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Event boundaries and memory improvement

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ABSTRACT

The structure of events can influence later memory for information that is embedded in them, with evidence indicating that event boundaries can both impair and enhance memory. The current study explored whether the presence of event boundaries during encoding can structure information to improve memory. In Experiment 1, memory for a list of words was tested in which event structure was manipulated by having participants walk through a doorway, or not, halfway through the word list. In Experiment 2, memory for lists of words was tested in which event structure was manipulated using computer windows. Finally, in Experiments 3 and 4, event structure was manipulated by having event shifts described in narrative texts. The consistent finding across all of these methods and materials was that memory was better when the information was distributed across two events rather than combined into a single event. Moreover, Experiment 4 demonstrated that increasing the number of event boundaries from one to two increased the memory benefit. These results are interpreted in the context of the Event Horizon Model of event cognition.

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1. Introduction

Daily life is a continuous stream of information. This stream is parsed into more manageable units through a process of event segmentation. These segments are then stored in memory. One of the consequences of segmentation is its influence on later memory, including better memory for information occurring *at* event boundaries (e.g., Swallow, Zacks, & Abrams, 2009), a disruption of memory for information that is carried *across* event boundaries (e.g., Radvansky & Copeland, 2006; Swallow et al., 2009), and better memory for information that can be *separated* by event boundaries, allowing people to capitalize on event structure to chunk and organize information (e.g., Zacks & Tversky, 2001). The aim of this study is to further explore the last of these processes.

According to theories of event cognition, when people process, comprehend, and remember information about events, they use mental representations called *event models* (e.g., Radvansky & Zacks, 2014). These event models serve as mental simulations of ongoing events, similar to the concept of situation models (van Dijk & Kintsch, 1983; Zwaan & Radvansky, 1998) and mental models (Johnson-Laird, 1983). For event cognition, experience and language are two ways to acquire information about events. The current experiments use both experience and language to look at how segmenting information into separate events affects memory.

1.1. Event boundaries and memory

The organization of information into event models helps a person structure the information that is being experienced or read about. One role of this structuring of information into event models is to often aid comprehension and memory by putting those elements that are more likely to belong together into a single representation and keeping elements from an irrelevant event from intruding. This is consistent with the general principle in memory research that structuring information often improves performance. One of the aims of the current study is to explore how event structure and the segregation of information into different event models plays this role.

The Event Horizon Model (Radvansky, 2012; Radvansky & Zacks, 2011, 2014) provides a framework for understanding how and when information is remembered as a function of event structure, and how this structure can influence the availability of information that is either integrated into a common event or distributed across events. The Event Horizon Model has five components: (1) events can be *segmented* and the different event models are stored as separate traces in memory, (2) information in the current working event model is being actively processed in working memory, (3) there is the storage of the causal relations among

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events (4) there is retrieval facilitation for noncompetitive attribute retrieval, and (5) there is retrieval interference for competitive event model retrieval. The work reported involves the operation of the first and fourth components.

The first principle is based on research in event cognition that has found that people actively parse the stream of incoming information, particularly at points when there were changes in the ongoing stream of action (e.g., Newtson, 1973; Newtson, Engquist, & Bois, 1976; Swallow et al., 2009; Zacks & Tversky, 2001; Zacks, Speer, Swallow, Braver, & Reynolds, 2007). When there are changes in event components, such as a change in space, these changes serve as event boundaries. This first principle can be thought of as embodying many of the principles of Event Segmentation Theory (Swallow et al., 2009; Zacks & Tversky, 2001; Zacks et al., 2007). In this way, the Event Horizon Model, subsumes Event Segmentation Theory. These event boundaries can be marked perceptually (e.g., Hard, Tversky, & Lang, 2006; Newtson et al., 1976; Zacks, 2004), inferred based an actor's location, intentions, or goals (Speer, Zacks, & Reynolds, 2007) or linguistically (Magliano, Miller, & Zwaan, 2001; Speer et al., 2007; Zwaan, Magliano, & Graesser, 1995; Zwaan & Radvansky, 1998). The current study does not assess this principle, per se, but relies on it in the sense that when an event boundary is encountered, people close off one event model and create another.

The fourth principle is the focus of the current studies. It is the idea that the distribution of event attributes across event models results in memory facilitation. One source of evidence consistent with this idea is a line of work on retroactive interference that later spawned work on environment-dependent memory retrieval. However, rather than focusing on how returning to a prior location facilitates retrieval, this earlier work focused on how moving from one location to another decreases retroactive interference (Bilodeau & Schlosberg, 1951; Greenspoon & Ranyard, 1957; Jensen, Dibble, & Anderson, 1971; Smith, Glenberg, & Bjork, 1978; Strand, 1970). In these studies, people were presented with two lists of items, one list in one room and a second in either the same or a different room. What was consistently found was that there is less retroactive interference for the first list after a spatial shift (an event boundary) compared to when learning was all done in the same room. Moreover, Strand (1970) suggests that other non-spatial factors also reduce retroactive interference, such as task disruption. In these studies, people were presented with two lists of items, again, one in one room and a second in either the same or a different room. Less retroactive interference was found for the first list after a spatial shift (an event boundary) and also when people left and then returned to the same room between lists.

More to the point of the current study, a number of studies by Smith (1982, 1984; Smith & Rothkopf, 1984) demonstrated an overall improvement in recall memory for word lists or lecture material when people memorized information across multiple spatial locations. One possible explanation is that recall is improved because people are associating information with the locations where the information was learned. However, this does not appear to be the case because providing the different locations as retrieval cues does not provide any retrieval benefit (Smith, 1984). The current work goes beyond these prior studies by exploring the influence of event structure on memory along with the physical environmental context that was assessed in that work. In the following studies we explore whether this improvement is a result of environmental context shifts or a more general principle of event structure. This event boundary benefit extends beyond the paradigm of word lists learned in physically different locations to events defined by computer windows as well as the context of narrative events with linguistically conveyed event boundaries. Thus, the events are experienced as changes in the location in which the information is encountered, as well as changes that were mentally simulated as part of narrative comprehension. These findings can now be assessed in the context of the Event Horizon Model of event cognition, as well as recent findings on the role of event structure on later memory. As information is distributed across multiple events, this provides structure for the information, leading to multiple event models, each containing fewer elements, as compared to a case where all elements would be part of one larger model. This organization and structure of information into small subunits can then facilitate the later retrieval of information.

