

Embodied Comparison of Functional Relations

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Abstract

The current study extends previous work of our group which aims to show that the comparison of functional relations is carried out by running dual perceptual-motor simulations. To this end, we present an experiment which tests the hypothesis that the asymmetries of human bodies may constrain performance in a relation comparison task. Participants were asked to compare functional relations between graspable objects while bearing sports weights on their wrists. The results of the experiment support the hypothesis. The fact that a manipulation of the participants' bodies may affect performance in a purely conceptual task is pointed out as strong evidence in support of the embodied cognition approach.

Keywords: embodiment; relations, perceptual-motor simulations

Introduction

Embodiment is a collective term encompassing a variety of approaches to understanding cognition which investigate the role of the body in shaping the mind (Wilson, 2002). The embodied theories of cognition contrast traditional views which construe cognition as abstract information processing, disconnected from the outside world and independent of the physical characteristics of the system (a human body or a computer machine) which hosts the mind. Such disembodied views of cognition regard action and perception as peripheral processes which play no role in higher level cognitive functions. It is assumed that the mental representations and reasoning processes which constitute intelligence can be successfully approximated by abstract symbols and symbolic operations (Newell & Simon, 1976).

The symbolic view of cognition dominated the earlier years of cognitive science. There were however several lines of research which adopted a radically different stance by emphasizing the role of sensory and motor functions in higher cognition. The origins of modern theories of embodied cognition could be traced back to, among others, the development psychology of Jean Piaget (1952), according to which human cognitive abilities emerge from sensorimotor experience; the ecological approach to visual perception of James Gibson (1979) which emphasized on the relation between perception and action; the theory of grounding abstract concepts in bodily states by means of metaphors (Lakoff & Johnson, 1980); the behavior robotics

of Rodney Brooks (1991) which demonstrated that intelligent behavior could emerge from interactions with the world. All these lines of research headed towards the idea that human cognition is grounded in the continuous interplay of action and perception and constrained by the properties of the body and the outside world.

The accumulating evidence in support of the pivotal role of perception and action on cognition and the failure of the classical symbolic approach to solve a number of theoretical and practical problems led to the proliferation of new theories and models of embodied cognition (Wilson, 2002). One of the most influential ones is the theory of Perceptual Symbol Systems (PSS) proposed by Barsalou (1999). The central claim of the PSS theory is that the concepts are grounded in perceptual-motor simulations. According to Barsalou, concepts are represented by 'simulators' – association areas in the brain which are able to reenact patterns of perceptual and motor activation. One of the implications of PSS theory is that any conceptual processing, irrespective of how abstract it is, requires the activation of the perceptual and the motor systems of the human body. This prediction has been successfully tested in various cognitive domains including, among others: conceptual organization (Goldstone & Barsalou, 1998), language (Fisher & Zwaan, 2007), memory (Glenberg, 2000), decision-making (McKinstry & Spivey 2008), mathematical reasoning (Landy & Goldstone, 2009), problem-solving (Grant & Spivey, 2003; Thomas & Lleras, 2007), emotions (Niedenthal, Barsalou, Ric & Krauth-Gruber, 2005), creative cognition (Friedma & Förster, 2002), social cognition (Barsalou, Niedenthal, Barbey & Ruppert, 2003).

Although a vast body of research has been devoted to finding empiric evidence in support of the hypothesis that conceptual knowledge is grounded in perceptual-motor interactions, a very little part of it has been directed to relational representations and processes. This is not surprising, given that relational reasoning is traditionally thought to be one of the most abstract and disembodied cognitive abilities. Recent findings however suggest that there at least certain forms of relational reasoning are embodied.

Yoon, Humphreys & Riddoch (2010) reported a series of experiments in which right-handed participants were presented with functionally paired objects and asked to judge whether the objects are typically used together. It was

found that participants responded faster when the paired object were presented in standard co-locations for right-handed actions relative to when they appeared in reflected locations. The results suggest that people simulate interactions with the objects in order to discover a functional relation between them. This result is consistent with findings showing that people detect faster and more accurately paired objects which location of presentation invites functional interactions with other objects (Riddoch, Humphreys, Edwards, Baker & Willson, 2003; Green & Hummel, 2006).

