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BRIEF REPORT

Walking Through Doorways Causes Forgetting: Younger and Older Adults

Gabriel A. Radvansky, Kyle A. Pettijohn, and Joonsung Kim
University of Notre Dame

Previous research on event cognition has found that walking through doorways can cause forgetting. The explanation for this finding is that there is a competition between event models, producing interference, and depressing performance. The current study explored the degree to which this might be affected by the natural aging process. This is of interest because there is some evidence that older adults have trouble coordinating sources of interference, which is what is thought to underlie this effect. This would suggest that older adults should do worse on this task. Alternatively, there is also evidence that older adults are typically not disrupted at the event level of processing per se. This would suggest that older adults should perform similarly to younger adults on this task. In the study reported here, younger and older participants navigated through a virtual environment, and memory was tested with probes either before or after a shift and for objects that were associated with the participant (i.e., just picked up). In general, both younger and older adults had memory disrupted after walking through a doorway. Importantly, the magnitude of this disruption was similar in the 2 age groups. This is consistent with the idea that processing at the event level is relatively unaffected by the natural aging process.

Keywords: event models, situation models, event boundaries, memory

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Recent work has shown that the availability of information in memory can be influenced by the structure of the environment (e.g., Radvansky & Copeland, 2006; Tamplin, Krawietz, Radvansky, & Copeland, 2013). Specifically, in one series of studies we have found that when a person moves from one room to another, memory for current goal information (i.e., remembering the identity of the object currently being carried) is compromised (Radvansky, Krawietz, & Tamplin, 2011; Radvansky, Tamplin, & Krawietz, 2010; Radvansky & Copeland, 2006). The explanation for this location updating effect is that when people move an object from one room to another, they have a mental representation, which we call an event model (Radvansky & Zacks, 2014), of the object being in the first room, as well as an event model of it being in the second, current room. Then, when a person is given a recognition probe for this object, because these event models share a common element (the object), there is retrieval interference. This is similar to our account of the fan effect (Radvansky & Zacks, 1991; Radvansky, Spieler & Zacks, 1993; Radvansky, Wyer, Curiel, & Lutz, 1997). The aim of the current research was to assess how the natural aging process influences this effect in light of the fact that (a) it has been found that older adults are less able to manage retrieval interference (Radvansky, Zacks, & Hasher, 1996, 2005) but (b) are also relatively facile at processing information at the event model level (Radvansky & Dijkstra, 2007).

To understand the event cognition process, we start with a consideration of the location updating effect. After this, we review work showing that older adults have trouble managing multiple sources of interference that could lead to a larger effect as a result of aging. After this we consider other lines of research that show that older adults are relatively unaffected by cognitive changes when it comes to processing at the event level.

Walking Through Doorways Causes Forgetting

Event cognition theory assumes that people create representations of the world around them that involve relevant prior knowledge and memories along with what we can observe. These are called event models, and they serve as mental simulations to capture the functional relations among the entities in an event. These event models are constantly updated according to the dynamic changes that are encountered (e.g., Glenberg, Meyer, & Lindem, 1987; Kurby & Zacks, 2008; Morrow, Greenspan, & Bower, 1987; Radvansky & Copeland, 2006; Zwaan, Magliano, & Graesser, 1995).

Work on event cognition has revealed that when people pass through a doorway to move from one location to another, they forget more information than if they do not make such a shift (Radvansky & Copeland, 2006; Radvansky et al., 2011, 2010). In this work, people moved through multiroom virtual environments using a large display screen, with people sitting very close to it, to provide a high degree of immersion. Each room had one or two tables. A person walked toward the table, set down one object (colored solids, such as a red cone or a blue disk), picked up

Gabriel A. Radvansky, Kyle A. Pettijohn, and Joonsung Kim, Department of Psychology, University of Notre Dame.

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Correspondence concerning this article should be addressed to Gabriel A. Radvansky, Department of Psychology, University of Notre Dame, 218-C Haggar Hall, Notre Dame, IN 46556. E-mail: gradvans@nd.edu

another, walked to the next table, which was either across the large room or in another room, and so on. The critical comparison was whether there was a shift to a new room or not. Note that the distance traveled was held constant, regardless of room change.

