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Grounded Spatial Belief Revision

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Abstract

Beliefs frequently undergo revisions, especially when new pieces of information are true but inconsistent with current beliefs. In previous studies, we showed that spatial belief revision is often guided by the functional asymmetry between the reference object and the located objects of the spatial relation. Here we first draw a connection between spatial belief revision and grounded cognition. In two experiments, we explored whether imagined physical properties of objects influence which object is relocated and which remains at its initial position. Participants mentally revised beliefs about the arrangement of objects which could be envisaged as small and large (Experiment 1) or easy to move and difficult to move (Experiment 2). The results show that (1) small objects are more often relocated than larger objects and (2) easy to move objects are faster relocated than difficult to move objects. The findings are in line with the idea of grounded cognition.

Keywords: Spatial cognition, grounded cognition, mental models, belief revision, spatial reasoning

Introduction

Imagine you have a date with a friend in a foreign city. He described to you how to come to the meeting point: “When you get off the train, you will see the kiosk to the left of you, and an ice cart to the right of you. To the left of the kiosk, I will wait for you.” This description is compatible with the following mental model:

Kiosk – I – ice cart

Almost arriving you get a call from your friend who tells you: “I made a mistake. The kiosk is to the right of the ice cart.” On which side is your friend waiting for you? In fact there are two possibilities:

(1) I – ice cart – kiosk
(2) Ice cart – kiosk – I

In everyday life, we are often confronted with such problems. People describe how to find certain objects and then realize that the description is wrong ("I left your key on the kitchen table, but it is actually on the table in the living room"); someone describes how to find a certain place in a foreign city and on your way, you realize that his description was wrong; your partner describes where he parked your car, but it is parked somewhere different, and so on.

All this has to do with the field of “belief revision”. Researchers in this field explore how people change their mind in the light of new contradicting information. The experimental studies mostly used conditional reasoning problems in which an inconsistency arises between a fact, contradicting a valid conclusion, and the conditional and categorical premises. Within this research, psychologists were able to show that belief revision is affected by many factors, including asymmetries between particular facts and general laws (Revlis, Lipkin, & Hayes, 1971), conditional and categorical premises (Elio & Pelletier, 1997; Dieussaert, Schaeken, De Neys, & d’Ydewalle, 2000; Girotto, Johnson-Laird, Legrenzi, & Sonino, 2000; Revlin, Cate, & Rouss, 2001), major and minor premises (Politzer & Carles, 2001), and reliable and unreliable information sources (Wolf, Rieger, & Knauff, 2012).

The present work is part of our current attempt to extend the cognitive research on human belief revision to the area of spatial reasoning. Our main motivation is that (1) spatial inferences are ubiquitous in our daily life (Goodwin & Johnson-Laird, 2005; Knauff, 2013), (2) reasoning with spatial relations is often easier than reasoning with conditionals (Johnson-Laird & Byrne, 1991; Knauff, 2007), and that space is one of the most fundamental dimensions of our physical and psychological reality (Gattis, 2001; Knauff, 1999, 2013). In our previous work, we have identified three main principle of spatial belief revision (Knauff, Bucher, Krumnack, & Nejasmic, 2013):

1. Spatial reasoning relies on mental models. A mental model is a unified representation of what is true if the premises are true. Reasoners use the meaning of assertions and general knowledge to construct single models of possibilities compatible with these assertions. Spatial relations are not represented explicitly in a propositional format but rather they are inherent in the model and thus can be (and must be) ‘‘read off’’ from the model by mental inspection processes (Johnson-Laird & Byrne, 1991; Polk & Newell, 1995; Goodwin & Johnson-Laird, 2005).

2. Spatial belief revision relies on the revision of mental models. If newly available information is inconsistent

with the current model (and new information must be taken for granted), a model revision is necessary to establish consistency. The revision process relies on local transformations in which tokens in the model are moved to new positions. If not all available information can be true at the same time, people ‘‘decide’’ which of the information to retain and which one to discard (Bucher, Krumnack, Nejasmic, & Knauff, 2011; Krumnack, Bucher, Nejasmic, & Knauff, 2011; Bucher & Nejasmic, 2012).

