Do People Update Spatial Relations Described in Texts?

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Abstract

Previous studies (e.g., Rieser, 1989) have established that physical rotations result in effortless updating of spatial information contained in visually perceived scenes. The present experiment provided evidence that this is not the case for scenes that are encoded through texts. Performance was better under the perspective that the scenes were learned than under novel perspectives, regardless of whether rotations were physical or imagined. In addition, the experiment suggested that the orientation of the ecological frame affects spatial performance even when people operate in a purely represented framework.

Introduction

Various studies (e.g., Chance, Gaunet, Beall, & Loomis, 1998; Klatzky, Loomis, Beall, Chance, & College, 1998; Rieser, Guth, and Hill, 1986; Simons & Wang, 1998; Wang & Simons, 1998) have established a link between active locomotion and the successful spatial updating of previously viewed scenes. Researchers have proposed that spatial updating is carried out by an internal mechanism that constantly computes the relative locations of objects as people move in the environment (Wang & Spelke, 2000). Indeed, when people change their position within an environment they seem to experience little difficulty with keeping track of how the locations of objects change, even when the objects are no longer in view (Attneave & Farrar, 1977; Fukusima, Loomis, & Da Silva, 1997; Loomis, Klatzky, Colledge, Cicinelli, and Pellegrino, 1993). In fact, responding to locations of objects after locomoting to a new position is no more difficult than doing so from the original standpoint (Rieser, 1989; Rieser et al., 1986). However, difficulties arise when judgments are made from perspectives that are imagined (Presson & Montello, 1994). For example, Rieser has shown that pointing to objects from a novel standpoint is slower and less accurate when the observer mentally rotates to the new standpoint than when she is physically rotated to it.

In short, the evidence suggests that moving organisms update their representations of their surroundings in an efficient and effortless manner. However, non-moving organisms need to engage in additional mental processing in order to reason about their surroundings from imagined standpoints.

The majority of the previous studies have examined spatial updating with paradigms that involved visually presented stimuli. Visual perception is not, however, the only way we form mental representations of the world. Very often, we learn about space by reading or listening to verbal descriptions. A number of studies (e.g., Denis & Cocude, 1989) have shown that at least in terms of geometrical properties, mental representations constructed from language are equivalent to those created through perception. In general, mental representations of space seem to preserve many of the characteristics of real environments (Zwaan & Radvanksy, 1998).

An interesting issue that arises is whether mental representations derived from text are updated when changes in the spatial relations come about. A study by De Vega and Rodrigo (2001) attempted to provide an answer to this question by contrasting how easily people locate objects after physical and imagined rotations. In that study, participants first read sentences that described spatial layouts in which objects were located at each of the four canonical horizontal directions from a protagonist. The protagonist was then described to rotate to novel perspectives. The subjects were probed with the names of the objects and were asked to determine their locations from the perspective of the protagonist. One group of participants performed the task by physically rotating along with the protagonist, while a different group performed the task with no physical rotation. De Vega and Rodrigo contrasted the judgment latencies of the two groups to assess whether spatial updating took place. In one experiment that required that subjects use spatial labels (i.e., front, left etc) to provide their answers, performance was equally fast for the two rotation modes. In another experiment in which subjects pointed to objects, performance was faster when rotation was physical instead of imagined. De Vega and Rodrigo concluded that physical rotations led to effortless updating only in the pointing experiment. Furthermore, they suggested that the actual body position of the participant is not important for performing the task when responses are made by using spatial labels. That is because subjects performed the task in a represented framework from which their actual self was disengaged.

Certain limitations of the study by De Vega and Rodrigo (2001) create concerns regarding the interpretation of the results. First, the absence of a difference between physical and imagined rotation latencies in the labeling task does not necessarily mean that participants failed to effortlessly update their representations. It could very well be the case that they were successful at updating their representations under both modes of rotation. This is quite possible given the simplicity of the scene and its relatively low working memory demands (only four objects needed to be tracked). Second, although no differences were observed in the latency measures, subjects were significantly more accurate in their judgments with physical rotations than with imagined rotations.

