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Walking through doorways causes forgetting: environmental effects

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ABSTRACT

Previous work has shown a decline in memory for objects carried through a doorway versus across a room. The aim of the current study is to extend this work to understand how variations in perceptual experience during these event shifts influence this finding. First a change in procedure to reduce memory load to a single item was assessed. Next we explored whether performance is influenced by spatial distance versus spatial categories, the ability to perceptually preview the next location, and changes in the colour and texture of the walls. The location updating effect was consistently observed for all manipulations, suggesting that such event transformations have a robust influence on human memory. This suggests that event cognition is driven more by the use of perceptual information to infer or impose a categorical shift from one event to another rather than by the nature of perceptual information available at the time.

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People must make sense of a continuous stream of incoming information. One way to organise this information into more manageable units is through the use of event models (e.g. Radvansky, 2012; Radvansky & Zacks, 2011, 2014). Event models are a form of mental model that represent a specific event, can vary along several dimensions, and include situation models (van Dijk & Kintsch, 1983; Zwaan & Radvansky, 1998). To be consistent with much of the literature, we reserve the term *situation model* for those event models that are derived from language, and use the more inclusive term *event model* that also encompasses the interactive events that are of concern here.

One important dimension along which event models are delineated is spatial location. A change in location can signal a new event, with a new event model being created for the current location. Previous work has demonstrated a *location updating effect* (Radvansky & Copeland, 2006a). In these studies, people navigated through a virtual environment, picking objects up and putting them down. In some cases, the object would be carried across a room and put down (no shift), while in others, it would be carried from one room to another before being put down (shift). The result was that memory for the object in the no-shift condition was remembered better than in the shift condition (Radvansky & Copeland, 2006a; Radvansky, Krawietz, & Tamplin, 2011; Radvansky, Pettijohn, & Kim, 2015; Radvansky, Tamplin, & Krawietz, 2010). This is similar to other research that has found that there is a decline in the accessibility of knowledge following a spatial shift, regardless whether that has occurred in language (e.g. Glenberg, Meyer, & Lindem, 1987; Morrow, Greenspan, & Bower, 1987; Zwaan, 1996), film (Swallow, Zacks, & Abrams, 2009; Zacks, Speer, Swallow, & Maley, 2010), or interactive events (Copeland, Magliano, & Radvansky, 2006).

The primary explanation for this finding is that when the object is carried across a room (no-shift condition) only a single event model is involved, however when an object is carried from one room to another (shift condition), it is represented in two different event models, one for each room. The reason for the decrease in performance in the shift condition relative to the no-shift condition is that when the recognition probe was presented there are two event models involved in the response process, one for each of locations the object was in (the one in which it was picked up in and the current one). These two representations then

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compete with one another during retrieval, causing interference, and performance is worsened, much as is observed in studies of the fan effect and situation models (e.g. Radvansky & Zacks, 1991).

This location updating effect has been found when words, rather than objects, are used (Radvansky et al., 2010) when the immersiveness of the environment is varied, when the environment is real rather than virtual (Radvansky et al., 2011), when recall rather than recognition is used, when a delay is adding prior to presenting the probe to allow any updating process to complete, or even by passively experiencing the location shift (Pettijohn & Radvansky, 2014). Finally, this effect is observed in similar magnitudes by younger and older adults (Radvansky et al., 2015).

The aim of the current study is to examine the impact of various experiences in the environment that may influence the location updating effect. It could be influenced by the type of experiences people have when they are either moving across a larger location or by moving from one location to another. In Experiment 1, we first demonstrated that a modification of the previously used procedure, so that the resulting memory load was only a single item, can still produce a location updating effect. Experiment 2 assessed whether the size of the various locations a person is involved in influences performance. Specifically, larger rooms were used which could open the possibility of a person dividing the space into subjectively defined subregions. Experiment 3 assesses the influence of a clear perceptual change by providing a preview of the location shift by including clear walls between rooms. Finally, Experiment 4 explored the influence of perceptual changes in location shifts brought on by changes in context as defined by changes in the visual patterns on the walls of the virtual environment.

