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Walking through doorways causes forgetting: active and passive interaction

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ABSTRACT

The current study explored the location updating effect when people passively interacted with an environment. This was assessed experimentally by having one person actively navigate through a virtual environment while picking up and putting objects down. A second person passively viewed the movement. Both participants responded to memory probes for objects they encountered. Probes appeared when the active participant moved halfway across a room or immediately after moving into a new room. Consistent with previous research, a location updating effect was found. That is, memory was worse following a shift to a new room. This effect was found for both active and passive participants but was smaller for the passive group. Thus, the shift from one event to another causes information to be harder to remember, reinforcing the importance of event cognition in memory. However, the more involved a person is in the interactive event, the more pronounced the effects.

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The world is constantly changing, and people must make sense of the information to which they are continuously subjected. One way to make sense of all the information a person experiences in daily life is to create event models. Event models are a type of mental model and contain a representation of the people, place, time course, and related information regarding an event (Radvansky & Zacks, 2011, 2014). Event models affect segmentation in everyday experience, as well as events as experienced when people read narratives or watch film (Magliano, Miller, & Zwaan, 2001; Zacks et al., 2001). The creation and storage of information in event models have several significant impacts on memory. For example, event models can structure the contents of memory, thereby aiding retention (e.g. Pettijohn, Thompon, Tamplin, Krawietz, & Radvansky, 2016; Radvansky, O'Rear, & Fisher, 2017). Alternatively, the information held in the current model is more available, with a concurrent reduction in the availability of information held in previous models (Glenberg, Meyer, & Lindem, 1987; Zwaan, 1996). This latter case is the focus of the current study.

In prior work, we have found that walking through doorways causes forgetting (e.g. Radvansky & Copeland, 2006). That is, when people move through an environment, if they move from one location to another, thereby crossing a spatial event boundary, memory about objects encountered in the environment may be lost, particularly for objects that are being carried. The aim of the current study was to explore how this finding is affected when the interaction with the environment is reduced. Specifically, we explored the impact of having people experience the flow of events passively.

In studies of the location updating effect, people pick up objects in one location, and then either walk across a large room (No-shift condition), or move to another room (Shift condition). When they are either halfway across the large room, or have just entered the new room, a recognition probe is given. People are to respond "yes" if the probe is either the object that is currently being carried (the Associated object), or the object that was just set down (the Dissociated object). People are to respond "no" to all other probes. The *location updating effect* is the finding that error rates are greater in the Shift than the No-shift condition. That is, when a person needs to update their event model, there is a shift

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in the accessibility of information from the prior event. Moreover, this difference is typically only present, or at least larger, for the Associated objects.

The location updating effect has been interpreted in the context of the Event Horizon Model (Radvansky, 2012; Radvansky & Zacks, 2011, 2014). The Event Horizon Model consists of five principles, the first of which is that people segment continuous streams of information into discrete events (Radvansky, 2012). This principle relies on Event Segmentation Theory (EST; Kurby & Zacks, 2008; Swallow, Zacks, & Abrams, 2009) to describe when people will identify an event boundary and create a new model for the current situation. For example, if someone is reading a book and a sentence begins "Two weeks later … ," that person will likely identify that as a shift in time and create a new model. One implication of EST is that the current model has privileged status in working memory, so the information contained in it is more available (Glenberg et al., 1987; Zwaan, 1996). Thus, EST might posit that there should be no decrement in memory for items following a spatial shift because they are contained in the current event model and are associated with the participant. However, the support for the availability of current-model information comes from studies in which items were probed that only existed in one model. That is, they were not carried from one location to another but were put down as the protagonist moved (i.e. equivalent to the Dissociated-Shift conditions in previous work).

The fifth principle of the Event Horizon Model, adds an explanation for the case when there are multiple representations of the probed-for object (i.e. equivalent to the Associated-Shift condition). That is, when a probe is presented, there is retrieval interference because the probed-for object is represented in both the old and current event models. This is similar to the fan effect in which the more locations an object is associated with, the harder it is to retrieve any one particular model (Radvansky, 1998, 2005; Radvansky et al., 2017; Radvansky & Zacks, 1991; Radvansky, Spieler, & Zacks, 1993; Radvansky, Wyer Jr, Curiel, & Lutz, 1997), although in this case both of the models point to the same response. What makes this finding particularly surprising is that (a) people are expecting the memory test, (b) they are tested repeatedly (so they have familiarity with the task), and (c) only two objects need to be tracked (a relatively small memory load).