In a series of experiments, Vankov and Kokinov (2009, 2010) provided evidence that the embodiment of functional relations is not limited to their encoding and recognition. We asked participants to compare the functional relations in two pairs of objects (Figure 1) and found that response times were shorter when the orientation of the objects afforded simultaneous manipulation. Additional control studies showed that this effect is specific to the relation comparison task and can not be attributed to the mere perception of objects with varying affordances.



Figure 1: An example of the stimuli used by Vankov & Kokinov (2009). 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.

Dual Simulations

The findings of Vankov and Kokinov (2009, 2010) can be explained by assuming that the comparison of functional relations involves running dual perceptual-motor simulations. Performance was facilitated when participants were able to simulate the functional underlying the two relations simultaneously or in close temporal proximity. Although a dual simulation is probably more demanding in terms of cognitive resources, such as attention and executive control, its advantage relative to running two consecutive perceptual-motor simulations is in reducing the overall simulation time.

Another advantage of running dual simulations in order to compare functional relations is that it makes it possible to compare not only the final outcomes of the two simulations (i.e. the encoded relational symbols) but also the intermediate states. In this view, the comparison of functional relations is not a purely symbolic operation

which compares two relational symbols, but a continuous process involving mapping perceptual, motor and symbolic representations. Such a mechanism 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. The actions involved in the representations of two instances of a functional relation need not necessary be the same, but if they are, the reasoner would benefit from being able to compare them. A similar idea has been advocated by Clement (2009) who observed that sometimes people consciously try to detect the perceptual motor similarities of different situations in order to evaluate how analogous they are.

In order to compare the intermediate perceptual and motor states of two simulations, one needs to be able to *dynamically align* the execution of the two simulations. Dynamical aligning means that corresponding states of the two simulations should occur in approximately the same moments. The effect of dynamical aligning would be particularly strong if the simulations have perceptual and motor commonalities.

The idea of dynamically aligning simulations of functional interactions in order to outline their perceptual and motor similarities has several consequences. For instance, it entails that people will perform better when comparing relations involving actions which can easily be coordinated. Another prediction is that an asymmetry of the human body, such as hand dominance, would have an effect on comparing relations to the extent that more pronounced hand dominance would impede the dynamic aligning of simulated actions which involve using both hands.

A closer look at the studies of Vankov & Kokinov (2009, 2010) reveals that the pattern of results is consistent with the hypothesis that hand dominance may constrain relation comparison. In both relation comparison experiments, the size of the effect of the affordance manipulation was bigger at the participants' non-dominant hand side. The reverse was found when the task was changed to object recognition. We conducted another experiment in order to test the effect of hand dominance on relation comparison in a more explicit way.

Experiment

The goal of the experiment was to show that the process of relation comparison is embodied and that the asymmetries of the human body may constrain its performance. To this end, we decided to directly induce such asymmetries by attaching weights to the arms of the subjects. Previous studies have shown that similar manipulations of the human body may have an effect on conceptual processing (Bhalla & Proffitt (1999); Proffitt, Stefanucci, Banton & Epstein, 2003; Ramenzoni, Riley, Shockley, & Davis, 2008). The prediction which was specific to this experiment was that the participants would respond faster when the manipulations of their body was symmetric. The rationale was that if people try to use both

their hands for dual simulation, then an asymmetric manipulation would make the dynamic alignment of the two simulations more difficult and it will result in slower response times.

Method

Participants Sixty four right-handed participants (32 females) took part in the experiment for course credit or as volunteers. Their average age was 23.83 years (age range from 18 to 55, SD = 5.17).



Figure 2: Examples of the stimuli used in 'analogous' (left) and 'non-analogous' (right) trials.

