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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 linguistic asymmetries provided by relational statements, play a crucial role in spatial belief revision. Located objects (LO) are preferably revised compared to reference objects (RO), known as the LO-principle. Here we establish a connection between spatial belief revision and grounded cognition. In three experiments, we explored whether imagined physical object properties influence which object is relocated and which remains at its initial position. Participants mentally revised beliefs about the arrangements of objects which could be envisaged as light and heavy (Experiment 1), small and large (Experiment 2), or movable and immovable (Experiment 3). The results show that intrinsic object properties are differently taken into account during spatial belief revision. *Object weight* did not alter the LO-principle (Experiment 1), whereas *object size* was found to influence which object was preferably relocated (Experiment 2). *Object movability* did not affect relocation preferences but had an effect on relocation durations (Experiment 3). The findings support the simulation hypothesis within the grounded cognition approach and create new connections between the spatial mental model theory of reasoning and the idea of grounded cognition.

1. Introduction

Imagine you have a date with a friend in a foreign city. He described to you how to get 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 receive a phone 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:

I–ice cart–kiosk 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 (Bucher, Röser, Nejasmic, & Hamburger, 2014). 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 (Dieussaert, Schaeken, De Neys, & d'Ydewalle, 2000; Elio & Pelletier, 1997; Girotto, Johnson-Laird, Legrenzi, & Sonino, 2000; Politzer & Carles, 2001; 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 endeavor (1) to extend the cognitive research on human belief revision to the area of spatial reasoning and (2) to combine this research 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, Graesser, & Glenberg, 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. It is very likely that you

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try to avoid carrying bulky objects and prefer to move objects which are easy to carry. The question arises whether the physical properties of the objects that we reason about have an effect on how we think about them and how we manipulate them in our mental representation. All experiments on spatial belief revision so far used objects such as mangos, oranges, and apples that can be considered "neutral" regarding their specific physical properties (e.g., Knauff, Bucher, Krumnack and Nejasmic, 2013). These objects are very similar regarding physical properties, weight, size, and so on and it has not been investigated so far whether properties of objects affect the process of reasoning. However, recent theories on "grounded" and "embodied" cognition suggest that bodily experiences with and physical properties of objects indeed matter when we reason about them, even if the properties are not relevant for the cognitive task at hand (Barsalou, 2007; Glenberg, Witt, & Metcalfe, 2013; Zwaan & Pecher, 2012). That is, although you just imagine you are moving your friend´s furniture you might prefer to reason about carrying a vase over towing a piano, although that all happens in your mind without any real physical effort. The aim of this paper is to study such effects of *grounded cognition* in the area of spatial belief revision, when people have to mentally — but not physically — relocate objects in their imagination to account for newly available information during reasoning.

The structure of this article is as follows. First, we report some empirical findings on the link between grounded cognition, spatial reasoning, and belief revision. Second, we describe how our research is related to previous work on spatial mental models and then develop our hypotheses on how physical object properties should impact mental spatial belief revision. Third, we test these hypotheses with three experiments. Finally, we discuss our findings and draw some general conclusions on the connection of mental models, grounded cognition, and spatial belief revision.

2. The link between grounded cognition, spatial reasoning, and belief revision

The theory presented in this paper postulates that when individuals are confronted with a spatial belief revision problem, they first construct a mental model of the described state of affairs. If they are confronted with new information which is inconsistent with this initial model they vary the model in order to obtain consistency (Johnson-Laird, Girotto, & Legrenzi, 2004; Ragni & Knauff, 2013; more details are described below). The experiments concern the question if and to what extent the properties of objects such as size, movability, weight, and the potential bodily experience with these properties in the physical world affect the model variation process. For example, when people carry small or bulky objects this engages their muscles in the arms and legs differently. The hypothesis that we test in this paper is that during mental reasoning people simulate this bodily strain in their imagination and therefore also prefer to move handy sized objects over bulky ones in their mental representation. The theoretical background and the empirical evidence for this assumption are as follows.

