IS ANALOGICAL MAPPING EMBODIED?

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ABSTRACT

This paper raises the question whether analogical mapping is embodied in real and/or simulated actions. An experiment is designed in which participants have to verify analogies between pairs of sentences. In half of the pairs the arguments are spatially (vertically) aligned and in the other half the arguments are spatially misaligned. Our assumption is that if mapping is embodied the participants will have to mentally simulate a spatial re-arrangement of the arguments during the mapping process. To test this prediction a moving dot was presented on the screen during the analogy verification task which should impede the eye movements needed for the mental simulation of spatial manipulation of the arguments. In half of the cases the dot was moving horizontally and in the other half – vertically. It turns out that the horizontally moving dot impedes to a greater extent the spatially misaligned analogical mappings than the aligned ones, supporting the hypothesis that in these cases people do simulate spatial re-arrangement.

INTRODUCTION

There is a family of related approaches to understanding human cognition which are popular under the names *embodied cognition* (Maturana & Varela, 1973, 1992, Varela, Thompson, & Rosch, 1992, Lakoff, 1987, Lakoff & Johnson, 1980, 1999, Lakoff, & Nuñez, 2001, Gallese & Lakoff, 2005, Clark, 1997, Bargh, Chen, Burrows, 1996, Turing, 1950, Brooks, 1991, 1999, Pfeifer & Bongard, 2007, Gibbs, 2005), *grounded cognition* (Bates, 1979, Harnad, 1990, Glenberg, 1997, Barsalou, 1999, 2008, Barsalou, Breazeal, Smith, 2007, Steels, 2003, Roy, 2005, 2008, Cangelosi, Riga, 2006), and *situated cognition* or *situated action* (Vygotsky, 1931, Gibson, 1977, Greeno, 1994, Clancey, 1997, Hutchins, 1995, Norman, 1993), and *dynamic systems approach* (Thelen & Smith, 1994, Spivey, 2008).

Although having a long history, these ideas are still considered somewhat vague or controversial by the opponents. There are various ways of conceptualizing the central ideas: *enactment* (all concepts, including the abstract ones, are implemented by specific motor activity, e.g. hand, leg or eye movements), *mental simulation* (the concepts can be implemented either by real motor activity or by mental simulation of this activity, e.g. mental rotation or mentally simulating a physical process), the body itself is used as a source for a *metaphor* (e.g. “up” is related to the head, “down” to the feet, “behind” to the back, and then metaphors are used for grounding abstract concepts such as happiness, sadness, etc. to these body parts), the abstract mental states correspond to *specific body states* (e.g. “being in love” corresponds to specific physiological state with high heart rate, high levels of nerve growth factor, testosterone, estrogen, dopamine, nor epinephrine, serotonin, oxytocin, and vasopressin, etc.), abstract concepts are *situated*, i.e. reside in the environment, in artifacts, in physical or social interactions (e.g. “North” is represented by a specific arrangement of a compass or a map, or by the procedure of “measuring” it;

the concept of "child" reflects a specific cultural construct in the society, a typical way of interaction with children, etc.).

A common idea shared by all these diverse versions of the embodied cognition approach is that cognitive processes transcend the traditional mind-brain pair (emphasized by the symbolic and neural network approaches) and partially or fully resides in the human body and its interactions with the environment. Reviews of various interpretations of the embodiment concept can be found in (Wilson, 2002, Gallese & Lakoff, 2005, Barsalou, 2008, Spivey, 2008, and Zwaan, in press).

Our own preference is for a soft version which is strongly related to perception and action involvement in all cognitive processes, but also accepts that these perception-action cycles can be learnt to be mentally simulated at some point and do not necessarily always involve the actual body. Still these mental simulations could at least partially activate motor programs (such as eye-movements, gestures, muscle activation), i.e. even the mental simulations cannot be completely detached from the body.