Explorations of this location updating effect have revealed a number of important features. It is observed regardless of whether the probes are pictures or verbal labels, when the to-be-remembered items were objects in the environment, or less integrated word pairs (Radvansky, Tamplin, & Krawietz, 2010). It is also observed when the immersiveness of the environment is varied by changing display size, and even when people actually carried physical objects from one room to another (Radvansky, Krawietz, & Tamplin, 2011). It is unaffected by aging (Radvansky, Pettijohn, & Kim, 2015). The location updating effect is present regardless of whether the perceptual characteristics of the environmental context are similar or different, and even when people can preview the next location via transparent walls (Pettijohn & Radvansky, 2016a). It is unaffected by the distance travelled, and is not an artefact of presenting the probe before or while the new model is constructed, as it is still found when the probe is delayed after traversing an event boundary (Pettijohn & Radvansky, 2016b). Interestingly, it even occurs when the shift from one location to another is not experienced, but only imagined (Lawrence & Peterson, 2016). Still, in all of these demonstrations, people are actively involved in the movement, in some form, through some kind of an environment.

That said, the effects of event boundaries on cognition have been found in a number of paradigms when an event is not experienced through active interaction, such as when watching a film (Magliano et al., 2001; Zacks et al., 2001) or reading a text (Speer, Zacks, & Reynolds, 2007). These cases demonstrate that passively experienced boundaries are recognised as such, and they do have similar effects on memory as actively experienced boundaries (Swallow et al., 2009). However, the focus is on assessing memory for objects or actions involved in a previous event, or at the event boundary, not for the particular issue of a decline in memory for items carried from one location to another. In addition, these studies were not intended to explicitly assess the difference between the active or passive experience of an event boundary. Active and passive experience can affect what is remembered. For example, people who actively navigate a route show better memory for visuospatial elements, while those who passively experience it show better memory for objects (Plancher, Barra, Orriols, & Piolino, 2013). Given that passively experienced boundaries are recognised and can affect memory, the issue explored here is how the location updating effect is affected by passive experience.

Experiment

In previous location updating effect studies, people actively navigated virtual environments while they picked objects up and set them down. The aim of the experiment was to assess how the location updating effect is influenced when the experience of the event is either active, as it has been done in the past, or passive, in which people do not actively navigate, nor are directly involved in picking up and setting down the objects.

Differences between the active and passive experience of space can have consequences for cognition. Several studies have found that active navigation results in better memory for the spatial layout of a route (e.g. Brooks, Attree, Rose, Clifford, & Leadbetter, 1999; Carassa, Geminiani, Morganti, & Varotto, 2002). As one example, Plancher et al. (2013) had people experience a virtual environment in one of three conditions: (a) one in which they planned a route but did not navigate, (b) one in which they navigated but were told where to turn, and (c) one in which people were completely passive. People who experienced the environment passively remembered objects from a route better, but the two active conditions had a better memory for visuospatial elements. This may be because interacting with the environment promotes more elaborative encoding. If the location updating effect depends on people expending more effort to create event models, then they will show a larger effect than people that only experience the environment passively.

For another example, a study by von Stülpnagel and Steffens (2012) examined control of movement and navigation by having people ride a course on a tandem bicycle. The person in front controlled its direction, and the person in back navigated based on experimenter instructions. People in front better-recognised landmarks, whereas those in back better remembered the route. This suggests that people who actively move through an environment pay more attention to objects in the environment, and so would be more likely to show a location updating effect.

In the face of the studies that show reduced cognitive processing for passively experienced spaces, an alternative view is that the location updating effect is driven not by the interaction with the environment, but by basic processes involved in understanding the unfolding of events. From this view, interaction with the environment is not critical. Instead, what is important is the movement from one spatial framework to the next. For both active and passive navigation, people would create event models to comprehend what they were seeing, and these models would be largely the same. According to this view, performance would be the same for both active and passive experiencers.

To assess the influence of passive experience on the location updating effect, people were tested in pairs. One person actively navigated and interacted with the virtual environment, just as has been done in other work. These people composed our Active group. In addition, a second person passively watched the display on a second, identical monitor, and saw the objects being picked up and set down. While they did not control movement through the environment, they did respond to the recognition probes. Because there was no active interaction with the environment, these people composed our Passive group.

Method

Participants

Sixteen pairs of people (16 female participants) were recruited from the participant pool in the Department of Psychology at the University of Notre Dame, and were given partial course credit. Sample size was selected based on an a priori power analysis that required 16 pairs of participants to detect a medium effect (Radvansky et al., 2015).