3. The model revision process is sensitive to the functional asymmetry between the “reference object” (RO) and the “located object” (LO). For instance, in the statement ‘‘A is to the right of C’’, the C is the RO and the A the object that is located in relation to the RO. To regain consistency the LO of the inconsistent statement seems to be relocated within the initial constructed mental model (Bucher et al., 2011; Krumnack et al., 2011; Bucher & Nejasmic, 2012; Knauff et al., 2013). The distinction has been made by several psychologists and linguists (Miller & Johnson-Laird, 1972; Talmy, 1983; Landau & Jackendoff, 1993). The common idea of all these theories is that a spatial relation refers to the position of a particular object in focus relative to another object or area (Tenbrink, Andonova, & Coventry, 2011).

In the present work we mainly focus on the third principle (LO-RO-asymmetry) and combine it with the idea that cognitive processes are not only abstract symbolic manipulations but grounded in perceptual, motoric, or emotional experience (for an overview, see de Vega, Glenberg, & Graesser, 2008). Imagine, for instance, you are helping a friend to move into a new apartment. You have to carry many things (sofas, tables, books, porcelain, washing machine, hopefully no piano, etc.) from his old apartment to the furniture truck and then later from the furniture truck into the new apartment. If you do that, it is very likely that you try to avoid carrying heavy objects and prefer to move objects which are less heavy. But, does this heaviness also affect how you think about the location and relocation of objects? In principle, the weight of objects should not matter if we just mentally move objects in a mental model from one position to another. We do not have to carry the objects physically; so why should their weight matter? On the other hand, the theory of grounded cognition claims that such physical properties have an effect on how we think. The process of thought is a mental simulation of bodily experiences and therefore the weight of objects should affect how we mentally process the information from a spatial reasoning problem (Glenberg & Robertson, 1999; Kaschak & Glenberg, 2000; Kaschak & Glenberg, 2002; Rinck & Bower, 2004; Bergen & Chan, 2005; Pulvermüller, 2005).

Two experiments of spatial belief revision and grounded cognition

In the following, we present two experiments on grounded spatial belief revision. In the experiments, participants received spatial information about the location of *small* or *large* objects (Experiment 1) or *easy to move* or *difficult to move* objects (Experiment 2), and then have to revise their initial model in the light of new contradicting information. Is this revision process affected by the *size* or *movability* of the objects that can be relocated? Do people prefer to relocate the smaller and easy to move object as the theory of grounded cognition suggests? We present a pilot study, because we did not want to use the actual physical mass and size of objects but rather how they are psychologically perceived and represented (although that should highly correlate). Then we report two experiments: in experiment 1, the size of the objects was varied; in experiment 2 the movability was varied. These factors were combined with the role of the objects as being the RO or LO of the relation in the newly available information. In our previous experiments, we found a strong preference of relocation the LO because the RO is considered less flexible. Can the size or movability of the envisaged objects overwrite this general preference? In the last part of the paper we discuss our findings and draw some general conclusion about grounded cognition and spatial belief revision.

Pilot study

Our first task was to define the set of objects to use in our experiments. To select the set of “large” and “small” objects, we developed a questionnaire with 64 objects. 46 participants rated the size of the objects on a five-point scale with the poles “very small” and “very large”. Then they rated the same objects regarding movability on a five-point-scale from “easy to move” to “difficult to move”. The order of objects was randomized. For the analysis, we computed the means over the group of participants and selected the objects with the lowest and highest mean ratings for size and movability. The objects are presented in Table 1. These objects were used for the following experiments.