Ample evidence has been collected in support of the embodied cognition view including *behavioral data* (Bargh, Chen, Burrows, 1996, Barsalou & Wiemer-Hastings, 2005, Bergen, Lindsay, Matlock, Narayanan, 2007, Bergen, 2007, Kaschak, M., Madden, C., Therriault, Yaxley, Aveyard, Blanchard, Zwaan, 2005, Spivey & Geng, 2001, Spivey, Richardson, & Cheung, 2001, Tucker & Ellis, 1998, 2004, Wilson & Knoblich, 2005, Zwaan & Yaxley, 2003, Thomas & Lleras, 2007, 2009), *mirror neurons* (Gallese, Fadiga, Fogassi, Rizzolatti, 1996, Rizzolatti & Craighero, 2004), *PET and fMRI studies* (Rizzolatti, Fadiga, Matelli, Bettinardi, Paulesu, Perani, Fazio, 1996), *developmental data* (Smith, Gasser, 2005, Thelen & Smith, 1994), *anthropological data* (Hutchins, 1995), etc.

However, most of these data are about the embodiment of language and specifically of its semantics, i.e. language understanding requires some form of motor or mental simulation. This focus the research is understandable since language has been considered the perfect example of abstract symbol system and it needed to be attacked.

At the same time almost no attention has been paid to abstract reasoning – another quintessence example of symbolic activity. The only series of studies, that we are aware of, tries to demonstrate a relationship between patterns of eye-movements and patterns of thinking (Grant & Spivey, 2003, Thomas & Lleras, 2007, 2009). Thomas and Lleras guided the eye movements of the subjects by a digit tracking dual task while at the same time solving Duncker's radiation problem. It turned out that if the eyes of the participants are moving in a radial way (from the periphery to the center and vice versa) they were more likely to find the convergence solution of the problem. Later on they demonstrated that even without explicit eye-movement, just following the same radial pattern of shifting covert attention with fixed eyes, the subjects achieved the same results, which was interpreted as simulated mental eye-movements giving the same result.

The analogy research community stayed isolated from these developments and virtually all of the models of analogy-making are disembodied (Gentner, 1983, Holyoak & Thagard, 1989, Kokinov, 1994, Hofstadter & 1995, Mitchell, 1993, French, 1995, Hummel & Holyoak, 1997, Kokinov & Petrov, 2001, Doumas, Hummel & Sandhofer, 2008). Moreover, to the best of our knowledge, there are even no attempts to study the issue of embodiment of analogy-making empirically. This paper is trying to make the first step in that direction. The question that we raise is whether analogical mapping is embodied and the first step is to explore whether eye-movements are involved in the abstract mental task of analogical mapping.

MAPPING AS INTERNAL SPATIAL REARRANGEMENT

The main hypothesis behind this experiment is that *the abstract mental operation of analogical mapping can be closely related to the task of physical rearrangement of objects*.

We are often ordering, aligning, and arranging physical objects from very early age on (Figure 1) and this learned perceptual-motor ability may be underlying our abstract mental ability for analogical mapping.

Figure 1. Arranging, rearranging, and aligning physical objects in the environment.

The physical rearrangement and alignment of objects may be "internalized" (Vygotsky, 1931, Piaget, 1953) and become a mental operation, but even then we would continue to mentally simulate the perception-action cycle just like in the mental rotation task (Shepard & Cooper, 1982). If that is the case, we should be able to find evidence for such mental simulation, e.g. the mental rearrangement of the participating objects should produce eye-movements with directions predictable from the nature of the mapping task.

EXPERIMENT

This experiment aimed to explore the effects of induced eye-movement on solving an analogy-making task. To this end, a task was devised, which required participants to determine whether two simultaneously presented sentences were analogous or not, while at the same time they viewed a dot moving around the screen (Figure 2). Although participants were instructed to ignore the moving dot, it was assumed that they will spontaneously generate eye-movements along the orientation of the dot trajectory.