Materials, apparatus, and procedure

As in prior work, the Valve Hammer editor (Valve Software, 2003) was used to create the virtual environments. The displays used were 46″ diagonal touchscreen monitors (Samsung model #460TSN-2). The virtual environment was composed of a series of 55-rooms, which were of two sizes. The large rooms were twice the length of the small rooms to allow the travel distance to be the same in the No-shift and Shift conditions. In each room, there were either one or two rectangular tables, with each table placed along a wall. There was one table in the small rooms, and a table on each end of the large rooms. On one side of a table was the object to be picked up, and the other side was empty. This empty side was where the object from the previous table was to be placed. There were two

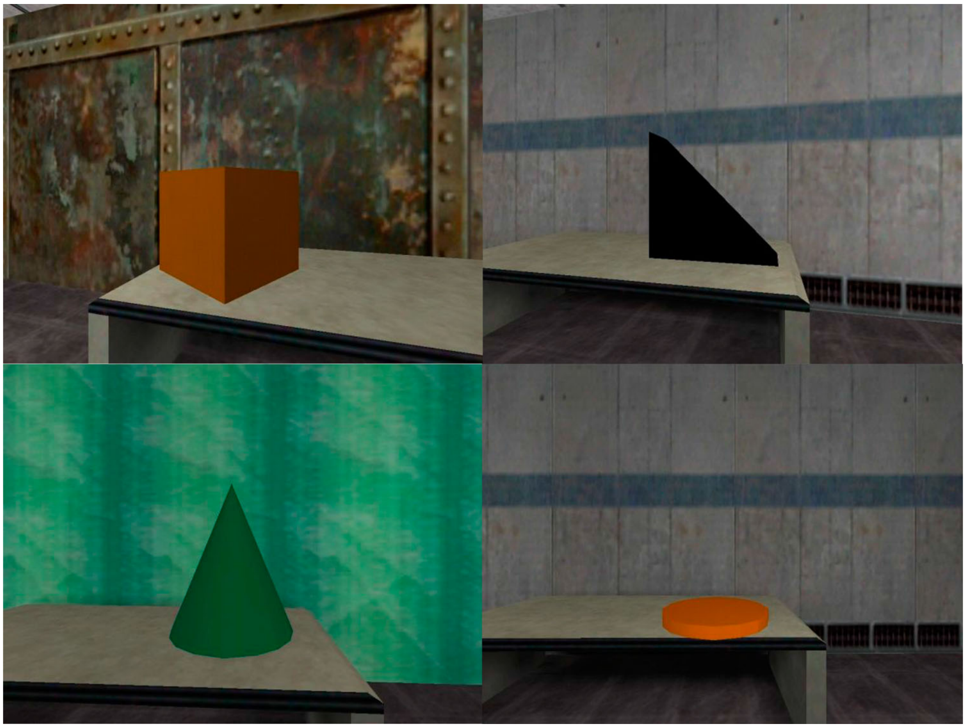

Figure 1. Examples of the shapes people picked up and put down throughout the experiment. From top left: Cube, Wedge, Cone, and Disc. [To view this figure in color, please see the online version of this journal.]

doorways in each room. These doorways were never on the same wall of the room. The objects that were interacted with in the environment were combinations of shapes and colours. The shapes used were: cube, wedge, pole, disc, cross (X), and cone, and the colours were: red, orange, yellow, green, blue, purple, white, grey, brown, and black (Figure 1). All shapes and colour combinations were used once within the experiment.

After giving informed consent, people were led to the room in which the experiment took place. The person who sat at the left terminal was the Active participant, and the person who sat at the right was the Passive participant. Because the computers were identical, there was no way for the participant to know ahead of time to which group he or she would be assigned. Thus, both Active and Passive participant data were collected at the same time. They sat approximately .5 m from the display; thus, the virtual world largely filled their field of view. Moreover, to make the experience seem more immersive, people wore headphones in which they could hear footsteps as they moved through the environment, and the lights were turned off in the room during the experiment.

People in the Active group were told that the task was to pick up an object from the table, move to the next one by either moving across a large room (No-shift) or by moving through a doorway to the next room (Shift), place the object on the next table, pick up the next object, and so on. Picking objects up and setting them down was done by using the touchscreen. These people were to use their nondominant hand to reach out and touch either the empty part of the table to set an object down or the object already on the table to pick it up.

People in the Active group moved through the virtual environment using a joystick held in their dominant hand. To ensure that they moved through the virtual world in the appropriate order, after a room was entered, the door behind them closed. The door to the next room did not open until the object being carried was set down on the table and the new object was picked up. In large rooms, an invisible wall prevented people from crossing the room before setting the object down and picking the next object up.