At critical points, people were probed with the name of an object (e.g., red cone) either halfway across a large room (no-shift condition) or just after having entered a new room (shift condition). Positive responses were made if the probe was either the object that was being carried or the one that was just set down. Note that the objects could not be seen when probed. The carried object disappeared when it was picked up, and people turned their backs from the object that had been set down, so it was no longer in the field of view when the probe was presented.

The results showed an effect in which people made more errors if they had moved to a new room. Thus, event model updating compromised memory for that object. This basic finding has also been observed when pictures are used as memory probes, memory for word pairs is tested (Radvansky et al., 2010), standard computer monitors are used, or a version of the task is used in actual, rather than virtual, reality (Radvansky et al., 2011). Note that this is unlikely to be a version of the encoding specificity effect as such effects more likely emerge after longer delay intervals to allow for some forgetting (Pettijohn & Radvansky, 2014), and the effect did not diminish in a study in which people returned to the original location (Radvansky et al., 2011). Finally, it should be noted that in the task as it is used here, people need to only maintain a single object identity in working memory, as such it is unlikely that context would be needed as a cue to recover this information.

This work stemmed from research on text comprehension that showed that memory declines when there has been a shift in location (e.g., Curiel & Radvansky, 2002; Morrow, Greenspan, & Bower, 1987; Radvansky & Copeland, 2010; Radvansky, Copeland, & Zwaan, 2003; Rinck & Bower, 2000). Essentially, an event boundary introduces a need to update one's understanding of the ongoing events. Also, this finding is consistent with work on event segmentation theory (Kurby & Zacks, 2008; Swallow, Zacks, & Abrams, 2009; Zacks, Speer, & Reynolds, 2009). Specifically, as people parse events, information that was present prior to an event boundary (e.g., a shift in location) becomes less available after the shift.

These results are interpreted in the context of the Event Horizon Model (Radvansky, 2012; Radvansky & Zacks, 2011, 2014), which subsumes event segmentation theory. Aspects of this model can be drawn upon to explain the location updating effect. The explanation is essentially that a person must choose one memory trace to verify the memory probe. When people move an object from one location to another, it is now associated with two locations—the one that it was picked up in, and the one where it was carried. Thus, there are two event models that contain the target information, which compete with one another at retrieval, producing interference, and making retrieval slower and more error prone (e.g., Radvansky, 1999). In essence, this is a kind of a fan effect (Anderson, 1974), and the more locations an object is in, the harder it is to retrieve one particular event model (Radvansky, 1998, 1999, 2005; Radvansky & Copeland, 2006; Radvansky, Spieler, & Zacks, 1993; Radvansky & Zacks, 1991), even though in this case they all point to the same response.

Aging and Interference

There is some evidence that older adults are more susceptible to interference in memory retrieval. That is, they have greater difficulty managing multiple sources of information that may be related but irrelevant to the current task. For example, in studies of the fan effect and aging (Cohen, 1990; Gerard, Zacks, Hasher, & Radvansky, 1991; Radvansky, Zacks, & Hasher, 1996, 2005) older adults exhibit greater increases in retrieval time and/or error rates with increases in the number of associations with a concept. The explanation for this is that older adults have difficulty suppressing related but irrelevant memory representations (Radvansky et al., 2005).

Given this, it is possible that if older adults were probed for memory for object information in the location updating task descried above, then they should show a larger disruption. This would be because when the two event models are formed, each with a token containing the probed-for object, this would set up the retrieval interference situation described in the previous section. Older adults' greater difficulty managing retrieval interference would then cause a larger disruption, resulting in an increased location updating effect.

Aging and Event Cognition

The other line of research that is relevant for the current study is that there is some evidence that older adults do not show major deficits at the event cognition level (Radvansky & Dijkstra, 2007). Of particular relevance here are two processes. The first is the updating of event models when an event boundary is encountered, and the second is management of event information across event boundaries.