Two cases of analogical mapping were contrasted. In the first case, the arguments of the relations involved in the analogy were spatially aligned (Figure 2, left panel) and in the second one their positions were misaligned (Figure 2, right panel). The direction of the moving dot was either along the horizontal or the vertical axis of the screen (Figure 2). The hypothesis was that there would be an interaction between the type of mapping (aligned, misaligned) and the orientation of the moving dot (horizontal, vertical). If indeed people tend to arrange the analogy elements in such a way, that corresponding items are spatially aligned, than in the case of misaligned mapping they would have to perform a mental operation which will set the corresponding sentence elements one below the other, i.e. to mentally rotate one of the sentences. Such an operation would require horizontal eye-movements and thus interfere with the induced by the moving dot eye-movements along the same orientation. In particular, it was expected that a horizontal orientation of the moving dot will impede more the performance on the misaligned than on the aligned sentences (Figure 3) and will result in greater difference in response times for the misaligned analogical sentences compared to the aligned ones, i.e. we expect to have an interaction between the type of the task (analogy between aligned vs. misaligned sentences) and the orientation of the induced eye-movements (horizontal vs. vertical).

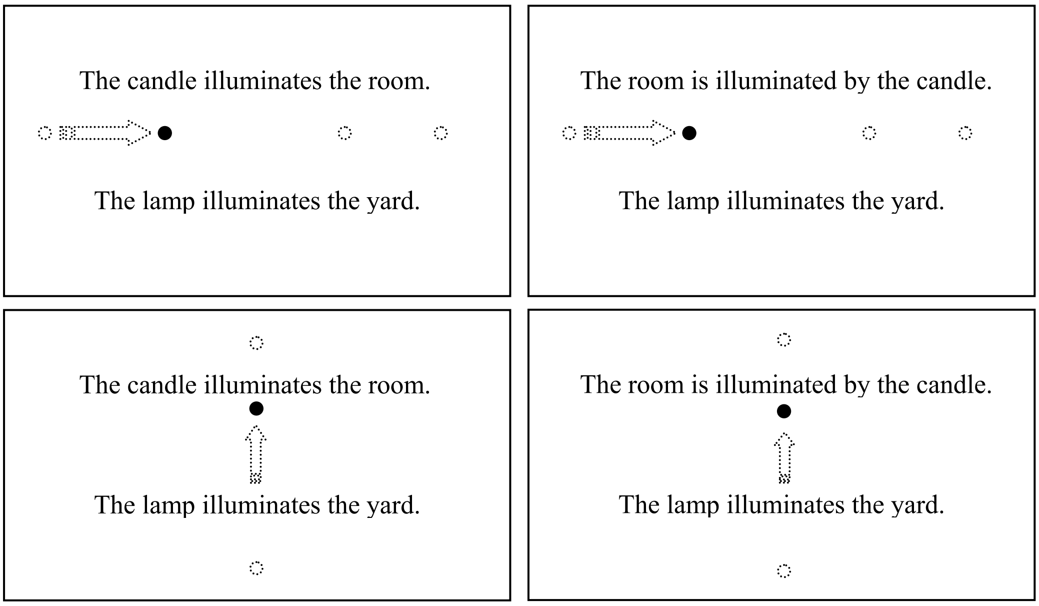

Figure 2. Stimulus material: pairs of analogous sentences and a moving dot. All four conditions are depicted: aligned (the left figures) vs. misaligned (the right figures), horizontal vs. vertical dot movement orientation.