Materials The stimulus set was the same one that was used in Vankov & Kokinov (2009, 2010). 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. The affordances objects were not manipulated and matched the presentation location (Figure 2).

The relations in the two pairs were the same in half of the stimuli ('analogous' trials) and different in the 'non-analogous' 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. 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 There were two independent variables. The trial type factor indicated whether the relations in given trial were analogous or not ('analogous'/'non-analogous'). The weights factor had four levels:

L – The weight was attached to the left wrist of the subject.

R – The weight was attached to the right wrist of the subject.

LR – There were weights attached to both wrists of the subject.

No – There were no weights on the subject's wrists.

The design of the experiment was between-subject - each subject participated in one experimental condition only. The dependent variable was speeded vocal response time.



Figure 3: The sports weights¹ which were attached to subjects' wrists.

Procedure At the beginning of the experiment each subject was assigned to one of the four experimental conditions. Subjects were then instructed how to attach the weight(s) to their wrists(s) (except for the 'No' condition in which no weight was attached). The weights were textile strips full of heavy material (Figure 3). Each of them weighted 500g. The weights were firmly attached to subjects' wrists so that the subjects were able to move freely their arms.

The subjects were seated in front of computer with a 17" touch screen display and asked to play with it for a while in order to see how it works. The experimenter asked them to open a calculator application by using the touch screen display and perform a series of ten predefined arithmetic operations such as addition and multiplication of numbers. All subjects performed half of the operations with their left hand and the rest with their right hand.

When the familiarization with the touch screen display was completed the experiment continued with a microphone training session in order to make sure that participants articulate their responses clearly enough. During the training session, they were presented with two simple geometric shapes (squares, triangles, stars, etc) and were asked to respond by saying 'yes' if the two shapes were identical and pronounce 'no' otherwise. If the experimental program was unable to detect the response, it warned the participant to respond louder and more clearly. All participants went through 20 such microphone training trials and were not admitted to do the rest of the experiment unless they had completed successfully at least 85% of them.

The real experimental session started with eight practice trials, none of which appeared in the experimental part. Each stimulus was presented once to each subject. The locations of presentation were counterbalanced across subjects. For example, half of the subjects saw the 'axe-log' relation presented in the left part of the screen and the other half saw it in the right part of the screen. The sequence of

¹http://www.alibaba.com/product-gs/286216239/for_Nintendo_Wii_Fit_Ankle_Wrist_Weights.html

target and filler trials was pseudo-randomized. The stimuli were presented in the same order to all subjects.

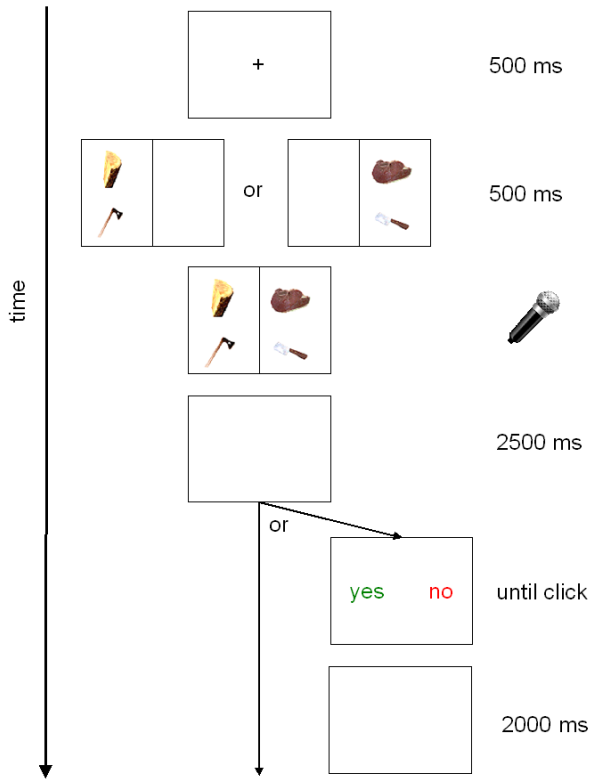


Figure 4: Experimental procedure. One of the relations was displayed 500 ms before the other. After some of the trials the subjects were asked to reconfirm their response by clicking on the corresponding word. They were told to use their left hand when the word they wanted to click was in the left part of the screen and use their right hand if they wanted to select the word to the right.