The present study uses a different measure to examine whether spatial updating takes place under either imagined or physical rotations. Performance under the original perspective (i.e. the perspective from which the scene is encoded) and novel perspectives is contrasted in the two modes of rotation. If subjects fail to update their original representation when they rotate – either physically or imaginary – to a novel orientation, then performance should be better when the task is performed from the original than from the novel perspectives. If any of the two modes of rotation results in successful updating, this should be indicated by equal performance between the original and novel perspectives.

A second goal of the study is to examine more closely the role – if any – of the participants' ecological frame in tasks that require judgments using deictic terms. A hypothesis of the present study is that the orientation of ecological frame affects how easily people discriminate the two poles of an axis and map spatial terms to the appropriate regions of space. If this is true then the orientation of the participants' bodies will affect the ease of using deictic terms in the task. This should be particularly true for judgments within the left/right axis because our bodies provide the only source of asymmetry for this axis. Manual dexterity is probably the least subtle cue that people can use to discriminate left from right (Corballis & Beale, 1976). Therefore, the prediction is that left Vs right judgments will be less difficult when the ecological reference frame of the participant is aligned with the reference frame imposed on the protagonist.

Experimental Task

The present study uses a paradigm that has been used widely in the past to study the accessibility of directions in spatial memory. The task, developed by Franklin and Tversky (1990), involves the presentation of a narrative which describes a naturalistic scene in the second person. Objects are described occupying positions at canonical directions from the protagonist (i.e., above, in the front, on the left etc). Participants are given unlimited time to study the narrative. Then, the protagonist is described to rotate to a new orientation. The narrative continues on a sentence by sentence fashion with participants pressing a key to request a new sentence. Occasionally, instead of a new sentence, the name of an object appears. Participants are asked to report where the object is with respect to the current perspective of the protagonist. The task continues until all objects are probed from various perspectives.

Studies that used this paradigm (e.g., Bryant & Tverksy, 1992) were primarily focused on the accessibility pattern for the various self-object directions. Therefore, latencies from the various protagonist perspectives were collapsed to provide a single average value for each direction. The major result from these studies is that objects on the above/below axis are located faster than objects on the front/back axis, which are in turn located faster than objects on the left/right axis. Furthermore, objects in the front are retrieved faster than objects at the back of the protagonist. An account for this accessibility pattern has been provided by the Spatial Frameworks model (Franklin & Tversky, 1990) which posits that the scene is represented on the basis of the three orthogonal body axes.

The current study uses the Spatial Frameworks paradigm to examine latency differences – if any- between the original and the novel perspectives of the protagonist. As in De Vega and Rodrigo (2001), a mode of rotation manipulation is introduced. A group of participants perform the task by physically rotating to novel perspectives while a different group of participants perform the task by only imagining rotations to novel perspectives. In contrast to the narratives of De Vega and Rodrigo, the present study involves narratives that are somewhat more complex. In addition to the four objects in the horizontal plane, another two objects are described to occupy the poles of the above/below axis. Because all protagonist reorientations occur in the horizontal plane, the positions of these two objects do not need to be updated at all throughout the task,. Nevertheless, they add an extra load on working memory, thus making the task more cognitively demanding.

In order to examine the role of the ecological frame, another variable is introduced. Half of the narratives require that subjects respond with a direction judgment (e.g., left, front etc) while in the other half they simply need to respond with an axis judgment. In the latter case, if for example the object is located on the left of the protagonist, the participant only need to respond with "left/right". This manipulation has been previously used with this paradigm in a study by Bryant and Wright (1999). The rationale for including the judgment type manipulation in the present study is that if the ecological reference frame helps to make easier direction judgments, then simply removing the need for such judgments will produce the same effect. Furthermore, if real rotations and axis judgments affect performance in the same way, then having one of them should be sufficient; that is, no better performance will be observed when both of them apply instead of just one.

Method

Participants Forty students (20 females) from psychology classes at the Pennsylvania State University participated in the experiment in exchange for course credit. Ten male and 10 female participants were randomly assigned to the physical and the imagined rotation conditions.