Table 1: Objects used in the experiment according to their property

small	large	easy to move	difficult to move
screen	power mast	wheelchair	pillar
vase	bridge	bicycle	counter
printer	railway station	carriage	gravestone
post	high rise	scooter	oven
lamp	spire	barrow	hydrant

Experiment 1: Small vs. large objects

Method

Participants. 21 students from the University of Giessen (9 male; age: *M* = 22.86; *SD* = 5.27) were tested individually. They gave written informed consent and received course credits for their participation.

Materials, design, and procedure. Each participant solved 48 revision problems. Six practice trials (not analyzed) preceded the experimental trials. All stimuli were generated and presented using Superlab 4.0 (Cedrus Corporation, San Pedro, CA, 1999) with a RB-530, on a standard personal computer with a 19” monitor. Number of correct decisions and corresponding revision times were recorded.

The structure of the problems was as follows: First, participants received sequentially two statements, also called premises (1, 2), which described the spatial relation between three objects, for example:

(1) “A is to the left of B”
(2) “B is to the left of C”

From these two premises the participants inferred that the three objects are in the arrangement A – B – C. They did that by choosing one of two arrangements (correct arrangement/correct arrangement mirrored) that were presented on the screen.

In the next step, participants were confronted with an additional statement, e.g., ‘‘A is to the right of C’’. This is the critical point in time where participants in our experiments had to realize that something must be wrong with their initial model about the layout of the three objects. Not all three statements can be true at the same time because the third statement contradicts the logical inference from the first two premises. Participants were told that the third statement is irrefutably true so they could not ignore the third statement. The only option was to decide which one of the first two premises may be abandoned. If the first premise is discarded this results in the arrangement B – C – A; if the second premise is discarded this results in the arrangement C – A – B. It is essential to see that the first revision strategy corresponds to the LO-Relocation, whereas the second revision strategy corresponds to the RO-Relocation. All statements used the relation “left of” and “right of” and were presented sequentially. Positions of the arrangements as well as the relations were counterbalanced across the experiment.

To study the effect of object size the terms, A, B, C were instantiated with the small and large objects from Table 1. To boost the possible effect of object properties we integrated a “you” into the problems. We expected that this would foster the perspective taking and that the participants are therefore even more sensitive to the object properties.

Here is an example problem:

(1) premise: “The vase is to the left of you.”
(2) premise: “You are to the left of the spire.”

Initial model: Vase – you – spire

Inconsistent fact: “The spire is to the left of the vase.”

Examples of revised orders:

Spire – vase – you (“relocation of the large object”) vs.
You – spire – vase (“relocation of the small object”)

Participants received instructions on the computer screen. They were instructed to imagine an arrangement determined by the premises and subsequently to choose the respective arrangement (on the screen) by pressing the corresponding button. Afterwards participants had to decide whether or not the presented fact is consistent with this model. For the problems with a fact contradicting the initial model (which was the case in half of the problems), participants were asked to revise the arrangement and to define the revised arrangement by pressing the corresponding button.

Results and discussion

Mean percentage rate of correctly constructed models was 98% (*SD* = 2.15) and in 94% (*SD* = 8.54) of the inconsistent problems participants correctly identified the inconsistency between the initial model and the contradictory fact. Erroneous trials were excluded from further analysis.

An ANOVA with the factors object size (small vs. large) × person´s position (leftmost, middle, rightmost) was conducted for the revision choice and the revision times. Level of significance was 5%.

This ANOVA revealed a significant main effect of object property for revision choices [$F(1, 20) = 8.21$; $p < .05$; $\eta^2 = .29$]. The main effect of person´s position and the interaction were non-significant ($p > .87$).

T-tests revealed that choosing of revised arrangements were based significantly more often on relocations of small objects (*M* = 56%, *SD* = 8.95) compared to large objects (*M* = 44%, *SD* = 8.95; $t(20) = 3.09$; $p < .01$) (see Fig. 1).

Results of the ANOVA for revision times were non-significant (all *p*s > .53). Implicitly, the analyses also showed that the differences between LO and RO were less important than the differences between small and large objects.

