli The target stimuli set consisted of the manipulable tool-like objects which used in the 'same' trials of Experiment 1. Each target stimulus consisted of two such objects (Figure 5). Objects were paired in the same way as they were in the previous experiment. There were 18 target trials. An equal number of fillers were compiled using 18 photos of man-made objects, none of which was used in the target trials, and 18 photos of natural objects (fruits, plants, rocks, etc).

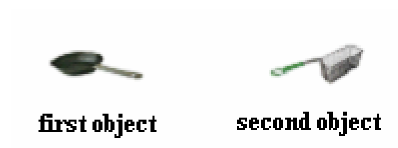

Figure 5a: An example of a target stimulus used in Experiment 2. Both objects are artifacts, so the subjects should respond by saying 'Yes'.

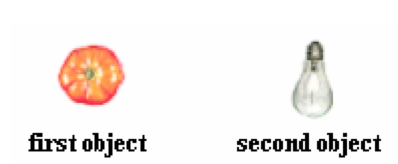

Figure 5b: An example of a filler. The correct response is 'No' as one of the objects is of natural origin. Either of the objects could be a natural one.

Design The design was identical to Experiment 1. The affordances of the objects were described by two independent variables – 'first affordance' and 'second affordance'.

Procedure The setting of the experiment was similar to Experiment 1 except for the task. Each trial began by a fixation cross (750 ms), followed by the presentation of the first object (2000ms). After that, the screen stayed blank for 1000 ms and the second object was presented. Subjects were instructed to say ‘yes’ if none of the objects was of natural origin and say ‘no’ otherwise. Response time was recorded since the onset of the second object. All objects were displayed in the center of the screen. The order of presentation of the objects and the affordance conditions were counter-balanced across subjects.

Results

Fillers and trials with invalid or incorrect responses were excluded from the analysis. Response times lying more than ±2.0 standard deviations from the mean RT time were removed. Thus a total of 92.40% of the originally collected non-filler RT data were included in further analysis.

A 2x2 repeated measures ANOVA was performed on subject means. It revealed main effects of the first ($F(1, 23) = 5.18$, $p < .05$, $\eta^2 = .18$) and the second object affordance ($F(1, 23) = 5.36$, $p < .05$, $\eta^2 = .19$). The interaction was not significant ($F(1, 23) = 0.22$, $p = .64$, $\eta^2 = .01$). Response times were faster when the affordances of both objects were right (Figure 6).

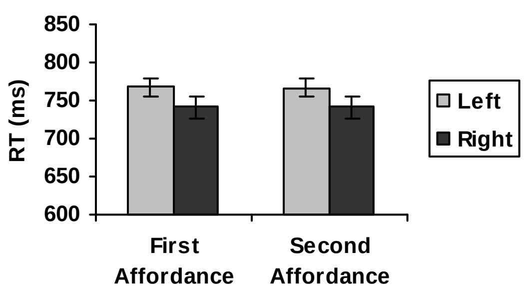

Figure 6: Results for trials with objects which were part of ‘same’ items in Experiment 1. Subjects were significantly faster when both objects were presented in such a way, that they were easier to be grasped with the right hand. Error bars represent standard errors.

Discussion

Experiment 2 showed that the main findings of Experiment 1 can not be explained by the automatic activation of motor programs by object affordances. Response times were shorter when the affordances of *both* objects were congruent to the subjects’ dominant hand. Also, there was no difference between the sizes of the effects of the first and the second affordance. These results are different from what was found in the previous experiment and they show that the results of Experiment 1 are specific to the relation comparison process.

General Discussion

The presented experiments provide further evidence in support of the hypothesis that the meaning of functional relations is grounded in the sensory-motor dynamics resulting from simulated interactions with the environment. The pattern of results is also consistent with the idea that comparing functional relations involves running two or more such simulations simultaneously or in close temporal proximity. The outcome of Experiment 2 rules out the possibility that the results were due to the object affordances per se.

The experiments were designed not to rely on the stimulus-response compatibility paradigm, unlike most other behavior studies of affordances (for instance Tucker & Ellis 1997, 2004; Spivey, Richardson & Cheung, 2001). In this way it was made sure that the results could not be attributed to accidental spreading of activation from conceptual to motor areas of the brain (Mahon & Caramazza, 2009). If the activation of motor areas was just a side effect it would not have had any effect on verbal responses as the motor areas dedicated to hand manipulations and language production are unlikely to be systematically connected. Informal debriefing after the experiments showed that subjects were completely unaware that the task had anything to do with their hands and simulations of actions.

The outcomes of the experiments are clearly in support of an embodied view on cognition. However one may attempt to interpret the results of Experiment 1 without adopting the specific idea of embodying relational representations and relational reasoning by referring to the theory of event coding (Hommel, Müsseler, Aschersleben & Prinz, 2001). According to this theory, elements of perception and action are encoded in a common medium. When the stimulus features related to perception and action are active for a long time period they become bound into an event file. Once bound, these features are less available for planning of other actions. Hence it is possible that a right affordance of the first pair of objects would bind the features representing the right hand of the subject to the stimulus features of the first relation. When the second relation is presented, the right hand of the subject would be less available for simulating the use of the presented objects and the response would be delayed. A result of this kind has been reported by Spivey, Richardson & Cheung (2001). Such an explanation reduces the role of simulated action to the process of object recognition.

However, the theory of event coding contradicts the results of the control study, unless it is assumed that the presentations times were too short for the event filing to happen. Such an assumption is highly unlikely to be true, as in the control study the first object was presented for a fixed period of 2000ms, followed by a 1000 ms inter-stimulus interval before the second object was displayed. This period is much longer than the time which was required for suppression of future actions in the studies of Spivey, Richardson & Cheing (2001) and Stoet & Hommel (1999). Also, there is no evidence so far that such a phenomenon could occur outside the stimulus-response compatibility paradigm and have an effect on verbal reaction time. Hence, the event filing explanation can not adequately account for the results presented in this paper.

The results of the present study are broadly consistent with the 'body-specificity hypothesis' (Casasanto, 2009), according to which 'people who interact with their physical environments in systematically different ways should form correspondingly different mental representations'. We demonstrated that an asymmetry of our bodies, such as hand dominance, constrains performance in a task which is traditionally thought to be highly symbolic and abstract in nature. It remains however an open question to what extent abstract concepts and reasoning abilities are dependent on our bodies and whether such constraints are the only source of meaning.

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