Materials Four narratives, taken from those used by Franklin and Tversky (1990) and two taken from Bryant & Wright (1999) were used in the present study. The first portion of the narratives described in the second person a naturalistic scene -- a barn, a construction site, a hotel lobby, a space museum, a lagoon, and a navy ship –in which objects were located at the six canonical axes of the reader-protagonist. Narratives were modified to include 6 instead of 5 objects and in contrast with Franklin and Tversky, the initial portions were also presented on computers. The six critical objects in each narrative appeared in blue upper-case characters, in contrast to the rest of the narrative which appeared in lower-case black characters. The order in which objects were introduced in the initial portions of the narratives was determined with the use of a 6 x 6Latin Square so that each object direction appeared at a different serial position in each narrative. For each participant, half of the narratives were randomly assigned to the direction judgment condition and the other half to the axis judgment condition. Narratives were presented to participants in a random order with the constraint that no more than 2 narratives of the same judgment type were presented in sequence.

Design The experiment was a 2 (mode of rotation: imagined, real) x 2 (type of judgment: direction, axis) x 2 (perspective: original, novel) x 6 (self-object directions: above, below, front, back, left, right) mixed factorial design. The type of rotation was manipulated between subjects while both the type of judgment and self-object directions varied within subjects. Each self-object direction was tested four times in each narrative, once under each of the four possible perspectives. Self-object directions were tested in a random order within each perspective. Also, the original perspective was never the first perspective that subjects were tested on.

Procedure The procedure was similar to the one used by Franklin and Tversky (1990). Two main differences from De Vega and Rodrigo (2001) were that a voice key was not used to collect responses and that the narratives included objects located on the above/below axis. The narratives were presented on a laptop computer that participants held onto their laps while sitting in a swivel chair. Participants were given unlimited time to study the first portion of the narratives. The narrative then continued in a sentence by sentence fashion with subjects pressing the space bar to request a new sentence. The second sentence after the first portion described the protagonist rotating to a new orientation in the horizontal plane. Depending on the condition they were assigned to, participants were instructed to either turn their selves by swiveling the chair to produce the reorientations that were described in the text, or to imagine their selves rotating without changing their actual orientation at any point throughout the experiment. After two filler sentences were presented, the name of one of the objects in the scene appeared. Subjects were instructed to press the space bar as soon as they were ready to report the relative position of the object. The time between the appearance of the object probe and the space bar press was the critical latency measure and will hereinafter be referred to as *response latency*. For direction judgments, when subjects pressed the space bar, a list with the terms "above", "below", "front", "back", "left", and "right", presented in a random order each time, appeared. Participants were instructed to press the key that corresponded to the integer (1 to 6) that appeared next to the direction they chose. For axis judgments, the list contained the choices "above/below", "front/back", and "left/right", and participants entered their answer using the 1 to 3 keys. The time between the appearance of the list and the key press for selecting the direction will be referred to as *answer latency*. Each narrative continued in the same fashion until all six objects were probed in each protagonist perspective. Each narrative involved 24 probes, 6 for each protagonist perspective. For each participant, three of the narratives were randomly assigned to the direction judgment type, and the rest to the axis judgment type. Below each object probe the words "direction" or "axis" were presented to remind participants of the type of response they needed to make.

Results

Participants responded correctly to 96.3% of the probes. Data from 2 subjects -- one from each rotation condition -- were discarded because accuracy did not exceed 60%.

Latency Incorrect responses were discarded from the latency analyses. Outliers in latency data were defined as reaction times deviating more than 3 standard deviations from each participant's type of judgment mean. Outliers in response RT resulted in an additional 6% of data and were also discarded from the analyses. Latency data for each self-object direction were collapsed to form three dimension means (i.e., a separate mean of each body axis). Moreover, latencies for the three novel perspectives did not differ from each other so they were collapsed to form a single novel perspective mean.

Answer Latency Analyzing answer RT provides a check on whether subjects successfully followed instructions on how to respond. Frequently, spillover effects of response RT on answer RT are observed. When this happens, however, answer RT patterns tend to mimic the ones observed in the response RT data and are either omitted from analyses (e.g., Bryant, Tversky, & Franklin, 1992) or combined with response RT (Franklin, Tversky, & Coon, 1992). No spill-over effects were observed in the present study. The only significant effect was a main effect for the type of judgment, F(1,36)=90.28, MSE=105394, p<.001. The average answer RT for direction judgments was greater than the corresponding RT for axis judgments (1944 ms and 1655 ms respectively). This is expected because the response choices were 3 for axis judgments and 6 for direction judgments.

Response Latency Several Analyses of Variance (ANOVA's) were performed. Interactions that are not discussed were not significant at a=.05.