To assess memory within the virtual environment, there were 48 probe trials. Thus, people were not probed following every shift or in the middle of every room. On probe trials, immediately upon either moving halfway across a long room or moving into a new room, a probe appeared in the middle of the screen. The screen dimmed and movement was disabled when the probe appeared, but the virtual environment could still be seen. People in both groups were told to respond "yes" if the probed object was either the one that was currently being carried or the one that had just been set down. They were also told to respond "no" to all other probes. These additional probes were created by recombining the shape and colour of the two potential "yes" probes. Therefore, for example, if the Associated object was a blue cone, and the Dissociated object was a green cross, a "no" probe might be "blue cross." Participants responded by pushing one of two buttons on the joystick. The "trigger" button was used for "yes" responses, and a button at the top of the joystick marked "N" was used for "no" responses. There were 36 "yes" probes, 12 in the Shift condition and 24 in the No-shift condition. Because this study used the same environment as Experiment 2 in Pettijohn and Radvansky (2016a), No-shift probes were divided evenly between long and short rooms. Filler probes were presented to balance the number of "yes" and "no" responses. The experimental procedure typically lasted between 15 and 20 minutes.

To allow the participants in the Active and Passive groups to be tested in tandem, the video and audio signals from the computer were replicated on a second identical and adjacent computer. Also, a second joystick was connected to the computer to allow responses to be collected from both participants. Finally, so that neither participant would be clearly aware how fast the other was responding, the probe remained on the screen until 1 s after both had made a response.

Table 1. Error rates (in proportions), response times (in ms), and travel times (in seconds) for experiment. Standard errors are in parentheses.

	Error rates		Response times		Travel time	
	No-shift	Shift	No-shift	Shift	No-shift	Shift
Active group						
Associated	.03	.26	1307	1663	13.1	12.4
	(.02)	(.06)	(73)	(108)	(1.0)	(0.9)
Dissociated	.20	.18	1619	1464	13.0	16.4
	(.05)	(.05)	(85)	(95)	(0.8)	(3.2)
Passive group						
Associated	.05	.14	1540	1767		
	(.03)	(.03)	(73)	(143)		
Dissociated	.15	.13	1708	1645		
	(.05)	(.05)	(117)	(122)		

Results

The error rate, response time, and travel time data are shown in Table 1. Each data type was submitted to a 2 (Group: Active/Passive) × 2 (Shift/No-shift) × 2 (Associated/Dissociated) mixed ANOVA, with the first factor being between participants, and the other two within. As noted before, this environment used a Long and Short No-shift manipulation as in Pettijohn and Radvansky (2016a) Experiment 2. However, in that experiment this manipulation did not change performance. That is, for the No-shift condition, error rates did not significantly differ in the Long and Short rooms. Additionally, the location updating effect was observed when comparing the Shift and No-shift conditions in that experiment, which suggests that the shift itself, not the distance travelled, is responsible for the location updating effect. Thus, these No-shift conditions were collapsed for this analyses.

For the error rate data, the main effect of Shift/No-shift was significant, $F(1,30) = 7.78$, MSE = 0.021, $p = .009$, $\eta_p^2 = 0.21$, with people making more errors following a location shift. However, neither the main effects of Associated/Dissociated, $F(1,30) = 2.55$, MSE = .028, $p = 0.12$, $\eta_p^2 = 0.08$, nor Group were significant, $F(1,30) = 1.20$, MSE = .067, $p = 0.28$, $\eta_p^2 = 0.04$. Importantly, the three-way interaction was, $F(1,30) = 7.32$, MSE = 0.006, $p = .011$, $\eta_p^2 = 0.19$.

To explore this interaction, we analysed the data from the two groups separately. For the Active Group, while the main effect of Associated/Dissociated was not significant, $F(1,15) = 1.53$, MSE = 0.24, $p = .24$, $\eta_p^2 = 0.09$, the main effect of Shift/No-Shift was, $F(1,15) = 7.33$, MSE = 0.026, $p = .016$, $\eta_p^2 = 0.33$, as was the interaction, $F(1,15) = 39.19$, MSE = 0.007, $p < .001$, $\eta_p^2 = 0.72$. Simple effects tests revealed that for the Associated probes, the effect of Shift/No-shift was significant, $F(1,15) = 20.81$, MSE = 0.021, $p < .001$, $\eta_p^2 = 0.58$, but not for the Dissociated condition, $F < 1$. This parallels previous work involving active interaction.