Experiment 1

In most of previous work on the location updating effect the probe object was either the object that the person was currently carrying (Associated) or what the person had just put down (Dissociated). This distinction between associated and dissociated derives from the fact that the original versions of these studies came from an attempt to replicate work by Glenberg et al. (1987) using an interactive environment rather than a series of vignettes. Often in the studies of the location updating effect, there was an association x shift interaction in which the location updating effect was more evident in the Associated condition. This makes sense, as this is the only condition where interference should be present at retrieval (Radvansky, 2012). In comparison, performance was generally worse in the Dissociated condition. Because the object is no longer associated with the person, it is less foregrounded in the event model (even in the absence of a spatial shift), thus becomes less available in memory (Glenberg et al., 1987). Given that most of the experiments that have been done to date have found an updating effect in the Associated condition, accompanied by either no effect or a smaller effect in the Dissociated condition, the aim of Experiment 1 was to assess the location updating effect by testing only the Associated condition. While there are no strong theoretical points at stake here, this experiment was needed as this altered methodology was used in the other experiments reported in this manuscript. In addition to accuracy rates and response times, travel times were collected to examine any potential differences in the retention period for each condition.

Method

Participants

Fifty-four people (24 female) were recruited from the participant pool in the Department of Psychology at the University of Notre Dame, and were compensated with partial course credit. No participants were removed for failing to meet a 75% correct threshold. Data for one participant was lost due to experimenter error, and one participant was eliminated for answering "yes" to every probe, leaving 52 in the final sample. Eight additional participants were replaced for motion sickness during the task.

Materials, apparatus, and procedure

A virtual environment created in the Valve Hammer editor was displayed on a 46″ diagonal touchscreen monitor (Samsung model #460TSN-2). The virtual environment was a 55-room series of locations. The rooms were two sizes – large rooms were twice the length of the small rooms. This difference allowed for the distance travelled in the virtual world to be equated in the Shift and No-Shift conditions. Each room had either one or two rectangular tables placed along a wall. In larger rooms, two tables were placed in each half of the room, while smaller rooms had only one table. On one side of each table was the object that was to be picked up next, and the other half was empty so the current object could be placed there. There were two doorways in each room, and they were never on the same wall. The objects present in the environment consisted of combinations of several shapes and colours. The shapes were: cube, wedge, pole, disc, cross (X), and cone, and the colours were: red, orange, yellow, green, blue, purple, white, grey, brown, and black. Each combination was used once during the experiment, although some combinations were not probed.

After signing a consent form, people sat in chairs approximately .5 meters away from the display. This meant that the virtual world largely filled their field of view. The lights in the room were turned off, and participants wore headphones through which they could hear their footsteps to make the experience more immersive.

People were told to move through the environment while picking objects up and setting them down. When they picked an object up, they would either cross the room (No-Shift) or walk through a doorway to the next room (Shift) to reach the next table. There, they would set the current object down, pick the next one up, and continue until the experiment ended. They picked the objects up and put them down by touching the screen. People were told to use their nondominant hand to reach out and touch the empty part of the table to put an object down or touch the next object to pick it up.

Participants controlled their movement through the environment by using a joystick with their dominant hand. For the Shift condition, upon entering a room, the door behind them would close, and the door to the next room would only open after they had put the current object down and picked the next one up. This ensured that they moved through the environment in the correct order. In comparison, for he No-Shift condition, people were prevented from going to the incorrect table by an invisible wall that stopped them from crossing the room. Additionally, the half of the room to be visited second was dimmed slightly until the object at the first table was picked up.

Probes appeared in the centre of the screen and were triggered immediately upon either crossing half of a long room or entering a new room. While the probe was onscreen, the rest of the screen was dimmed, and participants were unable to move until they made a response. People responded "yes" by pressing the joystick's trigger if the probed object was the one that they were currently carrying and "no" by pushing a button marked "N" on the top of the joystick if it described anything else. Thirty-six "yes" probes were presented; along with an additional 36 filler probes to balance the number of "yes" and "no" responses. The experimental procedure typically lasted between 15 and 20 minutes.

Results and discussion

The error rate, response time, and travel time data are reported in Table 1. Each data type was submitted to a one-way repeated-measures ANOVA. The error rate data, consistent with previous work, showed a significant effect of Shift, $F(1,51) = 7.29$, MSE = .008, $p = .009$, $\eta^2_{\text{partial}} = .13$, with people producing more errors in the shift condition compared to the no-shift condition.