As predicted, a significant mode of rotation x perspective x dimension interaction was obtained, F(2,72)=4.23, MSE=75530, p<.05 (figure 1).

Separate ANOVAS were performed for each mode of rotation.

When rotation was imagined, a significant perspective x dimension interaction was obtained, F(2,36)=8.05, MSE=114939, p<.01. Significant main effects for both perspective and dimension were obtained, F(1,18)=22.93, MSE=264189, p<.001 and F(2,36)=19.57, MSE=212008, p<.001 respectively. Performance was faster with the original than the novel perspective for above/below and left/right. For front/back the difference was not statistically significant, F(1,18)=2.73, MSE=193450, p=.12. Nevertheless, even in this dimension the average for the original perspective was smaller than that for novel perspective (2127 ms and 2363 ms respectively). Overall, the patterns of accessibility of the three axes conformed to the predictions of the Spatial Frameworks model for both the original and novel perspectives. Judgments on the left/right dimension were particularly slow when performed under a novel perspective (3025 ms) than under the original perspective (2208 ms), F(1,18)=32.83, MSE=193290, p<.001.

When rotation was physical, latency for the original perspective was shorter than the average latency for the novel perspective (1821 ms and 2149 ms respectively), F(1,18)=57.26, MSE=53699, p<.001. The perspective x dimension interaction was not significant, F(2,36)=1.99, MSE=36120, p=.15. However, there was a main effect of dimension, F(2,36)=21.61, MSE=55533, p<.001. The pattern of latencies for the three body axes corresponded with the pattern predicted by the Spatial Frameworks model.

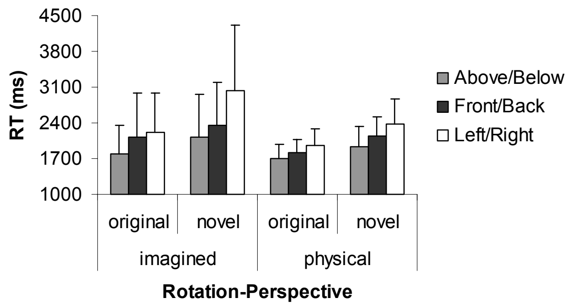

Figure 1: Latency for body axes as a function of the mode of rotation and the perspective of the protagonist.

Additionally, the analysis revealed a mode of rotation x judgment type x dimension interaction, F(2,70)=3.49, MSE=60334,
p<.05.

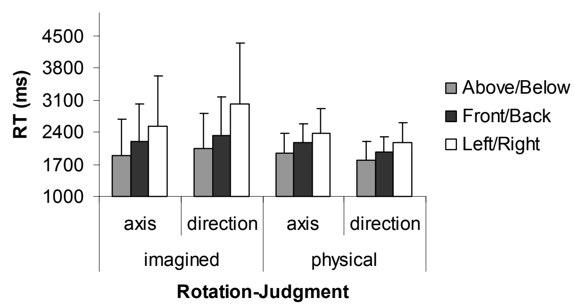

Figure 2: Latency for body axes as a function of the mode of rotation and the judgment type.

Further analyses were performed separately for each judgment type. When judgment was direction, a significant rotation x dimension interaction was obtained, F(2,72)=6.61, MSE=134329, p<.01. Overall with direction judgments, subjects were faster when the rotation was physical than imagined (2507 ms and 1979 ms respectively), F(1,36)=5.48, MSE=1448481, p<.05. An effect for dimension was also present, F(2,72)=31.49, MSE=134329, p<.001. Latency patterns conformed to the Spatial Frameworks model for both rotation modes. However, times were longer for all dimensions when rotation was imagined. The interaction was caused by a very long latency average for the left/right dimension under imagined rotations. When the judgment was axis, latencies for the various axes were similar for both types of rotation. The rotation x dimension interaction did not approach significance, F(2,7)=1.23, MSE=84641, p=.30. Similarly, no main effect for rotation mode was obtained, F(1,35)=.07, MSE=1353673, p=.80. However, a significant main effect for dimension was obtained, $F(2,70)=30.96$, $MSE=84641$, $p<.001$. The Spatial Frameworks pattern was observed in the dimension latencies. As seen in figure 2, the average latency for the left/right dimension (2452 ms) was shorter than the respective average of imagined rotation with a direction decision (3045 ms) but longer than that of real rotation with a direction decision (2170 ms).