In comparison to the Event Horizon Model account, there are alternative explanations for why memory would be improved in the presence of event boundaries. The first is that people will use the different events as mental categories. The idea that structure and organization can aid memory for word lists is well known (e.g., Bower, Clark, Lesgold, & Winzenz, 1969). By categorizing the items into two sub-lists rather than one long list, people could use list half as a cue to retrieve information. The prediction from this view would be that memory will be better when there is an event boundary present.

With an event boundary, people would be more likely to recall together (cluster) information from the same event and not alternate between information that is distributed across two events. This is because either event could serve as a memory cue, activating all of the information from it more so than that from the other event, or because information learned in the same event would be more likely to prime each other. This is consistent with other work in event cognition assessing event structure and memory. For example, in a study by Ezzyat and Davachi (2011) people were given narratives to read that contained event boundaries. Afterward, they were given a cue recall test in which people were provided with a sentence from the narrative and the task was to recall the next sentence. What was observed was that people were better able to recall the next sentence if there was not an event boundary between the two as compared to if there was. In other words, people were better able to retrieve information if it was part of the same event than if it were part of separate events. Thus, the expectation would be that events are acting like categories to structure retrieval.

Regardless of the precise mechanism, there would be increased event-based recall organization when there is an event boundary present. This idea is supported by the fact that Smith (1982, 1984) found that there was increased clustering with multiple learning environments. That said, the measure of clustering used did not correct for chance which we do in our experiments. To assess clustering, we used Adjusted Ratio of Clustering (ARC) scores (Roenker, Thompson, & Brown, 1971). ARC scores are calculated as follows:

$$\mathrm{ARC} = \frac{(R - E(R))}{(maxR - E(R))} \tag{1}$$

The expected number of repetitions, $E(R)$ is calculated as follows:

$$E(R) = \frac{\sum_i n^2}{N} - 1 \tag{2}$$

where n represents the number of items recalled from a category i, and N represents the total number of items recalled. They convey the ratio of repetitions in recall from a particular category to the maximum number of possible repetitions ($maxR$), accounting for both the number of items recalled by a person and the number of repetitions expected by chance. An ARC score of 1 would indicate perfect categorization and an ARC score of 0 would indicate random organization. For example, if a person were to recall six items clustered perfectly (i.e., three items from list 1 followed by three items from list 2), $N = 6$, $n = 3$ for each category, and the maximum number of repetitions is four (six items recalled minus two categories). The number of repetitions in this case is four (the second and third items from list 1 and the second and third items from list 2), and the expected number of repetitions is 2 ((18/6) − 1). The ARC score is then

$$\text{ARC} = \frac{(4-2)}{(4-2)} = 1 \quad (3)$$

If a person were to recall six items in the order (in terms of recall list) list 1, list 1, list 2, list 1, list 2, list 2 the ARC score will be less than one. In this case, the other variables are the same, but the number of repetitions is two. The ARC score will be

$$\text{ARC} = \frac{(2-2)}{(4-2)} = 0 \quad (4)$$

In this example, the number of repetitions is equal to what would be expected by chance, so the ARC score is zero.

Finally, another alternative is that overall memory for information is better, not because memory for the entire set of information is improved, but because there is evidence for superior memory for information that occurs at or around event boundaries. In particular, people show improved memory for information that occurs at event boundaries (Swallow et al., 2009). According to Event Segmentation Theory (EST) there is better memory because of an increase in processing activity when an event boundary is encountered. EST suggests that a person forms working event models that capture what is happening 'right now' (Kurby & Zacks, 2008). Observers use these event models to generate predictions of future input. These event models are robust to further modification for as long as they accurately predict what is currently happening. However, when there is an event shift, these predictions are violated. When an event changes, prediction accuracy generated from the event model decreases and prediction error increases. High levels of prediction error trigger some sort of gating mechanism to open, causing the event model to be reset and rebuilt. As a consequence, as event models are being rebuilt, incoming information (such as information about objects and actors) is processed more than would otherwise be the case. Thus, the prediction here is memory will be better when there is an event boundary present, but closer analysis will reveal that this benefit will largely be confined to information that is encountered closer to the event boundary.

2. Current experiments

The aim of the current experiments was to explore the idea that the presence of event boundaries can improve memory when information is represented across multiple events. Experiment 1 was essentially a replication and extension of work that has been done before using word lists and physical movement in space (Bilodeau & Schlosberg, 1951; Greenspoon & Ranyard, 1957; Jensen et al., 1971; Smith et al., 1978; Strand, 1970), but with the added consideration of other theoretical accounts. Experiment 2 was a conceptual replication, again using word lists, but this time using computer windows in the place of rooms to assess whether the pattern of findings observed were due to spatial factors per se, and not more general event structure. Experiment 3 went further and dropped the use of word lists and instead looked at memory for narrative text information. Moreover, in Experiment 3 the event boundary was conveyed linguistically in the text rather than being a physical/perceptual change as in Experiments 1 (different rooms) and 2 (computer windows). Finally, having established the generality of the finding that event boundaries can improve memory, in Experiment 4 we used the method for Experiment 3 to assess whether increasing the number of event boundaries would further increase the memory benefit.

3. Experiment 1

The aim of Experiment 1 was to assess whether recall of a word list would improve when an event shift occurred halfway through a study list, as was found in previous work (Smith, 1982, 1984), and to explore this improvement. More specifically, whether any such improvement was due to processes suggested by alternative accounts, such as the clustering of information at retrieval, or superior memory for information at and around the event boundary. For Experiment 1, in the Shift condition, halfway through the word list, people moved from one room to another, where the second half of the list was given. In comparison, in the No-Shift control condition, people were given half of the word list on one side of a larger room and then travelled to the other end of the room for the other half of the list. The distance travelled was the same in both conditions. The only difference was whether an event boundary occurred between the two list halves. As a result of the segmentation process, the information from each side of the boundary is stored in a separate event model. In the context of this experiment, when there is a shift from one room to another, two event models are created, one for each room. However, if people remain in one spatial framework, even when they move from one side of the room to another, there is no clear event boundary. As such, only one event model is created. Note that it is possible that people could have perceived moving across the room as a new event. However, the absence of moving to a different room makes such an interpretation less likely, or at least makes the potential boundary less dramatic.

3.1. Method

3.1.1. Participants

Forty-eight undergraduates (23 female) at the University of Notre Dame participated for class credit.