For the response time data, people responded more slowly in the shift condition than the no-shift condition, although this difference was only marginally significant, $F(1,51) = 3.04$, MSE = 71,706, $p = .09$, $\eta^2_{\text{partial}} = .06$. As noted earlier, while the primary data in this paradigm is the error rate data, when effects are observed in the response time data, they are consistent with that in the error rates, as is observed here.

Finally, for the travel time data, the difference between the shift and no-shift conditions was not significant, $F < 1$. Thus, the observed effects in the error rate and response times are not be due to differences in the length of the retention period.

Experiment 1 provides a straightforward demonstration of the location updating effect. Without the additional burden of tracking dissociated items, participants still showed increased error rates following a shift. Thus, even though people needed to track only a single item during the course of the study, the presence of a shift in location was sufficient to disrupt memory processing.

Experiment 2

Prior work on spatial processing in narrative comprehension has shown that performance is influenced by the number of locations that are passed through, not their size (Rinck, Hähnel, Bower, & Glowalla, 1997). However, that previous work assessed the influence of spatial distance while people read narratives. Any differences in the size of the spatial

Table 1. Error rate, response time, and travel time data for Experiment 1.

	Measure					
	Error rates		Response time (ms)		Travel time (ms)	
	Shift	No Shift	Shift	No Shift	Shift	No Shift
Associated	0.097 (0.019)	0.050 (0.018)	1425 (55)	1334 (50)	12,707 (689)	13,800 (1470)

Note: Standard errors appear in parentheses below means.

locations were derived from a map memorised prior to reading. The aim of Experiment 2 was to assess whether the experience of spatial distance itself can influence the availability of information in memory, apart from the number of spatial regions that are encountered. To this end an environment was created in which the length of rooms, thus the distance travelled, in the No-Shift condition was varied. More specifically, some of the large rooms in the No-Shift condition were made three times as large as those used in any of the previous studies. For these very large room, people may subjectively divide them into smaller subregions, which may then influence memory performance, as has been observed in other studies of spatial memory (e.g. McNamara, Hardy, & Hirtle, 1989; Radvansky, 2009). This could potentially lead to the observation of a location updating effect in what would otherwise be considered a No-Shift condition.

Method

Participants

Forty-two people (37 female) were recruited from the participant pool in the Department of Psychology at the University of Notre Dame, and were compensated with partial course credit. No participants were removed for failing to meet a 75% accuracy threshold. Fifteen additional participants were replaced for motion sickness during the task.

Materials, apparatus, and procedure

A virtual environment similar to that used in Experiment 1 was created using the same software. The environment consisted of 47 rooms. Twenty-two were long rooms, and 25 were short rooms. The long rooms were three times the length of the short rooms. Thirty-six "yes" probes were presented; of these, 12 were Shift probes, and 24 were No-Shift probes. The 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 rest of the materials, apparatus, and procedure were the same as in Experiment 1.

Results and discussion

The error rate, response time, and travel time data are reported in Table 2. For each of the dependent measures they were first submitted to one-way repeated-measures ANOVAs comparing the Shift and No Shift-Short conditions. This served as an estimate of the ability of the study to replicate the basic location updating effect. Second, the data were submitted to one-way repeated-measures ANOVAs comparing the No Shift-Short and No Shift-Long conditions. This was done to assess whether spatial distance may influence performance, perhaps by encouraging people to subdivide the larger areas into subregions.

For the error rate data, the effect of Shift was significant, $F(1,41) = 14.59$, MSE = .006, $p < .001$, $\eta^2_{\text{partial}} = .26$, with higher error rates following a shift. Of interest here is what difference, if any, there was between the probes that occurred in the Long and Short rooms within the No-Shift condition. These data were also submitted to a one-way repeated-measures ANOVA comparing the Long and Short conditions. For the error rate data, the effect of room length was not significant, $F < 1$.

For the response time data comparing the Shift and No Shift-Short conditions, the main effect of Shift was significant, $F(1,41) = 42.98$, MSE = 25,358, $p < .001$, $\eta^2_{\text{partial}} = .51$, with longer response times in the Shift than the No Shift-Short condition. Within the No-Shift condition, the difference in response time between long and short rooms was significant, $F(1,41) = 9.30$, MSE = 7955, $p = .004$, $\eta^2_{\text{partial}} = .18$, with longer response times occurring in the Long condition.