Critically important to the location updating effect is that comprehenders should notice that an event boundary has been encountered and that event model updating needs to happen. There is some evidence that this process is similar across younger and older adults. This evidence comes in the form of the explicit marking of event boundaries (e.g., Newtson, 1973) and the increase in processing time during reading (Zwaan, Magliano, & Graesser, 1995). In terms of explicit marking, people are typically presented with a narrative in the form of a text or a film and are asked to explicitly indicate when they think that one event has ended and another has begun. Work by Magliano, Kopp, McNerney, Radvansky, and Zacks (2012) revealed that older adults segment narrative texts, both in verbal and picture form, in a similar manner as younger adults, although there is also some work by Kurby and Zacks (2011) that when asked to segment films of a continuous activity event, such as washing clothes, there may be some age differences in segmentation consistency.

In addition to the explicit marking of event segments, which shows conscious awareness of when event boundaries occur, there is also evidence of more implicit processing of the event boundaries. Specifically, there is work on reading comprehension that shows that reading times increase at event boundaries, indicating the increased cognitive effort involved in updating an event model of the described situation. Younger and older adults show similar patterns of reading time increases at event boundaries (Radvansky, Zwaan, Curiel, & Copeland, 2001) supporting the idea that younger and older adults process event boundaries similarly.

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Beyond the detection of event boundaries, another issue of importance for the current study is the change in the availability of information when an event boundary has been crossed. A standard finding in event cognition research is that information that is part of a previous event model is harder to access after an event boundary has been encountered in a narrative (Radvansky & Copeland, 2010; Zwaan, 1996). Work by Radvansky, Copeland, Berish, and Dijkstra (2003) found that this decline in prior event information, using a probe task, was similar across younger and older adults. This suggests that the updating and management of event information is similar throughout the aging process.

Another line of work that addresses the accessibility of information in prior event models is based on the finding that when readers track a story protagonist through a series of previously learned spatial locations, there is a decrease in availability of object information as the protagonist moves further from the object's location, what has been known as the distance effect (Morrow, Greenspan, & Bower, 1987). Aging work has shown that a similar pattern of availability is observed in younger and older adults (Morrow, Leirer, Altiteri, & Fitzsimmons, 1994; Morrow, Stine-Morrow, Leirer, Andrassy, & Kahn, 1997), and if anything, older adults are more likely to show such a distance effect even for objects that were not part of the previously memorized layout (Stine-Morrow, Morrow, & Leno, 2002).

Thus, overall, the prior evidence suggests that younger and older adults update their understanding of the ongoing described event similarly. What has been demonstrated to this point is that information from prior events becomes less available and that this decline in availability is similar for younger and older adults. What has not been demonstrated is the influence of aging on the decline in currently relevant information following movement from one location to another, namely the location updating effect. Nor has there been any influence of aging on event model updating in nonnarrative settings. The current study fills in this gap.

Again, if older adults have difficulty managing sources of interference during retrieval, then they should show a larger location updating effect than younger adults. This may be the case because it has been argued that this task involves the management of sources of interference. That said, those studies that have shown increased interference for older adults at the event level (i.e., fan effect studies) have largely focused on situations in which the event models are being retrieved from long-term memory, whereas the current task involves the management of information during an ongoing task, and reference to prior event models that are distantly removed from working memory is kept at a minimum.

Alternatively, it may be the case that older adults show a memory disruption that is similar to that of younger adults because of relatively preserved online comprehension processing at the event level. This may be the case because it has been argued that older adults appear to manage ongoing event information as effectively as younger adults as measured by event segmentation, reading time, and comprehension probe studies. That is, all of those studies involve language comprehension, whereas the current task involves the comprehension of an ongoing interactive event, which places different demands on cognition than language comprehension in terms of the information that is readily available and how it is being processed.

Experiment

The aim of this experiment was to assess if the memory of older adults is more affected by the event boundary of moving from one room to another. If this were the case, then it is expected that older adults' memories would be more disrupted than those of younger adults. Alternatively, it may be that, because of relatively well-preserved processing at the event cognition level, older adults would perform similarly to younger adults. If this were the case, then it is expected that older adults' memories would be disrupted by moving from one room to another, but no more so than for younger adults.