2.1. Grounded cognition and object properties

Classical theories of human cognition rely on the idea that human thinking is based on an abstract language of thought (Anderson, 1993; Fodor, 1975; Pylyshyn, 1984). Arbitrary symbols stand for what they represent and humans are equipped with mental procedures to combine and manipulate theses abstract symbols. The results of such syntactic mental operations are again abstract symbol structures. Meaning arises from the combination of symbols that are arbitrarily related to what they signify (Glenberg & Robertson, 1999). The body and the information from the brain's modal systems for perception and action play, if any, just a marginal role because the symbols represent meaning in an abstract way that does not capture modality-specific information about the physical properties of objects, actions, or events. This classical approach is supported by numerous experimental findings and was very important for the development of cognitive psychology (e.g., Adler & Rips, 2008; Anderson, 1983, 1993; Pylyshyn, 2006; Rips, 1994). Today this classical approach is criticized by many psychologists. Some argue that the approach must be complemented by theories paying more attention to the representation of bodily experiences (Barsalou, 2007). Others are even more radical and completely deny the existence of abstract symbols in the human mind (e.g., Glenberg et al., 2013). The common idea of all these approaches is that people's understanding of language and memory representations are grounded in their physical interactions with the world (Beveridge & Pickering, 2013).

In fact, many authors reported that the processing of information in the mind is largely affected by the physical characteristics of the human body. For example, Glenberg and Kaschak (2002) asked participants to make judgments on sentences that describe actions toward the body (e.g., "Mark dealt the cards to you") or away from the body (e.g., "You dealt the cards to Mark"). The authors found that participants responded faster when the response requires an arm movement in the same direction as the action described by the sentence, which is called the Action-Sentence Compatibility Effect. Stanfield and Zwaan (2001) found that participants can respond faster to a picture of a *vertical* nail following the sentence "Mary pounded the nail into the floor" than after the sentence "Mary pounded the nail into the wall". The reverse response times were found for a picture of a *horizontal* nail. Proffitt (2006) studied visual perception and showed that people overestimate distances when wearing a heavy backpack or when of low physical fitness. Based on these findings, Proffitt argued that the perceived distance is affected by the bodily effort needed to traverse the distance.

The reported findings are only a few under many other results suggesting that simulated bodily states can affect mental states (Barsalou, 2008; Barsalou, Simmons, Barbey, & Wilson, 2003; Lakoff & Johnson, 1980; Smith, 2005). The theory of grounded cognition is also supported by functional brain imaging studies showing that the neural systems for meaning and action are reciprocally connected with each other (Isenberg et al., 1999; Martin & Chao, 2001; Gernsbacher & Kaschak, 2003; Kan, Barsalou, Solomon, Minor, & Thompson-Schill, 2003; Zwaan, Taylor, & de Boer, 2010; for an overview see: Pulvermüller, 1999).

Of particular importance for the present topic are cognitive studies on the effect of cognizing object properties such as size, weight, or movability. The question here is whether or not things that are hard to physically move are also hard to imagine moving. Flusberg and Boroditsky (2011) investigated this question by asking participants to manipulate wooden objects similar to the figures in the classic mental rotation experiment by Shepard and Metzler (1971). In the experiments, the wooden objects were mounted on rotation platforms with either empty devices or devices filled with sand. Thus, one pair of objects was easy to physically rotate while another pair was difficult to rotate, because of the sand. Flusberg and Boroditsky (2011) reported that participants were slower to mentally rotate objects that were harder to physically rotate. Object properties obviously had an effect on motor imagery. Similar results are reported in a study by Amorim, Isableu, and Jarraya (2006), who could demonstrate a cognitive advantage of imagined spatial transformations of the human body over that of more unfamiliar objects. These results, along with related findings have been used to argue that there is a close relationship between perceptual and motoric experiences and mental imagery (Barsalou, 2008; Kosslyn, Ganis, & Thompson, 2006).

A further characteristic of grounded cognition is to emphasize the importance of perspective taking in spatial thinking and language. Perspective taking means that it matters whether people mentally represent a scene from their own or a different spatial perspective (Kosslyn, Ganis, & Thompson, 2001; Pulvermüller, 2005; Rizzolatti & Arbib, 1998). Further, and probably more important, for embodiment theories it also matters whether persons simulate an action as if they were performing the action, or as if another person performs the action