For the travel time data, the effect of Shift was significant, $F(1,41) = 37.49$, MSE = 4,888,900, $p < .001$, $\eta^2_{\text{partial}} = .48$, with longer travel times in the Shift condition than for the No Shift-Short condition. While this is consistent with the idea that the location updating effect observed in the error rate and response time data could be due to a longer retention time, we should note that this is the only time this effect has been observed, and is actually in the opposite direction in Experiment 3. Additionally, the correlation between error rates and travel times in the Shift condition was low and non-significant, $r(40) = .06$, $p = .69$. As such, we are

Table 2. Error rate, response time, and travel time data for Experiment 2.

	Error rates		Response time (ms)		Travel time (ms)	
	Shift	No Shift-Short	Shift	No Shift-Short	Shift	No Shift-Short
Shift vs. No Shift-Short						
Associated	0.118	0.055	1416	1188	15,157	12,202
	(0.016)	(0.010)	(41)	(37)	(656)	(592)
Short vs. long						
Associated	0.055	0.057	1188	1247	12,202	13,400
	(0.010)	(0.010)	(37)	(41)	(592)	(590)

Note: Standard errors appear in parentheses below means.

inclined to view this significant effect as anomalous. For the comparison of the short and long No-Shift conditions, not surprisingly, the effect of room length was significant for travel time comparing the short and long no shift rooms, $F(1,41) = 5.83$, MSE = 5,167,639, $p = .020$, $\eta^2_{\text{partial}} = .12$, with people taking longer to travel through rooms in the Long versus Short condition.

Experiment 2 replicated the location shift effect. Error rates were greater and response times were longer following a spatial shift, as has been found previously. More importantly, at the same time, we found that varying the length of the room, and thus the perceptual experience of Euclidean distance, did not result in a meaningful change in performance. This suggests that it is the event shift itself that is responsible for the effect, rather than this factor. This is line with other work showing that cognition is influenced by the structure of the events and the boundaries between them more so than the internal "size" of the events themselves. Most notably, this work is in line with that found by Rinck et al. (1997), despite the fact that in that study people memorised a map and then read narratives, whereas in the current study people did not have any preview of the layout of the virtual environment and experienced it more directly by interactive navigation. Thus, the treatment of events in a more categorical manner is a general principle of event cognition.

Experiment 3

A previously unconsidered potential explanation for the location updating effect is that there is a relatively large change the perceptual experience of people as they navigate the environment when they change spatial locations. Specifically, in the No-Shift condition, people can see across the entire length of the room, including the object on the next table. In comparison, in the Shift condition, there is an opaque wall between a person in the first room and the object in the second room. There is a doorway that is open between the two, but very little of the next room can be seen. As such, this leaves open the possibility that this effect is not due to the shift in spatial location per se, but to the large change in perceptual information available during movement.

To address this possibility, the aim of Experiment 3 was to assess the impact on the location updating effect when the shift change has a smaller perceptual change. This was done by using transparent "glass" walls. Specifically, in the virtual environment the texture of some of the walls was changed to the glass setting, which allowed the participant to see into the next room before entering it (Figure 1). The question of interest is whether being able to see the next room and its contents reduces the location updating effect by reducing the amount of perceptual change associated with the shift.

Method

Participants

Forty people (26 female) were recruited from the participant pool in the Department of Psychology at the University of Notre Dame, and were compensated with partial course credit. No participants were removed for failing to meet a 75% accuracy threshold. Data for one participant was lost due to an experimenter error, and seven participants were eliminated for failing to follow instructions and answering "yes" to every probe, leaving 32 in the final sample. Four additional participants were replaced for motion sickness during the task.

Materials, apparatus, and procedure

The virtual environment and the equipment was the same as in Experiment 1 except that in some of the rooms, one wall was transparent as if it were made of glass, to allow participants to see into the next room. Of the positive probes, 12 were in the Shift-Solid (the participant could not see into the next

Figure 1. Example of the Shift-Glass condition in Experiment 3.

room) condition, 6 were in the Shift-Glass (the participant could see into the next room) condition, and 6 were in the No-Shift condition. The rest of the procedure was like that used as in Experiment 1.