For the Passive Group, neither main effects of Associated/Dissociated, $F(1,15) = 1.09$, MSE = 0.033, $p = .31$, $\eta_p^2 = 0.07$, nor Shift were significant, $F(1,15) = 1.13$, MSE = 0.015, $p = .31$, $\eta_p^2 = 0.07$. However the interaction was, $F(1,15) = 8.10$, MSE = 0.006, $p = .012$, $\eta_p^2 = 0.35$. Simple effects tests revealed that the effect of Shift/No-shift was significant for the Associated probes, $F(1,15) = 5.27$, MSE = 0.011, $p = .04$, $\eta_p^2 = 0.26$, but not the Dissociated probes, $F < 1$. This parallels the Active Group, although the location updating effect was smaller for the Passive Group. In fact, the effect size measure was about half the size in the Passive Group as it was for the Active Group.

For the response time data, while the main effect of Shift/No-shift was significant, $F(1,30) = 4.30$, MSE = 62,134, $p = .047$, $\eta_p^2 = 0.13$, with people responding slower after a shift, neither the main effect of Associated / Dissociated, $F < 1$, nor the main effect of Group, $F(1,30) = 1.36$, MSE = 5,40,523, $p = .25$, $\eta_p^2 = 0.04$ were significant. While the Group × Associated/Dissociated and Group × Shift/No Shift interactions were not significant, both Fs < 1, there was a significant Associated × Shift interaction, $F(1,30) = 16.27$, MSE = 78,889, $p < .001$, $\eta_p^2 = 0.34$. Simple effects tests revealed that for the Associated probes, the effect of Shift/No-shift was significant, $F(1,30) = 16.93$, MSE = 80,388, $p < .001$, $\eta_p^2 = 0.35$, replicating prior work, but neither the main effect of Group, $F = 1.46$, nor the interaction, $F < 1$, were. For the Dissociated probes, the main effect of Shift/No-shift was marginally significant, $F(1,30) = 3.13$, MSE = 60,635, $p = .09$, $\eta_p^2 = 0.09$, but the main effect of Group and the interaction were not, Fs < 1. Finally, the three-way interaction was not significant, $F = 1.22$ MSE = 96,195, $p = .28$, $\eta_p^2 = 0.03$. Thus, whether the environment was experienced actively or passively had only a small influence, at best, on the pattern of response times.

For the travel time data, there were no significant differences, all Fs < 1.52, all ps > .24. Thus, observed effects were not due to any artefacts or differences during the retention period.

Discussion

Overall, the pattern of data largely replicates that seen in prior work on the location updating effect. Moreover, it was observed for both the Active and Passive groups. Thus, decreasing how interactive the experience was did not alter the basic pattern of results. That said, the effect was stronger for the Active group than the Passive group. Thus, the event boundaries impacted memory more for active participants.

The current findings are in line with other work that has found that active navigation results in better memory for spatial information of a route, perhaps by focusing more attention on aspects of the experienced space (e.g. Brooks et al., 1999; Carassa et al., 2002; Plancher et al., 2013; von Stülpnagel & Steffens, 2012). Thus, even passively experiencing transitions in spatial regions can result in a structuring of information in event models, which can then influence performance. This is less evident for more passive spectators.

More generally, this result supports the idea that the structure of information across event models can affect memory. People navigated through a virtual environment and responded to probes describing encountered objects. The basic finding was that memory was worse for objects the person was currently carrying following a spatial shift. According to the Event Horizon Model, this is because the change in space triggers the creation of a new event model to accommodate the change. When an object was carried from one room to another, it was represented in both the old model and the newly created model. When a probe describing this object was presented, both models that contained a representation of the object competed with one another, and the resolution of this competition was reflected in increased error rates and slower response times. Passively experiencing the change in space does not eliminate the effect.

The current work further supports findings that suggest that change in the unfolding events, and how information is structured in those events, can affect performance. This basic principle is not tied to experienced space, but also applies to more passive experiences, such as text comprehension (Curiel & Radvansky, 2002; Morrow, Bower, & Greenspan, 1989; Radvansky & Copeland, 2010; Radvansky, Copeland, & Zwaan, 2003; Rinck & Bower, 2000) and watching film (Kurby & Zacks, 2008; Swallow et al., 2009; Zacks, Speer, & Reynolds, 2009). The experiments reported here along with previous research demonstrate that the structure of events, unfolding as they occur, affects memory for information encountered in those events. In the present case, memory was worse when people moved from one spatial framework to the next. Human cognition is strongly and meaningfully influenced by the structure of events (Radvansky & Zacks, 2014). By taking note of how people are experiencing a string of events, we can better understand how memory and cognition will be affected.

Disclosure statement

No potential conflict of interest was reported by the authors.

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