3.1.2. Materials

Forty words were used in this study. All were five letters long, contained one syllable, and ranged in word frequency from 20 to 103 per million ($M = 29.7$) (Coltheart, 1981). These forty words were divided into 4 sub-lists of 10 words each. The order of the words within a sub-list was always the same.

3.1.3. Procedure

This study was done in the Memory Laboratory at the University of Notre Dame. A plan view of the lab with the testing locations, marked as positions A, B, C, and D, is provided in Fig. 1. People were told, "In this study you will move about and listen

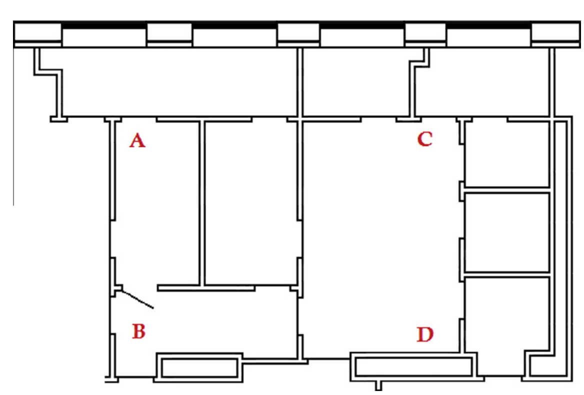

Fig. 1. This is a plan overview of the Notre Dame Memory Lab. A and B are the locations for either the spatial shift or no-shift pairs. Note that the order of the pairs was completely counter-balanced across participants.

to words read to you by the experimenter. Your task is to remember the words and complete the tasks asked of you as best you can." They started at one location, where they were read one of the sub-lists at a rate of approximately one word per second. Then, the person moved to the opposite location within a pair: A to B, B to A, C to D or D to C. Next, the person was read the second sub-list. Importantly, there was a change in spatial location (an event boundary) for the A–B pair, but not for the C–D pair. Thus, these pairs were the Shift and No-Shift conditions, respectively. At the end of the second sub-list, people were given a two-minute distractor task of multiplication problems (e.g., $57 \times 78 = ?$) to encourage some forgetting. Subsequently, they were given a sheet of paper and asked to recall as many of the twenty words from both sub-lists as possible. After completing the recall, the procedure was repeated with the other position pair and the remaining two sub-lists.

The order of the conditions, and sub-lists were counterbalanced across subjects. The experimental procedure lasted approximately ten minutes.

3.2. Results and discussion

The accuracy data were submitted to a one-way repeated measures analysis of variance (ANOVA). The effect of Shift was significant; $F(1,47) = 4.66$, $MSE = .007$, $p = .036$, $\eta_p^2 = .09$. People recalled a larger proportion of the words in the Shift condition ($M = .31$; $SE = .02$) than the No-Shift condition ($M = .27$; $SE = .02$). As predicted, improved recall was found consistent with the idea that event boundaries provide a means of structuring and organizing the information. Now, we explore the alternative possible causes for this improvement.

To assess the possibility that people are spontaneously using events as mental categories, with each location serving as a cue to retrieve the items learned in it, ARC scores were calculated using the list halves as categories for people who recalled three or more words in both conditions, for a total of 44 scores in the analysis. Contrary to the idea that people are using locations as retrieval cues, there was actually nominally lower clustering in the Shift condition ($M = .27$; $SE = .10$) than the No-Shift condition ($M = .31$; $SE = .11$), although this difference was not significant, $F < 1$. Thus, there was no evidence to support an event cueing account.

A second possibility was based on encoding changes that can occur at event boundaries. As suggested by Event Segmentation Theory (e.g., Kurby & Zacks, 2008; Swallow et al., 2009; Zacks, Speer, & Reynolds, 2009), items presented near an event boundary are better remembered than those further away (Swallow et al., 2009). This is because, prior to an event boundary, the situation is stable, and not as much attention is required to predict what will happen next; however, when an event boundary is encountered, prediction violations increase. These violations lead to attentional gates opening, and a greater likelihood of information from this time being stored in memory. So, it may be that people do better in the Shift condition because an event boundary could boost memory for words in the middle of the list (items 10 and 11) which are the items most likely to be affected by such a process. As such, there should be an increase in the recall rate for the items immediately prior to and after the shift. The two words just before and after the event boundary were chosen to assess memory at the event boundary as one would expect these items to be the most affected.

To assess this possibility, a 2 (Boundary) $\times$ 2 (Shift) repeated measures ANOVA was done, in which Boundary items were those at positions 10 and 11, and the Non-Boundary items were all other items. These data are reported in Table 1. There was a main effect of Shift, $F(1,47) = 4.43$, $MSE = .029$, $p = .041$, $\eta_p^2 = .09$, with people being more accurate when there was a shift. Moreover, there was a main effect of Boundary, $F(1,47) = 12.98$, $MSE = .049$, $p = .001$, $\eta_p^2 = .22$, with people being less accurate for those items around the event boundary. Importantly, if the improvement in the overall memory score in the Shift condition is due to an increase for items around the event boundary, the interaction should be significant (with a larger shift effect for the Boundary items). Although there was a nominally larger increase for boundary items, this critical interaction was not significant, $F = 1.61$, $p > .20$. Thus, the evidence is weak that in this paradigm there is better memory for items occurring near an event boundary.

Table 1
Recall accuracy data (in proportions) for Experiments 1–4 as a function of the presence of an event shift and whether the items were at the event boundary or not. Standard errors are presented in parentheses.

	No Shift	Shift
Experiment 1		
Nonboundary	.30 (.02)	.31 (.02)
Boundary	.15 (.04)	.24 (.04)
Experiment 2		
Nonboundary	.35 (.03)	.37 (.03)
Boundary	.32 (.03)	.36 (.03)
Experiment 3		
Nonboundary	.22 (.01)	.25 (.02)
Boundary	.12 (.01)	.23 (.02)

	No Shift	One Shift	Two Shift
Experiment 4			
Nonboundary	.13 (.01)	.24 (.02)	.28 (.03)
Boundary	.18 (.02)	.21 (.01)	.24 (.01)

4. Experiment 2

The aim of Experiment 2 was to extend the findings of Experiment 1 to a situation in which (a) there were more trials, (b) different word lists were involved, and (c) computer windows rather than rooms in a building were used to create event boundaries. So, for Experiment 2, there were 12 word lists per condition, rather than a single list. The last change is the most interesting. Specifically, we assessed whether these sorts of effects are due to changes in a person's physical location (their environmental context), or due to any change that could serve to segment experienced events. That is, is this a more event-based finding? In the Shift condition of Experiment 2, halfway through a word list, people had to close the current computer window and open another, in which the second half of the list was given. In comparison, in the No-Shift control condition, people were given the entire word list in a single computer window.