Results and discussion

The error rate, response time, and travel time data are reported in Table 3. For each of the dependent measures they were first submitted to one-way repeated-measures ANOVAs comparing the Shift-Solid and No-Shift conditions. This served as an estimate of the ability of the study to replicate the basic location updating effect. Second, the data were submitted to one-way repeated-measures ANOVAs comparing the Shift-Solid and Shift-Glass conditions. This was done to assess whether the ability to perceptually preview the next region may influence performance, perhaps by reducing the amount of mental updating required by the larger change in perceptual experience when a doorway is placed in a solid wall.

These data were submitted to one-way repeated-measures ANOVAs comparing the Shift-Solid and No-Shift conditions. For the error rate data, the difference was significant, $F(1,31) = 5.30$, $MSE = 0.006$, $p = .03$, $\eta^2_{\text{partial}} = .14$, with more errors in the Shift condition. Of particular interest is if, in the Shift condition, the presence of a glass wall changes the location updating effect. A one-way ANOVA indicated that there was no difference between the Shift-Solid and Shift-Glass conditions, $F < 1$.

For the response time data, a comparison of the Shift-Solid and No-Shift conditions showed the effect of Shift was not significant, $F(1,31) = 1.96$, $MSE = 73{,}394$, $p = .17$, $\eta^2_{\text{partial}} = .06$. A comparison of response times for the Shift-Solid and Shift-Glass was also not significant, $F < 1$. This is in line with previous studies, in which there are no differences in response times.

Table 3. Error rate, response time, and travel time data for Experiment 3.

	Error rates		Response time (ms)		Travel time (ms)	
	Shift-Solid	No Shift	Shift-Solid	No Shift	Shift-Solid	No Shift
Shift-solid vs. No shift						
Associated	0.092	0.047	1445	1350	13,1157	14,968
	(0.017)	(0.015)	(56)	(66)	(738)	(1010)
Solid vs. glass						
Associated	0.092		1445		13,157	
	(0.017)	0.107	(56)	1458	(738)	21,489
		(0.030)		(63)		(2143)

Note: Standard errors appear in parentheses below means.

For the travel time data, comparing the Shift-Solid and No-Shift conditions, the effect of Shift was significant, $F(1,31) = 8.61$, $MSE = 6{,}097{,}232$, $p = .006$, $\eta^2_{\text{partial}} = .22$. In contrast to Experiment 2, people took longer in the No-Shift condition. A comparison of Shift-Solid and Shift-Glass travel times found a significant effect, $F(1,31) = 16.57$, $MSE = 67{,}037{,}626$, $p < .001$, $\eta^2_{\text{partial}} = .36$, with people taking longer in the Shift-Glass condition. The analysis of overall travel time stands in contrast to Experiment 2, where people took longer in the Shift condition. While there was a difference in travel times depending on wall material, the error rate and response time data are in line with previous results (and with Experiment 2). Thus, these results appear to be due to differences in event structure rather than retention period.

Overall, Experiment 3 demonstrates that the location updating effect was present, just as has been observed in other work, even when the shift involves less of a perceptual change from one room to another. Thus, this effect is not due to a large change in the person's perceptual experience but rather to the actual movement from one event to another. This is paralleled by other work by Copeland et al. (2006) in which people played a World War I biplane simulator game. When flying there were no clear boundaries that the plane crossed as the air is fairly continuous. That said, there were changes in terrain that the plane flew over, such as villages, lakes, mountains, etc. What was found was that even location shifts such as these, which are far more subtle, and largely not consequential to flying the biplane, performance was still affected by location shifts. Thus, this supports the general idea that event shifts involve some sort of categorical change in the mental representations people use, and that performance is affected by these rather than by the perceptual information available at the time. Instead, perceptual changes are influential only in so far as they provide information about where a person can infer or impose event boundaries to parse up their otherwise continuous experience of the world.