Each test trial began with a centrally location fixation cross (300ms), followed by the stimulus onset. The stimulus stayed on the screen for 5000ms or until a response was generated. In order to control for the order in which the subject look at the relations, the onset of one of the relations was delayed for 500ms. The order of presentation of relations was counter-balanced across subjects (for a given subject either the left or the right pair objects always appeared first). Response time was measured from the onset of the delayed relation.

Participants responded by saying ‘yes’ or ‘no’. The inter-trial interval was 2500 ms. There was an additional task after one fourth of the trials (selected randomly). The additional task required the participants to reconfirm their response by pointing to the touch screen display and clicking on the ‘yes’ or ‘no’ words (Figure 4). This part of the procedure was introduced in order to keep the subjects aware of the weights attached to their wrists.

Stimulus presentation and response recordings were controlled by E-prime software (E-prime Psychology Software Tools Inc.; Pittsburgh, USA). The experimenter stayed with the subjects during the experiment and marked the response to each trial during the inter-trial interval. The experimenter also marked invalid trials in which the subject fail to articulate their response clearly. The experiment took about 15 minutes.

Results

Six subjects had more than 60% incorrect responses and their data were not analyzed. Trials in which the remaining 58 subjects failed to articulate their response clearly (13.60% of the data) or responded incorrectly (6.60%) were not analyzed. Thus, a total of 79.80% of the originally collected response times were considered for further analysis.

Weight	Trial type	RT _{norm}
	Non-Analogous	2.04 ± 0.34
	Analogous	1.59 ± 0.34
	Non-Analogous	2.03 ± 0.39
	Analogous	1.72 ± 0.39
	Non-Analogous	2.6 ± 0.35
	Analogous	1.99 ± 0.35
	Non-Analogous	1.91 ± 0.35
	Analogous	1.62 ± 0.35

Table 1: Median subject normalized response times and confidence intervals obtained in the eight experimental conditions.

The design of this experiment was between-subject. This was a problem as response times are subject to individual differences. In order in attempt to rule out the possibility that any effects found are due to individual differences, we searched for a way to normalize subjects’ response times.

The procedure of the experiment required all participants to go through a microphone training section in order to make sure that they articulate their responses clearly enough. During the microphone training session the subjects had to respond whether two shapes are the same by saying

‘yes’ or ‘no’. These responses were recorded and we were able to calculate the mean response time in the microphone training section for each subject. This value indicated how quickly a subject responds in a task which was not supposed to involve any perceptual-motor simulations. Hence the mean subjects’ response time in the microphone session could serve as a baseline.

In order to normalize the response times of a subject in the actual experiment we divided them by the mean subject’s RT from the microphone training session. In this way, we created a new dependent variable – normalized response time (RT_{norm}) –which allowed us to set apart the effects of the experimental conditions from the individual differences between participants.

Table 1 presents the subject normalized response time means data in each of the eight experimental conditions. People responded fastest in the LR and No conditions.

A 2x4 univariate ANOVA analysis of subject median RT_{norm} s revealed significant main effects of trial type ($F(1, 108) = 10.69, p < .01, \eta = .09$) and weights ($F(3, 108) = 3.73, p < .05, \eta = .09$). The interaction was not significant ($F(3, 108) = .34, p = .80, \eta = .01$). The results are presented in Figure 5. A set of Tukey HSD post-hoc tests revealed significant differences between conditions L and No ($p < .05$) and between L and LR ($p < 0.05$).