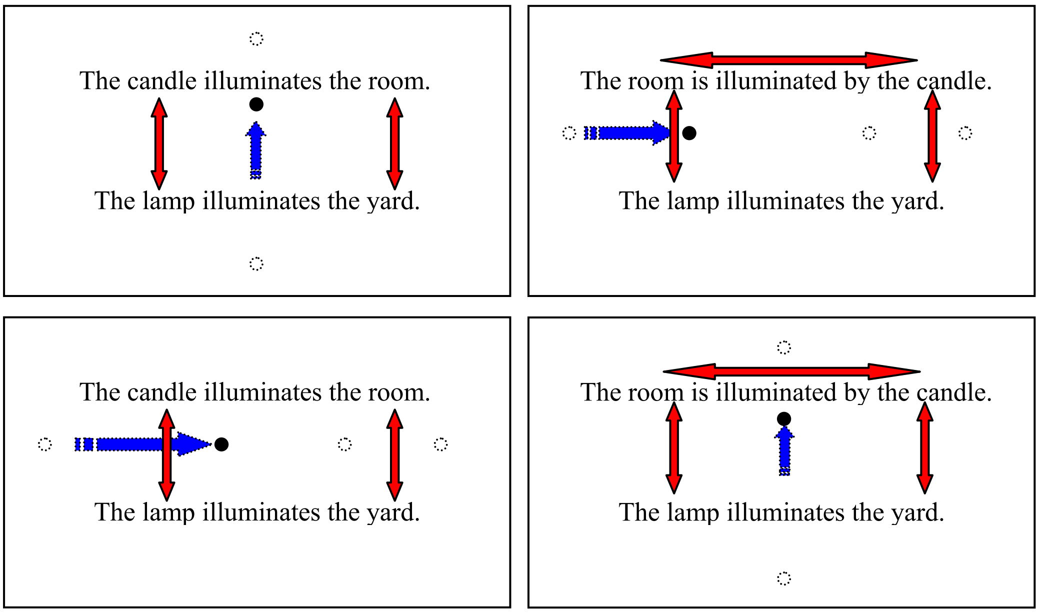

Figure 3. Expected interactions between two patterns of eye-movements: the red ones produced by the analogical mapping and the blue ones produced by the moving dot on the screen.

Method

Design A 2x2 within-subject design was used in the experiment. The two independent variables were the type of *mapping* (aligned, misaligned) and the *orientation* of the moving dot (horizontal, vertical). The dependent variable was response time.

Stimuli The stimulus set consisted of 20 pairs of analogous sentences and an equal number of fillers (non-analogous sentences). The sentences in both the analogous and the filler pairs used the same verb words. In the analogous trials the meaning of the verb was the same in both sentences, while in the non-analogous ones two distinct meanings of the verb (homonymic or distant polysemic words) were employed. For example:

An analogous pair of sentences:

The boat sunk in the river.
The ship sunk in the sea.

A non-analogous pair of sentences:

The submarine fired a torpedo.
The owner fired a worker.

Half of the sentences (in both the analogous and the filler trials) were spatially aligned and the rest were spatially misaligned. Spatial misalignment was implemented by putting one of the sentences in passive voice. Thus, when the two sentences were displayed one below the other, the corresponding arguments in the sentences were either one below the other (in the spatially aligned trials) or not (in the spatially misaligned trials). For example:

Spatially aligned sentences:

The army attacked the city.
The rebellions attacked the village.

Spatially misaligned sentences:

The city was attacked by the army.
The rebellions attacked the village.

All stimuli were given in Bulgarian language.

Procedure Participants were tested in a sound-proof booth. The stimuli were being presented on a 17” computer monitor with a resolution of 800x600 pixels. The experimental session started with 8 practice trials, none of which appeared in the experimental part. Each trial began with the presentation of two sentences. At the same time, a dot appeared at the centre of the screen and started moving along the vertical or the horizontal axis. The participants were instructed to respond as soon as possible whether the two sentences are analogous or not by pressing two predefined buttons of a serial response button box. They were also instructed to ignore the moving dot entirely and to pay attention to the verbal stimuli only. Each subject went through 40 trials, including 20 filler trials. Stimulus presentation and response recordings were controlled by *E-prime* software. The order of stimulus presentation was randomized across subjects. The experiment took about 8 minutes.

Participants 84 NBU students (39 female, 45 male) participated in the experiment for course credits or volunteered. Their average age was 22.80 (SD = 4.97).