Experiment 4

Experiment 3 demonstrated that making a shift from one room to another with a drastically reduced experience of perceptual change, as would occur when walking through a doorway in a glass wall, did not eliminate the shift effect. That said, there was a perceptual change that did occur when a person moved from one room to the next, even when there was a glass wall separating the two. Specifically, in that study the texture of the walls changed when moving from one room to the next. This is a perceptual difference that could have some influence on the observed location updating effect. The aim of Experiment 4 was to assess further how much impact this change in the perceptual experience, in this case, a change in the perceptual context, has on the location updating effect. This was done by making two changes to the virtual environment. First, in some cases, two different rooms in the Shift condition were made visually similar by maintaining the same wall colour and texture. Thus, the perceptual context was made more similar across the location shifts. Second, some of the rooms in the No-Shift condition had different texture walls halfway through. Thus, the perceptual context altered as a person crossed a large room, potentially allowing for people to treat this change as if a person were moving from one room to another.

Method

Participants

Forty-eight people (32 female) were recruited from the participant pool in the Department of Psychology at the University of Notre Dame, and were compensated with partial course credit. No participants were removed for failing to meet a 75% accuracy threshold. Eight participants were replaced for failing to following the instructions and answering "yes" to all of the probes, and four were replaced because their data were lost due to experimenter/program error. Four additional participants were replaced for motion sickness during the task.

Materials, apparatus, and procedure

The virtual environment from Experiment 1 was modified so that in some cases, when the participant moved from one room to another, the wall texture in the second room remained the same as it was in the first room. Other rooms were changed so that halfway through the room, the wall texture was completely different (an equivalent perceptual change to entering a new room). Fifty probes were presented, 24 were "yes" probes. The same apparatus and procedure were used as in Experiments 1 and 2.

Results and discussion

The error rate, response time, and travel time data are reported in Table 4, and they were submitted to 2 (Shift) x 2 (Texture) repeated-measures ANOVAs. For the error rate data, the main effect of Shift was significant, $F(1,47) = 7.44$, MSE = .093, $p = .009$, $\eta^2_{\text{partial}} = .14$, with higher error rates following a shift. Neither the main effect of texture, nor the interaction were significant, $F < 1.02$.

For the response time data, neither the main effect of Shift, nor the main effect of Texture were significant, $F < 1$ and $F(1,47) = 2.39$, MSE = 60,386, $p = .129$, $\eta^2_{\text{partial}} = .05$, respectively. However, the interaction was, $F(1,47) = 12.96$, MSE = 355,438, $p = .001$, $\eta^2_{\text{partial}} = .22$. Simple effects tests revealed that when the wall texture changed, the location shift effect was marginally significant, $F(1,47) = 3.70$, MSE = 172,466, $p = .060$, $\eta^2_{\text{partial}} = .07$, with response times slower in the No-Shift condition. However, when the wall texture remained the same, response times were slower in the Shift condition, $F(1,47) = 6.69$, MSE = 183,051, $p = .013$, $\eta^2_{\text{partial}} = .12$.

For the travel time data, the main effect of Shift was not significant, $F(1,47) = 1.73$, MSE = 18,388,341, $p = .195$, $\eta^2_{\text{partial}} = .04$, but the main effect of Texture was, $F(1,47) = 27.82$, MSE = 1,497,8912, $p < .001$, $\eta^2_{\text{partial}} = .37$, with travel times longer in the Same Texture condition. The interaction was not significant, $F(1,47) = 3.25$, MSE = 35,803,634, $p = .078$, $\eta^2_{\text{partial}} = .06$. It is unclear what principled process could be producing the main effect of Texture here. Importantly, the location updating effect, which is of primary concern cannot be attributed to differences in the retention interval.

The results of Experiment 4 replicated the location shift effect in the error rate, which is the dependent measure that it is primarily observed in, even when the visual change associated with the shift was reduced by maintaining the same room characteristics across a boundary. Further, changing the appearance of the room midway through did not induce a location updating effect, thereby suggesting that a change in the perceptual context per se is insufficient to induce a strong event boundary.

In comparison to the error rate data, there was an influence of wall texture on response times. The location updating effect in the No texture change condition is consistent prior works' error rate data and response time effects when they are observed. However, when there was a change in wall texture, the pattern of response times was in the opposite condition. Given that this is more closely aligned with the typical paradigm, and that the results are in the opposite direction of what is typically observed in response time data in the past, and the absence of any clear sensible explanation for why this reversal would have occurred, we are inclined at the moment to regard this one particular finding as anomalous. Taken together, the results indicate that it is the shift itself that triggers updating and not the visual change generally associated with it.