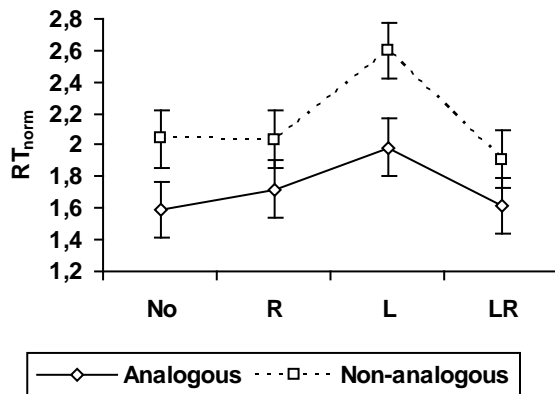


Figure 5: Median subject normalized response times. The longest response times occurred when a single weight was attached to the left wrist of the subjects (all subjects were right-handed). Error bars represent standard errors.

The major prediction that this experiment had to test was that people would respond faster when they their bodies were manipulated symmetrically. So we ran a contrast test which compared conditions the asymmetric conditions ‘L’ and ‘R’ against the symmetric conditions ‘LR’ and ‘No’. A significant difference was found between symmetric and asymmetric conditions ($F(1, 108) = 5.33, p < .05, \eta = .05$).

An analysis of item median RT_{norm} s revealed the same pattern of results.

Discussion

The outcome of the experiment confirmed the prediction. First, it was demonstrated that manipulations of subjects’ bodies can have an effect in a task, which seemingly involves no limb-based motor activity. Second, we found that subjects responded faster when the manipulation of their arms was symmetric. This result renders support for the hypothesis that the process of relation comparison is dependent on specific constraints of the human body, such as the symmetry of the limbs.

We did not find any significant difference between the two symmetric conditions. People responded equally fast either when both their wrists were loaded with weights or none of them. This lack of difference implies that the effect of the weights factor was not related to the perception of the relations, but to the process of their comparison.

The analysis of the normalized response times revealed that attaching a weight to the left wrist of the subjects had a bigger effect than when the weight was on the right wrist. Such a result is reasonable considering the fact that all subjects were right-handed. When a weight is attached to the dominant hand of a subject, its movements are impeded and the dynamics of the simulated sensorimotor simulations related to this limb is made closer to the dynamics of the non-dominant one. On the other hand, when the movements of the non-dominant hand are impeded, the asymmetry becomes even bigger and the comparison of the relations becomes harder. This result is consistent with the results of Vankov & Kokinov (2009, 2000), which revealed bigger effect sizes of the affordances of relations which were supposedly simulated with the non-dominant hand.

There was no significant interaction between trial type and the weights factor. This result suggests that the manipulation of the subjects’ bodies constrained the very processes of relation comparison and is not related to specific outcomes of the comparison task. The lack of interaction also implies that the results reported can not be attributed to any kind of stimulus-response interference.

Conclusion

The present study extends the findings of previous works of our group which have showed that the grasping affordances of functionally paired objects constrain performance in a relation comparison task (Vankov & Kokinov, 2009; 2010). We demonstrated that a similar effect can be achieved by attaching weights to the participants’ arms. This manipulation rules out any perceptual explanation of the role of object affordances. The subjects from all the experimental groups saw exactly the same stimuli on the computer screen. Taken together, the results from the all the experiments discussed clearly speak in favor of the hypothesis that people simulate interactions with the presented objects in order to comprehend the functional relationships between them.

In more general terms, the outcome of the presented experiment constitutes strong evidence in support of the embodied cognition account. The opponents of embodiment

often criticize it on the grounds that it is unable to explain how abstract representations and complex cognitive functions can be grounded in action and perception (Dove, 2009; Mahon & Caramazza, 2008). We believe that the current study makes steps a further in this direction by showing that relation reasoning, which is usually considered as an example of a highly sophisticated cognitive function (Penn, Holyoak & Povinelli, 2008), may be constrained by the physical characteristics of the human body.

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