4.1. Method

4.1.1. Participants

Thirty-seven undergraduates (27 female) at the University of Notre Dame participated for class credit.

4.1.2. Materials

There were 288 nouns used as the to-be-remembered words in this study. These nouns were 4–6 letters long, contained 1–2 syllables, and ranged in word frequency from 1 to 672 per million ($M = 25.2$) (Coltheart, 1981). For each participant, these nouns were randomly divided into 24 lists of 12 words each. The order of the words within a sub-list was randomized.

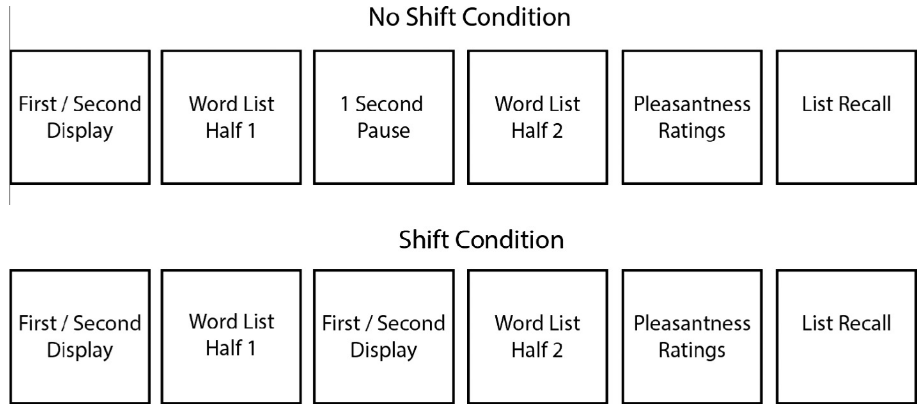

Fig. 2. This is the sequence of events for the No Shift and Shift trials for Experiment 2.

4.1.3. Procedure

The sequence of each trial is shown in Fig. 2. For this experiment people sat at a desktop computer. The screen resolution was set at 1024 × 768 pixels. At the beginning of the study there was a 324 × 297 pixel window with two response buttons. The first (labeled "first") was activated but the second (labeled "second") was not. For the two window trials (Shift condition), pressing the "first" button opened a new window that was 655 × 516 pixels in size. The nouns were presented one at a time for 1 s each. People were told to memorize the words as efficiently as possible. Halfway through the list a close button appeared on the bottom of the screen. When this button was clicked, the window closed, and the screen with the two buttons was shown again, this time with the "first" button deactivated and the "second" button activated. Clicking on the second button brought up the list presentation window again and the second half of the list was shown. After all 12 words were presented, a new 1024 × 768 pixel window opened for the distractor task. For the distractor task, people were asked to rate a series of adjectives for pleasantness on a 1–7 scale. This continued until two minutes elapsed. After this, a 1024 × 768 pixel recall screen opened. People were told to type in as many words from the list as they could remember. When they were done, they clicked on a "done" button at the bottom of the screen.

In comparison, for the one window trials (No Shift condition), pressing the "first" button started the process like the Shift condition. However, rather than having to close the first window halfway through and then open a second window, halfway through the first list there was a 1 s pause and the list continued within the same window. At the end of the word list, the remainder of a trial was like that for the two window trials. It is important to note that from the participants' perspective, there was no way to tell if a trial was a one or two window trial until the halfway point of the list was reached. The order of the conditions was randomized for each participant.

4.2. Results and discussion

The accuracy data were submitted to a 2 (Shift) repeated measures ANOVA. There were significant main effects of Shift, $F(1,36) = 9.90$, $MSE = .003$, $p = .003$, $\eta_p^2 = .21$. Importantly, people recalled a higher proportion of words in the Shift ($M = .37$; $SE = .03$) than the No-Shift condition ($M = .34$; $SE = .03$). As in Experiment 1, the presence of an event boundary improved recall, consistent with the idea that the increased structure and organization of the information served to aid later retrieval.

As in Experiment 1, to assess whether people were using the separate window-based events categories and then using event category as a recall cue, ARC scores were calculated using the list halves as categories. Like Experiment 1, and contrary to the idea that the event boundary might increase clustering, there were no ARC score differences in the Shift ($M = .20$; $SE = .01$) and No-Shift conditions ($M = .19$; $SE = .01$), $F < 1$. So, again, there is no evidence that the increased recall performance is due to the use of the events per se as retrieval cues.

Also, like Experiment 1, we explored the possibility that people do better in the Shift condition because there is increased processing at the event boundary, which then improves overall recall. To assess this, a 2 (Boundary) × 2 (Shift) repeated measures ANOVA was performed, in which Boundary items were those at positions 6 and 7, and the Non-Boundary items were all other items. These data are reported in Table 1. There was a main effect of Shift, $F(1,36) = 13.62$, $MSE = .003$, $p = .001$, $\eta_p^2 = .28$, with people being more accurate when there was a shift. The main effect of Boundary was not significant, $F(1,36) = 2.26$, $MSE = .005$, $p = .14$, $\eta_p^2 = .06$, with people being nominally less accurate for those items around the event boundary. Importantly, if the improvement in the overall memory score in the Shift condition is due to an increase for items around the event boundary, the interaction should be significant (with a larger shift effect for the Boundary items). However, this was not the case; $F < 1$. So, again, there is no evidence of superior memory in this paradigm for information experienced near the event boundary.

5. Experiment 3

The aim of Experiment 3 was to assess whether the presence of an event shift in a narrative text, rather than physical locations such as rooms or computer windows, would improve memory. According to theories of event cognition, any change in an event will result in the creation of a new event model, even if that is a mental shift in context, such as when there is an event shift in a narrative text. If the segregation of different elements into separate event models is a general principle, this should apply to sets of information other than word lists and the perceptual changes that would accompany a shift in room or computer window, as was the case for Experiments 1 and 2. Thus, Experiments 3 and 4 will extend the results of Experiments 1 and 2 by looking at the impact of an imagined, rather than physical event change.