General discussion

The present study explored the influence of different types of experience on the location updating effect. After establishing that a change in procedure that involved only single item memory load did not influence the basic I effect (Experiment 1), we assessed whether performance would be altered by various changes in the perceptual experience of people. These differences included the experience of spatial distance versus the experience of location shifts (Experiment 2), the ability to preview an upcoming location (Experiment 3), and the influence of a change in the perceptual context apart from a change in the spatial framework (Experiment 4). Across all of these manipulations, a clear location updating effect was observed as in previous work (Radvansky & Copeland, 2006a; Radvansky et al., 2010, 2011, 2015). This reinforces the idea that the location updating effect is robust and it occurs across a wide range of situations.

The current work also helps to address one of the issues about how people decide when to identify something as an event boundary, when to create a new event model, and when to interpret the flow of action as part of a continuous event. People can exhibit a great deal of flexibility on this point, with points in the dynamic stream of action sometimes corresponding to an event boundary and sometime not. This varies both across people and within a person on different occasions, depending on the goals, disposition, and experiences of a person. This idea is supported by studies of event segmentation that show that there is both within and across person variability (Kurby & Zacks, 2011; Magliano, Kopp, McNerney, Radvansky, & Zacks, 2012; Speer, Zacks, & Reynolds, 2007; Zacks, Speer, & Reynolds, 2009) and that segmentation can vary depending

Table 4. Error rate, response time, and travel time data for Experiment 4.

	Measure					
	Error rates		Response time (ms)		Travel time (ms)	
	Shift	No Shift	Shift	No Shift	Shift	No Shift
Overall	0.074	0.031	1322	1304	14,710	16,352
	(0.012)	(0.011)	(33)	(34)	(728)	(904)
Same texture	0.068	0.036	1351	1264	15,610	16,352
	(0.015)	(0.013)	(41)	(34)	(896)	(904)
Different texture	0.077	0.021	1300	1385	14,220	11,850
	(0.013)	(0.015)	(34)	(43)	(930)	(592)

Note: Standard errors appear in parentheses below means.

on the instructions one gives to a person, such as whether they should segment the events in a fine- or coarse-grained manner (Magliano & Zacks, 2011; Speer et al., 2007; Zacks et al., 2009).

As with many aspects of human cognition, in the face of such variability, there is also some underlying stability. The current study demonstrates that some experiences have a more consistent influence in the derivation of event boundaries. Specifically, changes in the spatial framework of on-gong stream of action are more likely to be treated as event boundaries and give rise to the location updating effect. While some perceptual change does occur as a person moves from one region to another, perceptual experience itself does not drive this effect. It is only when the perceptual change is interpreted as defining a new region in space that people are likely to interpret that as an event shift. The presence of perceptual changes in context (Experiment 4) were not treated the same, nor did previews of upcoming locations, which would diminish the abruptness of any change in perceptual experience, remove the effect (Experiment 3). Thus, while changes in location are often accompanied by changes in perceptual experience and are treated as event boundaries, changes in perceptual experience per se are insufficient.

The shift from one location to another is, in some sense, an analog to other cognitive effects in which people impose categorical boundaries on experience, that then influence performance. For example, in spatial perception and memory, spatial boundaries influence the use of coordinate versus categorical decisions about displays (e.g. Kosslyn et al., 1989) and distort memories in ways concordant with the presence of region defining boundaries (Curiel & Radvansky, 1998, 2002, 2004; Huttenlocher, Hedges, & Duncan, 1991; McNamara, 1986; McNamara, Ratcliff, & McKoon, 1984). This sort of processing was also observed in the current study in Experiment 2 which showed that the location updating effect was influenced by the passage from one area to another, and not by Euclidean characteristics of the occupied environments.

The finding that changes in spatial location serve as strong event boundaries is not unique to the current work with interactive events, but is also found in other areas of event cognition in which changes in spatial location are treated as event boundaries. This is clearly seen in work that uses event segmentation tasks in which people are asked to explicitly segment some string of action into separate events. In these cases, whether the events are experienced through film (Magliano & Zacks, 2011) or written texts (Magliano et al., 2012), people regularly treated changes in the spatial work as a change in events.