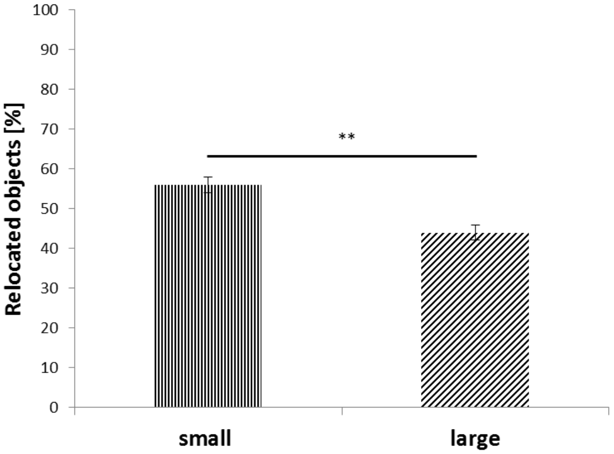

Figure 1: Relative frequency (in %) of model selections based on the relocation of small and large objects. Error bars show standard errors.

Our results show that physical properties of objects have an effect on how people revise their existing belief about the arrangement of objects in space. People have a strong tendency to relocate those objects that would also be easier to move physically. This finding agrees with the grounded cognition approach and is more difficult to explain based on purely symbolic cognitive theories. The finding also agrees with the mental model theory of reasoning, in which people reason spatially by constructing, inspecting and varying spatial mental models that mirror the situation described in the premises (Knauff, Rauh, & Schlieder, 1995; Ragni, Knauff, & Nebel, 2005; Rauh, Hagen, Kuss, Knauff, Schlieder, & Strube, 2005; Nejasmic, Krumnack, Bucher, & Knauff, 2011). If such a model is then contradicted by a new fact, people try to revise the model by local transformations. In fact, they move the objects in the model around to obtain a model consistent with the newly available information. We could show these mental operations are affected by the imagined physical properties of the objects. With the next experiment, we tried to replicate this effect with objects which are easy or difficult to move. The question is again: does object property affect reasoning and belief revision? Is the physical challenge related to a difficult movable object somehow reflected when we manipulate it mentally?

Experiment 2: Easy and difficult to move objects

Method

Participants. 24 students from the University of Giessen (5 male; age: M = 22.71; SD = 6.60) were tested individually. They gave written informed consent and received course credit for their participation. Data from one participant were excluded from the analysis due to a technical problem.

Materials, procedure, and design. The instructions on the computer and the procedure were the same as in experiment 1. The only difference between experiment 1 and 2 was the object property. Again, we manipulated two factors: object mobility (easy and difficult to move objects) and person´s position ("you") in the spatial arrangement (leftmost, middle, and rightmost) as the independent within subject factors. Again, the dependent variables are revision choice and revision times.

Results and discussion

As in experiment 1, participants selected correct arrangements in more than 95% (M = 97%, SD = 3.70) of the cases. They detected inconsistencies between the initial constructed arrangements and the contradictory facts in 94% (SD = 4.97), correctly. Erroneous trials were excluded from further analysis.

An ANOVA with the factors object property (easy and difficult to move objects) × person´s position ("you") in the spatial arrangement (leftmost, middle, and rightmost) was conducted for the revision choice and the respective revision times. Level of significance was 5%.

The ANOVA for revision times revealed a significant main effect of object property [$F(1, 16) = 4.76$; $p < .05$; $\eta^2 = .23$]. The main effect of person´s position and the interaction were non-significant (ps >.23). One-tailed t-tests revealed that participants needed less time for a revision based on a relocation of an easy to move object (M = 2956.04 ms, SD = 1257.80) compared to a difficult to move object (M = 4189.31 ms, SD = 714.77; $t(22) = 1.93$; $p < .05$) (see Fig. 2). In this experiment, the ANOVA for revision choices were non-significant ($p > .41$). Although participants did not show a clear preference for a relocation of an easy to move object compared to a difficult to move object, they needed more time to establish consistency, when the revision was based on a relocation of a difficult to move object.