An interesting result was the pattern observed for the rotation x judgment interaction, $F(1,35)=11.66$, $MSE=216901$, $p<.01$. When rotation was imagined, axis judgments (2212 ms) were faster than directional judgments (2463 ms), $F(1,17)=8$, $MSE=212424$, $p<.05$. However, when rotation was physical, the pattern of judgment times were actually opposite than the one obtained with imagined rotations. Axis judgments took longer than direction judgments (2155ms and 1979ms respectively). This difference was marginally significant, $F(1,18)=4$, $MSE=221130$, $p=.06$. A further analysis revealed that a significant type of judgment x perspective interaction for imagined rotations, $F(1,17)=5$, $MSE=24966$, $p<.05$. For novel perspective, direction judgments were performed significantly faster than axis judgments, $F(1,17)=13.6$, $MSE=56705$, $p<.01$. However, for the original perspective the two judgment types were not statistically different, $F(1,17)=0.95$, $MSE=150568$, $p=.34$.

Accuracy In contrast to the latency analysis, the ANOVA on accuracy revealed a significant main effect for the mode of rotation, $F(1,36)=4.41$, $MSE=.017$, $p<.05$. Accuracy was higher when rotations were physical instead of imagined (98% and 94% respectively). An advantage for physical rotation is also reported by De Vega and Rodrigo (2001). A significant mode of rotation x type of judgment interaction, $F(1,36)=5.32$, $MSE=.017$, $p<.05$, revealed that the effect of rotation was confined to direction judgments.

As in the latency analysis, a significant mode of rotation x perspective x dimension interaction was obtained, $F(2,72)=3.84$, $MSE=.0008$, $p<.05$. The mode of rotation x judgment x dimension interaction that was obtained in the latency analysis, was marginally significant, $F(2,72)=3.07$, $MSE=.002$, $p=.05$. For both interactions, the pattern of results resembled the patterns obtained in the latency analysis to a great extent. The only deviation from the latency data was that sometimes the judgments for front/back were no less accurate than judgments for above/below.

Discussion

The present experiment produced results that deviated from those reported by De Vega and Rodrigo (2001). When participants made direction judgments – the condition tested by De Vega and Rodrigo – they were both faster and more accurate with physical than imagined rotations. De Vega and Rodrigo reported that their subjects were more accurate but not faster with physical rotations. Perhaps, the use of only four objects in their narratives made it easy for participants to keep track of how their relative locations of objects changed with the protagonist reorientations.

Although the performance advantage for physical rotation would qualify as evidence for successful updating under De Vega and Rodrigo's (2001) methodology, other results from the present study suggest otherwise. Results suggest that the fastest performance under physical rotations was due to the relative ease with which direction judgments, especially left Vs right, were made when rotation was physical. The same result was obtained for imagined rotation when axis judgments were introduced. Indeed, when participants were not required to make a direction judgment, their performance was similar to that of participants with physical rotations. This suggests that the orientation of the ecological reference frame is important for making difficult discriminations between the poles of body-centric axes. The differences between the three dimensions were smaller when the ecological frame was aligned with the frame of the protagonist. This was true both when participants performed the task from the original perspective, under which their ecological frame is aligned with the protagonist frame, in either mode of rotation.

Despite the performance advantage with physical rotations, the present results provide clear evidence that participants did not update the self-object direction with either imagined nor physical rotations. In both cases, performance was both faster and more accurate when the task was performed from the original than a novel perspective. This result is not obtained in studies that use visually presented scenes (e.g., Rieser et al., 1986), and suggests one aspect that mental representations derived from texts might differ from those derived from perception. A possible account for this dissociation is provided by De Vega and Rodrigo (2001). While visually perceived scenes are anchored in a sensorimotor framework based on the ecological reference frame of the observer, mental representations of described scenes are grounded into a mental framework from which the self is detached. While physical movements can provide proprioceptive feedback that helps updating the mental representation in the sensorimotor framework, this feedback is not very helpful for representations that are anchored in a mental framework. However, as shown in the present study, although the ecological self might be disengaged from the mental framework, it is still important for making spatial decisions in it.