For Experiment 3, people read stories that did or did not contain an event shift. The presence of situation changes in narrative text have repeatedly been shown to be treated as event boundaries in that people explicitly mark them as such when asked to do so (Magliano et al., 2001), and are typically accompanied by increases in reading time reflecting the increase in cognitive activity of setting up a new event (Mandler & Goodman, 1982; Zwaan et al., 1995; Zwaan, Radvansky, Hilliard, & Curiel, 1998). After reading all of the stories, people were given a free recall test. If the findings of Experiments 1 and 2 reflect general principles of event structure and memory, and are not specific to physically defined region or to memory for word lists, then stories containing an event shift will be better remembered than those with no event shift.

5.1. Method

5.1.1. Participants

Forty-seven participants (32 female) were recruited using Amazon's Mechanical Turk website. Participants ranged in age from 18 to 64 ($M = 34.81$, $SD = 12.39$). Subjects were paid $1.00 for their participation, and the study was presented via Qualtrics, an online survey software program. Participation was limited to those who were over 18 and native English speakers located in the United States.

5.1.2. Materials

There were twelve stories used, eight experimental stories and four fillers. For the experimental stories, the event boundary sentence conveyed a causal, spatial, activity, or temporal event shift. For example, the sentence "She went down the hall to take a shower" conveys a change in the character's spatial location, whereas the sentence "She thought about going down the hall to take a shower" does not. Stories were 10–14 sentences in length and varied in topic. An example of one of the experimental stories is provided in Appendix A. Each of the 8 experimental stories had two versions that differed only in terms of one critical sentence. One version of the critical sentence conveyed an event shift, and the other did not. A given participant saw four Shift story versions and four No-Shift versions. In addition to the experimental stories, the filler stories were dispersed throughout with two of them beginning the task to orient the participants to the format of the study.

In addition to the stories themselves, there were two comprehension questions per story. These questions assessed various aspects of the stories except the critical sentences and were answered by a 'yes' or 'no' click response. These questions served as a gauge to make sure that the participants were actively reading the stories. No participants were eliminated for failing to answer at least 75% of the comprehension questions correctly.

5.1.3. Procedure

Participants were given a brief explanation of the study and a screen to indicate their consent to participate. After this, people read instructions and continued on to the stories. At the beginning of each story a title was presented. Afterwards, each story was presented one sentence at a time, and participants advanced through the story by pressing the space bar. After each story the two comprehension questions were presented. After the practice stories, which were always presented first, stories were presented in a random order for each person. Each person saw an equal number of shift and no-shift stories.

After reading all of the stories, participants completed a recall test. They were prompted with the title and the first sentence of each story and were asked to recall as much of the rest of the story as they could. Participants made their responses by typing into a text box on the computer screen. Recalls were scored using a proposition-based criterion in which the abstract idea units in each text element were identified a priori and each recall report was scored as to whether it contained these elements.

Demographic questions were asked at the end of the experiment. This demographic information included gender, age, education level, ethnicity, handedness, environment, noise level, computing device, Internet connection, native language, and current state of alertness. Data from subjects in noisy environments and those completing the assessment on a smart phone or tablet were excluded.

5.2. Results and discussion

The recall data were analyzed using a one-way repeated measures ANOVA comparing Shift and No-Shift stories. The difference in proportion of propositions recalled was significant, $F(1,46) = 9.05$, $MSE = .004$, $p < .01$, $\eta_p^2 = .16$. People recalled more idea units in the Shift ($M = .25$, $SE = .02$) than the No-Shift condition ($M = .21$, $SE = .01$). As in the previous experiments, the presence of an event shift improved recall.

Although there are many aspects of texts that bias people to retrieve information as part of whole events, to be complete and parallel the analyses of Experiments 1 and 2, ARC scores were calculated. There was no ARC score difference between the Shift ($M = .96$, $SE = .02$) and No-Shift conditions ($M = .98$, $SE = .01$), $F < 1$. Moreover, given the fact that the materials in this experiment were narrative texts, it is not surprising that these scores are near ceiling. Still, like the previous experiments, this does not support the idea that people are using the separate event a retrieval cues.

To assess whether the improved memory in the Shift condition was due to increased processing at the boundary sentence per se, the data were submitted to a 2 (Boundary) $\times$ 2 (Shift) repeated measures ANOVA. The boundary shift sentence was used as the measure of event processing here because this was the text unit that actually conveyed the event boundary, whereas the other sentences did not. Thus, an important difference between Experiment 3 (as well as 4) and Experiments 1 and 2 is the nature of the boundary shift to the to-be-remembered information. Specifically, the event boundary in Experiments 1 and 2 (the room and computer window shifts) was more visual in nature. In contrast, with narrative texts, the event boundary is conveyed in one of the text sentences itself, so it is more context-based. That said, it should still be possible to assess whether the overall increase in memory observed here is due to the segregation of information into separate event models or to better memory for information at the event boundary.

Both the main effect of Boundary and Shift were significant, $F(1,46) = 15.45$, $MSE = .012$, $p < .001$, $\eta_p^2 = .25$, and $F(1,46) = 17.87$, $MSE = .014$, $p < .001$, $\eta_p^2 = .28$, respectively. Moreover, this was modified by a significant interaction, $F(1,46) = 7.86$, $MSE = .010$, $p = .007$, $\eta_p^2 = .15$. Simple effects tests revealed that the effect of Shift was significant for the Boundary sentences, $F(1,46) = 15.17$, $MSE = .020$, $p < .001$, $\eta_p^2 = .25$, with greater recall in the Shift than the No-Shift condition. The effect of Shift was also significant for the Non-Boundary sentences, $F(1,46) = 6.82$, $MSE = .004$, $p = .012$, $\eta_p^2 = .13$, again, recall was greater in the Shift condition than the No-Shift condition. The difference in the size of these effects is consistent with the idea that memory is more greatly improved in the Shift condition for the boundary sentence than for the other non-boundary sentences. This results is similar to those found by Zacks et al. (2009) in which memory was better for boundary information. Unlike Experiments 1 and 2, there is some evidence in this experiment that superior memory might be due to better memory for information occurring at the event boundary, as the size of the effect is larger for the Boundary sentences.