Method

Participants

Twenty-nine younger adults (11 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. These people had an age range of 18 to 22, with an average age of 19.7 (SD = 1.7), and had an average of 14.2 (SD = 1.7) years of education. They had an average score of 12.0 (SD = 4.5) on the speeded comparison test (Salthouse & Babcock, 1991), an average comprehension span score (Waters, Caplan, & Hildebrandt, 1987) of 17.8 (SD = 15.7), and an average Shipley vocabulary (Zachary, 1986) score of 31.0 (SD = 3.2).

Sixteen older adults (10 female) were recruited from the South Bend community, provided their own transportation to the testing site, and were paid $20 for their participation. These people had an age range of 61 to 84, with an average age of 73.9 (SD = 7.9) and had an average of 15.9 (SD = 2.1) years of education. They had an average score of 8.0 (SD = 3.1) on the speeded comparison test, an average comprehension span score of 10.5 (SD = 12.0), and an average Shipley vocabulary score of 35.4 (SD = 2.0). All of the older adults had satisfactory scores on the Mini Mental State Exam (Folstein, Folstein, & McHugh, 1975) indicating that they were at least largely free of neurological dysfunction or dementia.

The older adults scored more poorly than the younger adults on the speed measure, $F(1, 43) = 10.04$, $MSE = 16.72$, $p = .003$, $\eta^2_p = .19$, and marginally worse on the comprehension span measures, $F(1, 43) = 2.58$, $MSE = 210$, $p = .10$, $\eta^2_p = .06$. However, the older adults had more years of education, $F(1, 43) = 12.14$, $MSE = 12.46$, $p = .001$, $\eta^2_p = .22$, and scored higher on the vocabulary test, $F(1, 43) = 24.95$, $MSE = 8.06$, $p < .001$, $\eta^2_p = .37$. Two additional younger and two additional older adults were removed for responding at chance levels.

Materials and Apparatus

As in previous studies, the virtual environments were created using the Valve Hammer editor. For this experiment, unlike previous studies, the displays were 46″ diagonal touchscreen monitors (Samsung Model 460TSN-2). The virtual environment was a 55-room series of locations. The rooms were two possible sizes. The large rooms were twice the length of the small rooms. This room size difference allowed for the distance traveled in the virtual world to be equated in the shift and no-shift conditions. Within each room were either one or two rectangular tables, with each table placed along a wall. There was only a single table for the small rooms, and a table in each half of each large room. On one table end was the object that was to be picked up, whereas the other half was empty. This empty spot was for the object taken from the previous table to be set down. There were two doorways per room, and they were never on the same wall. The objects that people interacted with were combinations of shapes and colors. The shapes were cube, wedge, pole, disk, cross (X), and cone, and the colors used were red, orange, yellow, green, blue, purple, white, gray, brown, and black. All combinations of shapes and colors were used once within the experiment.

Procedure

After signing an informed consent form, people were first seated at a standard computer and given the speeded comparison, vocabulary, and comprehension span measures. In addition, older adults were administered the Mini Mental State Exam.

For the primary task, people 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 their own "footsteps" as they moved through the environment, and the lights were turned off during the experiment.

People 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 up and setting down objects was done by using the touchscreen. People were to use their left hand to reach out and either touch the empty part of the table to set an object down or the object already on the table to pick it up.

People moved through the virtual environment using a joystick held in their right hand. To ensure that people 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 a person from crossing the room before setting the object down and picking the next object up.

To assess the availability of information within the virtual environment, there were 48 probe trials. Thus, people were not probed at every possible location. On probe trials, immediately upon either moving halfway across a large room or upon entering a new room, a probe was presented in the middle of the screen. Note that the screen dimmed when the probe appeared, so the virtual environment could still be seen. People were to respond "yes" if the probed object was the one that was currently being carried. People were to respond "no" to all other probes. The "trigger" button on the joystick was used for "yes" responses, and a button at the top of the joystick was used for "no" responses. For each condition half of the probes occurred after a spatial shift and half did not. There were 24 positive probes and 26 negative probes. Of the positive probes, six were in the no-shift condition, and 18 were in the shift condition. The experimental procedure typically lasted between 15 and 20 min.