Finally, the accessibility patterns for the three dimensions conformed to the predictions of the Spatial Frameworks model (Franklin & Tversky, 1990). Objects on the above/below axis were located faster than objects on the front/back axis, which were in turn located faster than objects on the left/right axis. The differences among the dimensions were greater when rotations were imagined and judgments were for direction. While this result might be due to the higher difficulty of performing the task under these circumstances, it could alternatively mean that a part of the Spatial Frameworks effect is due to the need for discriminating the poles of the axes. Results from Bryant and Wright (1999) suggest that the difficulty of making discriminating decisions within the axes does not fully account for the Spatial Frameworks results.

In summary, the present study provided more substantial evidence to confirm the conclusions of De Vega and Rodrigo (2001), while at the same time provided a better understanding of how the ecological self interacts with spatial reasoning about imagined spaces derived from texts. While physical rotations led to no spatial updating of the original mental representation, they produced better performance by reducing the difficulty with making discrimination between the poles of body-centric axes. This result can have important practical implications for situations where spatial reasoning occurs from imagined perspectives (e.g., teleoperating robots for rescue mission and space exploration).

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References

Attneave, F., & Farrar, P. (1977). The visual world behind the head. *American Journal of Psychology, 90*, 549-563.

Bryant, D. J., Tversky, B., & Franklin, N. (1992). Internal and external spatial frameworks for representing described scenes. *Journal of Memory and Language, 31*, 74-98.

Bryant, D. J., & Wright, G. W. (1999). How body asymmetries determine accessibility in Spatial Frameworks. *The quarterly journal of experimental psychology, 52A*, 487-508.

Chance, S. S, Gaunet, F., Beall, A. C, & Loomis, J. M. (1998). Locomotion mode affects the updating of objects during travel: The contribution of vestibular and proprioceptive inputs to path integration. *Presence, 7*, 168-178.

Corballis, M. C., & Beale, I. L. (1976). *The psychology of left and right*. Hillsdale, NJ: Lawrence Erlbaum.

De Vega, M., & Rodrigo, M. J. (2001). Updating spatial layouts mediated by pointing and labelling under physical and imaginary rotation. *European Journal of Cognitive Psychology, 13*, 369-393.

Denis, M., & Cocude, M. (1989). Scanning visual images generated from verbal descriptions. *European journal of cognitive psychology, 1*, 293-307.

Franklin, N., & Tversky, B. (1990). Searching Imagined Environments. *Journal of Experimental Psychology: General, 119*, 63-76.

Franklin, N., Tversky, B., & Coon, V. (1992). Switching points of view in spatial mental models. *Memory & Cogntion, 20*, 507-518.

Fukusima, S. S, Loomis, J. M, & Da Silva, J. A. (1997). Visual perception of egocentric distance as assessed by triangulation. *Journal of Experimental Psychology: Human Perception and Performance, 23*, 86-100.

Klatzky, R. L, Loomis, J. M, Beall, A. C, Chance, S. S, & Golledge, R. G. (1998). Spatial updating of self-position and orientation during real, imagined, and virtual locomotion. *Psychological Science, 9*, 293-298.

Loomis, J. M, Klatzky, R. L, Golledge, R. G, Cicinelli, J. G, Pellegrino, J. W, & Fry, P. A. (1993). Nonvisual navigation by blind and sighted: Assessment of path integration ability. *Journal of Experimental Psychology: General, 122*, 73-91.

Presson, C. C, & Montello, D. R. (1994). Updating after rotational and translational body movements: Coordinate structure of perspective space. *Perception, 23*, 1447-1455.

Rieser, J. J, Guth, D. A, & Everett, W., & Hill, E. W. (1986). Sensitivity to perspective structure while walking without vision. *Perception, 15*, 173-188.

Rieser, J. J. (1989). Access to knowledge of spatial structure at novel points of observation. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 15*, 1157-1165.

Simons, D. J, & Wang, R. F. (1998). Perceiving real world viewpoint changes. *Psychological Science, 9*, 315-320.

Wang, R. F., & Simons, D. J. (1998). Active and passive scene recognition across views. *Cognition, 70*, 191-210.

Wang, R. F., & Spelke, E. S. (2000). Updating egocentric representations in human navigation. *Cognition, 77*, 215-250.

Zwaan, R. A, & Radvansky, G. A. (1998). Situation models in Language comprehension and memory. *Psychological Bulletin, 123*, 162-185.