6. Experiment 4

The aim of Experiment 4 was to assess whether the presence of more than one event shift provides an additional memory benefit. If the segmentation of information into multiple event models helps a person manage the information that was encountered previously, then dividing this information up even further should provide even more benefit. This further explores how the segmentation of events into separate models affects the benefit to memory found in the previous experiments. In Experiment 4, people read stories that contained zero, one, or two event shifts.

6.1. Method

6.1.1. Participants

Data were collected from 48 participants (33 female) using the Mechanical Turk website. Participants ranged in age from 18 to 68 ($M = 37.4$, $SD = 13.75$). They were paid $1.00 for their participation.

6.1.2. Materials and procedure

The same eight stories from Experiment 3 were used in Experiment 4; in each story one sentence was rewritten to convey an additional event shift to create the two-shift version. An example story is provided in Appendix A. Four additional stories were included as fillers. The procedure was the same as Experiment 3 and participants were replaced using the same criteria. No participants were eliminated for failing to answer at least 75% of the comprehension questions correctly.

6.2. Results and discussion

The recall data were analyzed using a repeated measures ANOVA comparing zero, one, and two shift stories. The overall analysis showed a significant difference in the proportion of propositions recalled, $F(2,94) = 9.01$, $MSE = .003$, $p < .001$, $\eta_p^2 = .16$. Simple effects tests revealed that people recalled more in the Two- and One-Shift conditions ($M = .27$, $SE = .01$, $M = .23$, $SE = .01$, respectively) than the No-Shift condition ($M = .14$, $SE = .01$). There was also a non-significant trend between the No- and One-Shift conditions, $F(1,47) = 3.20$, $MSE = .003$, $p = .080$, $\eta_p^2 = .06$, as well as a significant difference between the One- and Two-Shift conditions, $F(1,47) = 6.39$, $MSE = .004$, $p = .015$, $\eta_p^2 = .12$. Finally, not surprisingly, the difference between the No- and Two-Shift conditions was significant, $F(1,47) = 15.41$, $MSE = .004$, $p < .001$, $\eta_p^2 = .25$. Thus, narratives that contain two event shifts were remembered better than those with one, which were remembered marginally better than those with none. A possible reason for the marginally significant difference in Experiment 4 compared with Experiment 3 for the No- versus One-Shift conditions is the fact that there were fewer observation per condition, which reduced the power somewhat.

Again, paralleling the first two experiments, to assess whether the three events served as categories during recall, ARC scores were calculated. There was no difference between the No-Shift ($M = .96$, $SE = .02$), One-Shift ($M = .94$, $SE = .02$), and Two-Shift conditions ($M = .95$, $SE = .01$), $F < 1$. Again, although we note that the ARC scores were near ceiling because of the nature of narrative text, we also note that results of this analysis do not support the idea that people are using the separate events as retrieval cues.

To assess whether the improved memory in the shift conditions is due to improved memory for the boundary sentence per se, as suggested by Experiment 3, the data were submitted to a 2 (Boundary) $\times$ 3 (Shift) repeated measures ANOVA. Again, these data are shown in Table 1. Both the main effect of Boundary and Shift were significant, $F(1,47) = 21.71$, $MSE = .008$, $p < .001$, $\eta^2 = .32$; $F(2,94) = 20.83$, $MSE = .011$, $p < .001$, $\eta^2 = .31$, respectively. Moreover, there was a significant interaction, $F(2,94) = 6.85$, $MSE = .010$, $p = .002$, $\eta^2 = .13$. Simple effects tests revealed that the effect of Shift was not significant for the Boundary sentences, $F(2,94) = 1.89$, $MSE = .010$, $p = .157$, $\eta^2 = .04$, but it was for the Non-Boundary sentences, $F(2,94) = 16.78$, $MSE = .016$, $p < .001$, $\eta^2 = .26$. Thus, while there is some memory benefit for the boundary sentences as they move from the nonboundary to boundary versions, this benefit was not as great as the benefit for the non-boundary sentences. These results are more consistent with Experiments 1 and 2 which did not find that improved memory for the boundary information disproportionately accounted for the memory benefit. Thus, the benefit for memory from the event boundary extends to the entire text.

The results of these studies are consistent with the idea that event shifts help people segregate information into different event models, and that this increases structure and organization and provides a means of encoding the information into several, sparser, sub-units. This segregation of information then allows people to be more successful in their attempt to later recall the entire set.

7. General discussion

In the current study, people were given event information that either had zero, one or two event shifts during presentation and then memory was tested. In all cases, memory was better in the presence of an event boundary. This was the case regardless of whether the to-be-remembered information were lists of words, as in Experiments 1 and 2, or narrative texts, as in Experiments 3 and 4. Moreover, this was the case when the event boundaries were defined by changes in spatial location, by computer windows, or conveyed linguistically. Finally, this memory benefit appears to be magnified by presence of increasing numbers of event boundaries, as shown in Experiment 4. Thus, increased memory in the presence of an event boundary during encoding is a generalized phenomenon.

Previous work has suggested that such shifts are due to decreases in interference (Bilodeau & Schlosberg, 1951; Greenspoon & Ranyard, 1957; Jensen et al., 1971; Smith, 1982, 1984; Smith et al., 1978; Strand, 1970), and such an account would be consistent with the idea that segregating the information into separate event models reduces the amount of additional information that can serve as competitors for the retrieval of any one item. Going beyond this, we were able to explore other alternative possibilities that could also be driving memory improvement.

Across all of the experiments we explored the possibility that the event boundary is providing structure to the information in such a way that people can use the various events as retrieval cues, much as categories have been used in list-learning studies. However, an assessment of organizational structure of recall in this way using ARC scores failed to gain support. Thus, while it does seem that people are spontaneously organizing the information into separate event models when boundaries are encountered, there does not appear to be any evidence that they are spontaneously using these events as cues per se to help them retrieve information. It is possible that some other measure of clustering, such as inter-item delays during recall (e.g., Patterson, Meltzer, & Mandler, 1971; Pollio, Richards, & Lucas, 1969), which was not collected in this study, could provide such information. These sorts of measures could be helpful when ARC scores are so high, as they were in Experiments 3 and 4.