Results

The error rate and response time data are reported in Table 1. These data were submitted to 2 (Age) × 2 (No-Shift/Shift) repeated-measures analyses of variance. For the error rate data, although older adults had nominally more errors than the younger adults, the main effect of Age was not significant, $F(1, 43) = 1.95$, $MSE = 0.006$, $p = .17$, $\eta^2_p = 0.04$. There was a main effect of no-shift/shift, with people making more errors when there was a shift from one location to another, $F(1, 43) = 20.60$, $MSE = 0.005$, $p < .001$, $\eta^2_p = 0.32$, which is the standard location updating effect. Importantly, the interaction was not significant, $F < 1$. Note that an a priori assessment of effect size required 16 participants per group to detect a medium effect, so the absence of a significant interaction is unlikely to be due to low power. Thus, older adults were like younger adults in having an increase in errors for memory for the object being carried, but the size of this increase was similar across the two age groups, consistent with the idea that cognitive processing at the event model level is relatively unaffected by the natural aging process.

Table 1
Error Rate and Response Time Data

	Error rates		Response time (ms)	
	No shift	Shift	No shift	Shift
Younger adults	0.02 (0.01)	0.08 (0.02)	1104 (37)	1024 (37)
Older adults	0.03 (0.02)	0.11 (0.02)	2150 (54)	2259 (178)

Note. Standard errors appear in parentheses after means.

In addition to the error rates, we also analyzed the response time data. For these data, there was a main effect of age, $F(1, 43) = 95.75$, $MSE = 280376$, $p < .001$, $\eta^2_p = 0.69$, with older adults responding more slowly than younger adults. However, the main effect of no-shift/shift was not significant, $F < 1$, nor was the interaction, $F(1, 43) = 2.33$, $MSE = 79670$, $p < .14$, $\eta^2_p = 0.05$. This is consistent with prior research in that this effect is primarily evident in the error rate rather than the response time data.

Discussion

Overall, the pattern of data for this experiment replicated that seen in previous work. Specifically, the location updating effect was observed; that is, walking through doorways caused forgetting. What is especially remarkable about this effect is that people need to remember only one thing, the object they are currently carrying, they are fully aware that they will be probed for the name of that object, and that they are probed for this object within a few seconds of picking it up. Yet, despite this, the act of walking through a doorway, even a virtual doorway, causes memory to be compromised. More importantly, this pattern of performance was unaffected by age. Here we address what processes give rise to this effect and why it does not change appreciably for older adults.

According to the Event Horizon Model (Radvansky & Zacks, 2014), there are three principles that most directly apply to the phenomenon of forgetting after walking through a doorway. The first is the idea that when an event boundary is encountered, a person will segment the ongoing activity into multiple event models at the event boundary. This certainly happened here as the presence of the location updating effect indicates that people were dividing their travel into separate events depending on the room they were occupying at the moment. Without such segmentation, the location updating effect could not be observed.

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A second principle that is relevant is the idea that the event actively being thought about, which is likely to be the one defined by the room a person is in at the time in this study, is captured by the current working model. This event model has privileged status in that it is in the foreground of processing. Prior events are going to be represented by other event models that have fallen or are falling away from a more highly active state. Thus, information that is associated with the current event will be more accessible in memory. Based on this, some might think that the representation of the probed-for object is less accessible because it would be part of the prior model. Although it would be the case that the prior event model is less accessible, it is also the case that the probed-for object has been carried to the new room, and so is part of the current event as well. Moreover, previous work has shown that returning to the original room, potentially reinstating the original model, does not benefit performance. Thus, although information that is part of the current working model does have special status, it seems unlikely to be driving the location updating effect. This line of reasoning is detailed further by Radvansky et al. (2011, pp. 1642–1643).

Finally, the third principle that is relevant here is the idea that when there are multiple event models that have salient, relevant elements in common—the objects in the case of the current study—then these models will compete with one another, producing interference, and lowering performance. In the case of the location updating effect, probed-for object is part of two event models when a person walks from one room into another: the one for the room in which the object was picked up, and the one for the room in which the person is currently in.