RESULTS AND DISCUSSION

Trials with errors were excluded from the analysis of reaction time (RT) data. Responses times lying more than ±2.5 standard deviations from the RT mean were removed as well. Thus a total of 92.08% of the originally collected non-filler data were included in further analysis. The data were aggregated by subject. The results are displayed in Table 1.

A 2x2 repeated measures ANOVA was performed on subject RT means. It revealed a main effect of the type of mapping ($F(1, 83) = 146.87$, $p < .001$). Subjects responded significantly faster when the analogous sentences were spatially aligned. This effect could be attributed to the use of passive voice constructions in the misaligned mapping condition. However it is also possible that the effect is due to the effort subject had to exert in order to put misaligned analogy elements in corresponding spatial positions (that is, one below the other).

	M	SD	N
Aligned Horizontal	3318 ms	918 ms	84
Aligned Vertical	3187 ms	925 ms	84
Misaligned Horizontal	4142 ms	1144 ms	84
Misaligned Vertical	3682 ms	1076 ms	84

Table 1. Mean reaction times and standard deviations in each of the experiment conditions.

A main effect of the moving dot orientation was also found ($F(1, 83) = 36.80$, $p < .001$). A reasonable explanation of this observation is that the horizontal orientation of the moving dot interfered with the direction of reading. The effect could also be attributed to the hypothesized aligning operation – subjects attempted to mentally align corresponding analogy items in space and this processes was impeded by the dot when it was moving along the aligning orientation.

Most importantly, a significant interaction between the two factors was found ($F(1, 83) = 8.30$, $p < .01$). The interaction is depicted in Figure 4.

A Turkey HSD post-hoc test revealed a significant effect of the moving dot orientation factor in the case when the sentences were spatially misaligned ($p < .001$), but failed to find an effect of the moving dot orientation when the sentences were aligned ($p > .3$).

An analysis of error rates in non-filler trials was performed as well. A 2x2 repeated measures ANOVA was performed on subject mean error rates. It revealed two main effects and a significant interaction ($F(1, 83) = 14.79$, $p < .001$). Thus the error rates analysis replicated the RT results pattern.

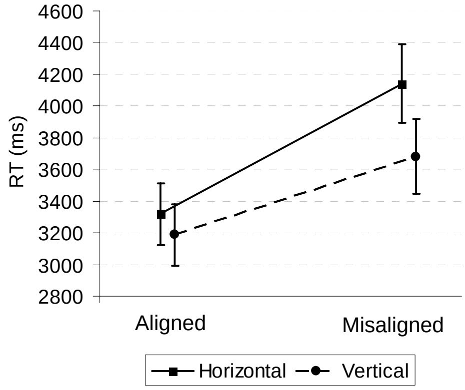

Figure 4. Interaction between the alignment of analogous sentences and the orientation of the moving dot. Error bars stand for confidence intervals.

The outcome of the experiment confirmed the initial hypothesis: inducing horizontal eye movements interferes much stronger with the analogical mapping when the analogous sentences are spatially misaligned. This result should be regarded as evidence in support of the hypothesis that people mentally align the corresponding elements of analogous sentences in order to facilitate analogical mapping.

CONCLUSIONS

In this paper we proposed that analogical mapping could be supported by performing or simulating physical actions. A particular hypothesis was formulated: when solving analogy problems, people mentally perform spatial transformations. The goal of these operations is to spatially align objects which are mapped to each other due to analogy-making. An empirical study was conducted in order to provide evidence for such behavior. The experiment demonstrated that inducing eye-movements along a specific orientation affects the performance of analogical mapping. The result renders support for the hypothesis that analogical mapping could be at least partly embodied in physical actions such as eye-movements.

It remains a matter of future research to further investigate the embodiment of analogical mapping. A particularly important question is whether eye-movements are the only kind of physical actions that are employed by analogical mapping. Another issue which remains is whether performing or simulating physical actions, such as spatial alignment, is prerequisite for analogical mapping, or its role is auxiliary.

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