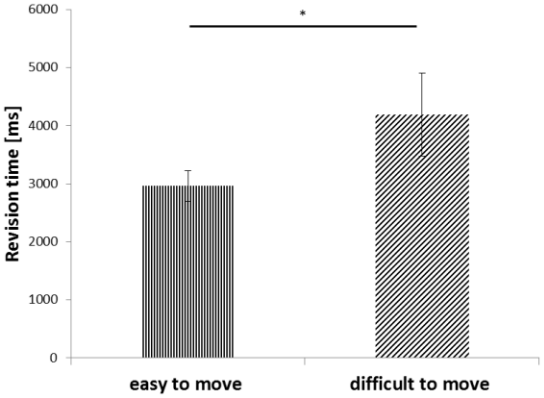

Figure 2: Revision times (in ms) based on the relocation of the respective object. Error bars show standard errors.

General discussion

We reported two experiments on the connection of spatial belief revision and grounded cognition. We showed that (1) small objects are more often relocated than larger objects and (2) easy to move objects are faster relocated than objects which are difficult movable. The findings are in line with the idea of grounded cognition. According to this approach, the mind is embodied, and thus cognitive processes must be grounded in perceptual, motoric, or emotional experience (for an overview, see de Vega et al.,2008). From this point of view, human thought is almost exclusively based on perceptual simulations and modality-specific representations (Barsalou, 2008, 2010).

Our results suggest that object properties effect spatial belief revision. The (imagined) properties of objects can overwrite the general preference for LO-relocation (experiment 1) and the time it takes to revise a mental model can be modulated by different object properties (experiment 2). These findings indicate that the physical effort that would be necessary when an object is actually relocated is reflected in revision preferences and revision speed. Moreover, the effort for different object properties (like size and movability) was reflected by different psychological measures in our experiment. On the one hand, size affected the frequency with which objects were mentally relocated. Participants preferably changed the position of small objects. Large objects were preferably left in the same position. What happens when we transfer this result to the physical world? It basically means that a vase is relocated preferably to a house. That makes sense, given that we indeed relocate vases more often and more easily than houses. On the other hand, movability modulated the time individuals needed for the revision process. This also agrees with real actions in the physical world. We might not have preferences in relocating ovens compared to wheelchairs, but it is more time consuming to move an oven than a wheelchair. Consequently, participants needed more time relocating heavy ovens than mentally "pushing" the wheelchair.

Of course, often size and movability (and many more properties of objects) are confounded. That was also the case in our experiments. However, we made an attempt to disentangle size and movability. Our results suggest that we were successful in doing so. An important corollary from our studies is that different properties affect different dependent measurements. This might be of concern in further experiments in this field.

We are aware that our findings are too weak to make a strong case for the grounded cognition approach in reasoning and belief revision. This is in particular important with regard to findings suggesting that effects of grounded cognition are more based on experimental demand characteristics considering the work of During et al. (2009). Another critical point is that, for instance, research on way-finding and navigation shows that some kind of spatial representations have an amodal representational format, which does not agree with the embodied cognition approach (Giudice, Klatzky, & Loomis, 2009). In that sense, our experiments can only be a very first step to draw a new connection between two fields that still work in isolation. However, another corollary from our findings is that the theory of grounded cognition and the theory of mental models fit well together. The theory of mental models also assumes that we reason by mentally simulating what might be the case. However, the model theory so far has focused on the simulation of spatial relations between objects. Today, the vast majority of researchers consider the model theory to be the empirically best supported theory of human spatial inference (Vandierendonck, Dierckx, & de Vooght, 2004; Goodwin & Johnson-Laird, 2005; Knauff, 2009, 2013; for an exception see: van der Henst, 2002). The present work shows that the idea of a mental simulation in mental models can also incorporate other physical features. We will continue to investigate this connection between mental models and grounded cognition in future experiments.

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