Beyond the location updating effect itself, and more importantly for the current study, it was found that this effect was similar for the younger and older adults. That is, both younger and older adults had trouble remembering the identity of the object that was currently being carried, and that this difficulty was similar in magnitude for both age groups. The normal aging process does not appear to cause older adults any greater difficulty remembering current goal information when they move from one event to the next. This is inconsistent with the idea that older adults would show a larger forgetting effect because they have trouble regulating sources of interference during memory retrieval (e.g., Radvansky et al., 1996, 2005). However, the data are consistent with the idea that, in the face of more general cognitive declines, such as declines in processing speed (e.g., Salthouse, 1996), working memory span scores (e.g., Salthouse & Babcock, 1991), attentional control (Hasher & Zacks, 1988), and episodic memory (e.g., Nyberg, Lövdén, Riklund, Lindenberger, & Bäckman, 2012), older adults do not appear to have difficulties processing information at the event model level (Radvansky, 1999; Radvansky & Dijkstra, 2007). What is notable here is that this is the first demonstration that this age-related preservation extends beyond narrative events to interactive events.

Let's address more specifically what is occurring in the current study and why older adults may not show any cognitive deficit in processing at the event level. The task in this study was to pick up objects, move them either across a large room, or from one room to another, and set them down. Either halfway across the room, or when they walk through a doorway, they were often presented with a memory probe. When people walk through a doorway, they update their event model to represent the new location and then respond to the memory probe. To do this, a person must (a) notice that they are in a new location, (b) deactivate the event model for the prior location, (c) create a new event model for the new location, and (d) maintain the episodic knowledge of the name of the object they are moving. When they receive a memory probe, this will activate both the prior event model and the current event model because they both contain the probed-for object. This retrieval process gives rise to interference, and performance declines.

Research on narrative comprehension shows that older adults are as effective as younger adults at noticing spatial shifts (e.g., Magliano et al., 2012), and they also appear to similarly deactivate prior spatial events (e.g., Radvansky et al., 2003). Finally, further data shows that when older adults encounter event boundaries they show increased reading times similar to younger adults because of the realization that there is a new event at hand (e.g., Radvansky et al., 2001). There is no reason to expect that any of the well-documented cognitive declines should impact an older adult's ability to notice that they have moved from one location to another. Even attentional control issues should not be particularly relevant here because the irrelevant information from the prior locations would be greatly overwhelmed by the input from the current event.

In comparison to this, the need to maintain a bit of knowledge that falls under traditional accounts of episodic memory, namely the name of the object currently that is being carried, is well documented. Thus, although the main effect of age for the accuracy data did not reach significance, the nominally greater number of errors in the current experiment reflects the difficulty of maintaining the object identities. That said, this alone cannot account for the absence of an interaction with age in our study. Similarly, the main effect of age in the response time data reflects general cognitive slowing, however, this is no theoretical account that would explain why cognitive slowing would have a major differential influence on older adults in the location shift and no shifts conditions here, nor in the ability to maintain the identify of a single object. As such, the absence of an age-related difference from this perspective is also not surprising.

This critical step in this process for the current study is when people respond to the memory probe. When a probe is presented, both the current and prior event models are activated. The competition and interference between these two models brings about the decline in performance. As noted in the introduction, previous work has shown that older adults have trouble managing multiple event models when retrieving them both from long-term memory (Cohen, 1990; Gerard et al., 1991; Radvansky et al., 1996, 2005). An important thing to note here is that in those studies the source of the interference is related but incorrect information. This may then call for the operation of some process such as the inhibition of the related but irrelevant memory traces. It is the deficit in managing inappropriate information that leads to the age-related differences. In comparison, in the current paradigm, although there are two event models that interfere with one another during retrieval, they both point to the same information. Thus, the need to bring in inhibition or some other process is not present. Given that the processes that older adults are deficient on are not relevant, age-related differences in interference management are not observed here.

In summary, the present study demonstrated that the location updating effect was present for both younger and older adults, and

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that these two groups did not differ in the magnitude of this effect. Thus, the absence of age-related differences in cognitive processing at the event level can be extended from work on narrative processing to interactive events. The absence of an age-related difference in this paradigm in the face of other age-related changes is likely due to the idea that the memory load and updating processes are not resource demanding, nor are there sources of irrelevant information that need to be managed. However, the need to manage multiple event models did compromise the performance of both younger and older adults. Thus, although there are a number of age-related changes in memory that do occur, the forgetting of information after walking through a doorway is not one of them.

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