This does not mean that event-based cues cannot help aid retrieval. There is substantial evidence in the literature showing the benefits of reintroducing a prior context after forgetting has occurred. As examples of this, memory is better when context is reintroduced in laboratory word list studies (Tulving & Thomson, 1973) as well as eyewitness testimony research (Geiselman, 1988). Moreover, as mentioned earlier, in a study by Ezzyat and Davachi (2011) people were better able to retrieve sentences in a cued recall test when the cue sentence was part of the same event as the target sentence as compared to when they were parts of different narrative events. Also, the effectiveness of cueing is observed when cues are used that single out a specific event in both sentence learning (Radvansky & Zacks, 1991) and autobiographical memory studies (Barsalou, 1988).

Thus, overall, while such event-based cuing is available and possible, this did not appear to be the primary means of accessing memory for many people in our study. Instead, the lack of grouping of the items into event-based clusters, especially in Experiments 1 and 2, where the information is not strongly tied to the structure of the unfolding events, is consistent with the idea that the increased memory performance is due to the decreased retrieval interference as noted in the earlier work (Bilodeau & Schlosberg, 1951; Greenspoon & Ranyard, 1957; Jensen et al., 1971; Smith, 1982, 1984; Smith et al., 1978; Strand, 1970). In comparison, in Experiments 3 and 4 where the structure of the information and the unfolding events are strongly tied to the boundary (or boundaries) in the narrative, the organization of the information by event was quite evident, and yet there was still memory improvement. This may be due to the added benefit of reduced retrieval interference experienced in those cases; however, it should be noted that while the current results point toward reduced interference, a more direct test of interference needs to be done.

Another possibility that was explored here was that memory improved when an event boundary was present not because of an overall improvement in memory for the information, but because there was increased attention to the words or propositions around the event boundary because such boundaries triggered an attentional gating process (Zacks et al., 2007). However, an analysis of the boundary items did not reveal any specific benefit with the exception of Experiment 3. It should be noted that in the current experiments, for the No-Shift condition, the "boundary" information is simply what occurred in the middle of a list or narrative. Thus, recall performance should be relatively low (i.e., what one would expect in the middle of a serial position curve). Again, other work shows superior memory for items occurring at event boundary (Swallow et al., 2009). Much of this work involves narrative film in which the information being probed is an object in a scene, and the event boundary involves a shift in space and/or time in the film. In these cases, the object is present when the event boundary occurs. In contrast, particularly for the first and second experiments, there is a gap in time, even if only a few seconds, between processing the event boundary and the appearance of the information that is to be recalled. This separation may be sufficient to not observe any processing benefit itself. In support of this idea, those objects that are probed for in film studies that are not classified as being near a boundary are often separated from the boundary by several seconds. This delay is long enough that no benefit is seen; while, in the current studies, the information closest to the boundary (i.e., the boundary items) is separated by a similar temporal gap.

The current research also helps reinforce the idea that events are one of the basic levels of cognitive processing. People are spontaneously parsing up the continuous flow of action in the world into separate events in the absence of any instructions to do so. These event model representations then have an influence on other cognitive processes. Moreover, the range of cognitive processes that reflect this influence is broad. These include perception (Zacks et al., 2007), language comprehension (e.g., Zwaan, 1996), and memory (Radvansky, 1999). In some cases, this event structure can improve performance, as was the case in the current study, whereas in other cases in can cause problems.

One question that may arise from this research is why, in the current study, do we find a memory benefit for walking through a doorway in Experiment 1, when in other research we have found the opposite (Radvansky & Copeland, 2006; Radvansky, Krawietz, & Tamplin, 2011; Radvansky, Tamplin, & Krawietz, 2010)? The explanation lies in how information is distributed across multiple events, as outlined by the Event Horizon Model. In the other line of research, an object was carried from one room to another. As such, the information about a given object was represented in two event models, one for each room. In this case, even though the two models point to the same answer, they interfere and compete with one another during retrieval, which impairs performance (e.g., Anderson, 1974; Radvansky, 1999; Radvansky & Zacks, 1991). This scenario reflects the fifth principle of the Event Horizon Model described in the introduction. However, in the current studies, the words or propositions were present only in a single room or section of text and were associated with only one event model, thus there was no competition, and performance improved.

In the current experiments, free recall was used to assess memory performance. One question that this raises is how performance would be affected if a recognition task were used instead. Recognition typically reflects the availability of information, while recall demonstrates how accessible it is (Mandler, Pearlstone, & Koopmans, 1969). It is possible that this different measure would find a different pattern of results. For example, the need to shift between different models during the recognition task could make it more difficult for people to respond accurately. More work is needed to assess the impact of event boundaries on recognition memory.

Overall, the current research lends further support to the idea that cognition is meaningfully influenced by how people structure information into separate events and store information in event models. Here, the division of information into separate event models resulted in improved memory for the whole. As such, this suggests that the processes involved in event cognition are fundamental and broad-based.

Appendix A

Example story used in Experiments 3 and 4. In Experiment 3, only the first event boundary was used, whereas in Experiment 4, and additional event boundary was possible for the two event boundary condition.

Cheryl is Late

Cheryl woke up when she felt the sun shining through her window.
She looked around her room, trying to wake up.
Her dorm was such a mess!
She snatched her glasses from her bookcase.
She went down the hall to take a shower/She thought about going down the hall to take a shower.
In her room there were clothes strewn everywhere.
Cheryl rummaged through the mess and found some clothes.
Now came the hard part – finding two shoes that matched.
After searching near her bed, she found two shoes.
One was a tennis shoe and the other was a sandal.
As she dug deeper, she came across her alarm clock.
The time read, "4:18 PM".
She ran to the lab as fast as she could./ She called the lab as fast as she could.
Some minor obscenities came out of her mouth.
Her Psych Methods class was at 4:30 and there was a paper due today.

Comprehension Questions:
Was Cheryl's dorm room organized? N
Does Cheryl wear glasses? Y

References

Anderson, J. R. (1974). Retrieval of propositional information from long-term memory. *Cognitive Psychology, 6*, 451–474.

Barsalou, L. W. (1988). The content and organization of autobiographical memories. In *Remembering reconsidered: Ecological and traditional approaches to the study of memory* (pp. 193–243).

Bilodeau, I. M., & Schlosberg, H. (1951). Similarity in stimulating conditions as a variable in retroactive inhibition. *Journal of Experimental Psychology, 41*, 199–204.

Bower, G. H., Clark, M. C., Lesgold, A. M., & Winzenz, D. (1969). Hierarchical retrieval schemes in recall of categorical word lists. *Journal of Verbal Learning and Verbal Behavior, 8*, 323–343.