Location shifts are found to serve as event boundaries in studies of language comprehension. In some work it has been found that when people read narratives and a location shift is encountered, people may show an increase in reading time, consistent with the idea that an event boundary has been encountered (Radvansky, Zwaan, Curiel, & Copeland, 2001; Zwaan, Magliano, & Graesser, 1995; Zwaan, Radvansky, Hilliard, & Curiel, 1998). Because this reading time increase is not always observed with changes in spatial location (McNerney, Goodwin, & Radvansky, 2011; Zwaan et al., 1995, 1998) it has been suggested that people do not always process spatial shifts during language comprehension. However, further work has shown that if people are given recognition memory probes after such locations shifts, responses to those probes show evidence of event model updating, even in the absence of an effect on reading times (Radvansky & Copeland, 2010). This may occur because people are so facile at updating event models when a location shift has occurred.

The use of spatial frameworks as a means of delineating events is also supported by work showing that if people memorise a map prior to reading a text, changes in spatial location within the narrative can result in an increase in the time needed to verify memory probes of objects in a building as those objects become further away in terms of the number of rooms along the path of travel (Bower & Morrow, 1990; Morrow, Bower, & Greenspan, 1989; Morrow et al., 1987; Rinck & Bower, 2000; Wilson, Rinck, McNamara, Bower, & Morrow, 1993). Moreover, there is also evidence of reading time increases for anaphoric references as the number of spatial regions from the current location increases (Bower & Rinck, 2001; Curiel & Radvansky, 2002; Rinck & Bower, 1995; Rinck et al., 1997; Stine-Morrow, Morrow, & Leno, 2002), although this effect is only observed if a person memorises a map ahead of time (Zwaan et al., 1998). Thus, this is a further example of spatial location serving to govern the availability of information from memory. While this work involved the availability of information during language comprehension, an effort to extend this to interactive virtual environments has revealed a different pattern of results (Tamplin, Krawietz, Radvansky, & Copeland, 2013), finding an inhibitory effect for information that was in the most recently occupied room, but similar performance for the availability of information from the other rooms. Despite this difference, the pattern of data is still being dictated by people's experience of the flow of action as defined by different spatial regions.

A final line of work that supports the idea that spatial location provides a strong basis by which people delineate different events comes from research on fact retrieval and associative interference. In a series of studies, if people learned sentences about objects in locations, such as "The welcome mat is in the library" then interference was observed during retrieval when there was a single object described as being in multiple locations, and hence multiple event models (Radvansky, 1998, 1999a, 1999b, 2005, 2009; Radvansky & Copeland, 2001, 2006b, 2006c; Radvansky & Zacks, 1991; Radvansky, Zacks, & Hasher, 1996, 2005). The idea is that these event models competed with one another during retrieval because they shared the same object. In comparison, if multiple objects were described as being in the same location, then no interference was observed because all of these facts could be integrated into a single event model, and so there was no source of interference at retrieval. Thus, people were using spatial location as a basis for organising their memory for the facts that they were learning in the experiment.

That said, there are some limitations to this use of spatial location as a means of defining events. For example, when people were given sentences to learn about people in small locations that typically hold only a single person at one time (e.g. a witness stand), then spatial location was not a plausible means of organising event models (Radvansky, Spieler, & Zacks, 1993). This is consistent with other research showing that information should easily be interpreted as a single event, otherwise integration will not occur (Radvansky, Zwaan, Federico, & Franklin, 1998). However, one could image a person going from place to place as part of a sequence of events. Consistent with this a person-based rather than location-based organisation was observed. Because both person-based and location-based organisations are possible, no clear organisation bias is observed in studies that involve facts about people in multiple locations (e.g. Anderson, 1974). Overall, this work further supports the idea that changes in spatial location are often interpreted as event boundaries, although there are limitations to this organisation scheme.

Conclusions

The current study further explored the location updating effect and, consistent with several other studies, consistently found that that people were more error prone when they had just moved from one location to another compared to if they had walked across a large room. This was observed even when the person only needed to track what was currently being carried (hence a memory load of 1), independent of the perceptual size of the rooms travelled, was not influenced by a perceptual preview of the next region, nor by a change in the perceptual context. Thus, the spatial framework can serve as a powerful cue to a person to create a new event model.

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