Coltheart, M. (1981). The MRC psycholinguistic database. *Quarterly Journal of Experimental Psychology, 33A*, 497–505.

Ezzyat, Y., & Davachi, L. (2011). What constitutes an episode in episodic memory? *Psychological Science, 22*, 243–252.

Geiselman, R. E. (1988). *Improving eyewitness memory through mental reinstatement of context*. John Wiley & Sons.

Greenspoon, J., & Ranyard, R. (1957). Stimulus conditions and retroactive inhibition. *Journal of Experimental Psychology, 53*, 55–59.

Hard, B. M., Tversky, B., & Lang, D. S. (2006). Making sense of abstract events: Building event schemas. *Memory & Cognition, 34*(6), 1221–1235.

Jensen, L., Dibble, J., & Anderson, D. C. (1971). Effects of a contextual change upon retroactive inhibition. *Psychological Reports, 29*, 39–46.

Johnson-Laird, P. N. (1983). *Mental models: Towards a cognitive science of language, inference, and consciousness*. Cambridge MA.: Harvard University Press.

Kurby, C. A., & Zacks, J. M. (2008). Segmentation in the perception and memory of events. *Trends in Cognitive Sciences, 12*, 72–79.

Magliano, J. P., Miller, J., & Zwaan, R. A. (2001). Indexing space and time in film understanding. *Applied Cognitive Psychology, 15*, 533–545.

Mandler, J. M., & Goodman, M. S. (1982). On the psychological validity of story structure. *Journal of Verbal Learning and Verbal Behavior, 21*(5), 507–523.

Mandler, G., Pearlstone, Z., & Koopmans, H. S. (1969). Effects of organization and semantic similarity on recall and recognition. *Journal of Verbal Learning and Verbal Behavior, 8*(3), 410–423.

Newtson, D. (1973). Attribution and the unit of perception of ongoing behavior. *Journal of Personality and Social Psychology, 28*(1), 28–38.

Newtson, D., Engquist, G. A., & Bois, J. (1976). The objective basis of behavior units. *Journal of Personality and Social Psychology, 35*(12), 847–863.

Patterson, K. E., Meltzer, R. H., & Mandler, G. (1971). Inter-response times in categorized free recall. *Journal of Verbal Learning and Verbal Behavior, 10*, 417–426.

Pollio, H. R., Richards, S., & Lucas, R. (1969). Temporal properties of category recall. *Journal of Verbal Learning and Verbal Behavior, 8*, 529–536.

Radvansky, G. A. (1999). The fan effect: A tale of two theories. *Journal of Experimental Psychology: General, 128*, 198–206.

Radvansky, G. A. (2012). Across the event horizon. *Current Directions in Psychological Science, 21*(4), 269–272.

Radvansky, G. A., & Copeland, D. E. (2006). Walking through doorways causes forgetting. *Memory & Cognition, 34*, 1150–1156.

Radvansky, G. A., Tamplin, A. K., & Krawietz, S. A. (2010). Walking through doorways causes forgetting: Environmental integration. *Psychonomic Bulletin & Review*.

Radvansky, G. A., Krawietz, S. A., & Tamplin, A. K. (2011). Walking through doorways causes forgetting: Further explorations. *The Quarterly Journal of Experimental Psychology, 64*(8), 1632–1645.

Radvansky, G. A., & Zacks, R. T. (1991). Mental models and the fan effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17*, 940–953.

Radvansky, G. A., & Zacks, J. M. (2011). Event perception. *Wiley Interdisciplinary Reviews: Cognitive Science*.

Radvansky, G. A., & Zacks, J. M. (2014). *Event cognition*. New York: Oxford University Press.

Roenker, D. L., Thompson, C. P., & Brown, S. C. (1971). Comparison of measures for the estimation of clustering in free recall. *Psychological Bulletin, 76*(1), 45–48.

Smith, S. M. (1982). Enhancement of recall using multiple environmental contexts during learning. *Memory & Cognition, 10*, 405–412.

Smith, S. M. (1984). A comparison of two techniques for reducing context-dependent forgetting. *Memory & Cognition, 12*, 477–482.

Smith, S. M., Glenberg, A. M., & Bjork, R. A. (1978). Environmental context and human memory. *Memory & Cognition, 6*, 342–353.

Smith, S. M., & Rothkopf, E. Z. (1984). Contextual enrichment and distribution of practice in the classroom. *Cognition and Instruction, 1*(3), 341–358.

Speer, N. K., Zacks, J. M., & Reynolds, J. R. (2007). Human brain activity time-locked to narrative event boundaries. *Psychological Science, 18*(5), 449–455.

Strand, B. Z. (1970). Change of context and retroactive inhibition. *Journal of Verbal Learning & Verbal Behavior, 9*, 202–206.

Swallow, K. M., Zacks, J. M., & Abrams, R. A. (2009). Event boundaries in perception affect memory encoding and updating. *Journal of Experimental Psychology: General, 138*, 236–257.

Tulving, E., & Thomson, D. M. (1973). Encoding specificity and retrieval processes in episodic memory. *Psychological Review, 80*, 352.

van Dijk, T. A., & Kintsch, W. (1983). *Strategies in discourse comprehension*. New York, NY: Academic Press.

Zacks, J. M. (2004). Using movement and intentions to understand simple events. *Cognitive Science, 28*(6), 979–1008.

Zacks, J. M., Speer, N. K., & Reynolds, J. R. (2009). Segmentation in reading and film comprehension. *Journal of Experimental Psychology: General, 138*, 307–327.

Zacks, J. M., Speer, N. K., Swallow, K. M., Braver, T. S., & Reynolds, J. R. (2007). Event perception: A mind/brain perspective. *Psychological Bulletin, 133*(2), 273–293.

Zacks, J. M., & Tversky, B. (2001). Event structure in perception and cognition. *Psychological Bulletin, 127*(1), 3–21.

Zwaan, R. A. (1996). Processing narrative time shifts. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*(5), 1196–1207.

Zwaan, R. A., Magliano, J. P., & Graesser, A. C. (1995). Dimensions of situation model construction in narrative comprehension. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*(2), 386.

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

Zwaan, R. A., Radvansky, G. A., Hilliard, A. E., & Curiel, J. M. (1998). Constructing multidimensional situation models during reading. *Scientific Studies of Reading, 2*(3), 199–220.