



# Situation model updating in young and older adults

Lara Hoeben Mannaert<sup>1</sup> and Katinka Dijkstra<sup>1</sup>

## Abstract

Over the past decade or so, developments in language comprehension research in the domain of cognitive aging have converged on support for resilience in older adults with regard to situation model updating when reading texts. Several studies have shown that even though age-related declines in language comprehension appear at the level of the surface form and text base of the text, these age differences do not apply to the creation and updating of situation models. In fact, older adults seem more sensitive to certain manipulations of situation model updating. This article presents a review of theories on situation model updating as well how they match with research on situation model updating in younger and older adults. Factors that may be responsible for the resilience of language comprehension in older age will be discussed as well as avenues for future research.

## Keywords

Situation model, cognitive aging, text comprehension

## Introduction

Cognitive aging research has been developing as a discipline in its own right over the past four decades. After an initial focus on age-related deficits in cognitive functions and processing speed (Salt-house, 1996), research has recently shifted toward the examination of preserved cognitive skills in language comprehension in older adults,<sup>1</sup> specifically with regard to situation models (Radvansky & Dijkstra, 2007). There have been developments in approaches with regard to the representation of texts as well. Initially, three levels of representation were identified: the surface form, which refers to the exact words and syntax used; the propositional text base, which involves the abstract representation of the ideas in the text; and the situation model, which is the mental representation of the events described in a text (Van Dijk & Kintsch, 1983; Zwaan & Radvansky, 1998). Successful comprehension of a text is considered to be the product of the creation and maintenance of an accurate situation model (Radvansky, 1999). Since the introduction to the concept of situation models (Van Dijk & Kintsch, 1983), many theories have been developed to explain not only how situation models are created but how they are updated as well. Readers create a new situation model whenever they encounter a change in the text and this is where updating of the situation model takes place.

Together, these developments provide better insight into the underlying mechanisms on situation model updating, either as a way to update changes gradually, taking one change at a time into account, or in a more global manner that keeps track of all of the available information in the changed situation. These developments also contribute to our understanding of how situation model updating occurs in young adult and older populations. The following section describes several of these prominent theories on situation model updating to provide an explanation of how situation models are updated, before we turn to how aging affects situation model updating. We limit ourselves to those theories that focus on updating processes as a result of a change in dimension(s) and whose

predictions also have been tested in empirical research that included younger<sup>2</sup> and older readers.<sup>3</sup>

## Theories on Situation Model Updating

According to the event segmentation theory by Radvansky and Zacks (2011), to make sense of the complex and ever-changing world we live in, people segment ongoing perceptual activity into separate events (Kurby & Zacks, 2008). An event here is referring to a “segment of time at a given location that is conceived by an observer to have a beginning and an end,” for example, brushing your hair (Kurby & Zacks, 2008, p. 72). Event segmentation is considered to be a cognitive process that creates these event models and is thought to result from the perceptual system trying to make predictions about the future. During an ongoing event, there exists a stable state that involves both perceptual predictions and the error monitoring of these predictions. As such, while an event is still ongoing (e.g., brushing your hair), it is reasonably easy to predict what will happen within that environment (e.g., looking at the mirror while brushing). Once these predictions are no longer accurate, an event boundary is perceived and the event model needs to be updated to accommodate the new information (e.g., leaving the house).

So when and how are these event boundaries perceived? According to the event-indexing model proposed by Zwaan, Langston, and Graesser (1995; see also Zwaan & Radvansky, 1998), readers track five dimensions of any situation: time, location, objects and characters, causal relationships, and intentions of

<sup>1</sup> Erasmus University Rotterdam, the Netherlands

### Corresponding author:

Katinka Dijkstra, Department of Psychology, Education, and Child Studies, Erasmus University Rotterdam, Rotterdam, the Netherlands.  
Email: k.dijkstra@essb.eur.nl

protagonists. During the reading process, comprehenders monitor story events to see if the situation needs updating. Continuation of the event would be the default mode but whenever there is a discontinuation as the result of a change in any of the five dimensions, the current situation is deactivated and a new situation model is created (Zwaan, Langston, & Graesser, 1995). This process is associated with longer reading times as understanding the text becomes more time-consuming to accommodate the updating of the situation model.

There is much empirical support for the notion that updating occurs as a result of changes in the events in a narrative. A recent study by Hoeven Mannaert, Dijkstra, and Zwaan (2019) illustrated that when a text describes a change occurring to an object's shape, participants deactivate the initial object states in their mental representations, while the newer object state becomes active, suggesting that situation models do not require the activation of all associated information, but only that which is required for the active model. Additionally, studies have found that memory for an event is worse once a person crosses an event boundary, such as going through a door into another room (Radvansky & Copeland, 2006, 2010; Radvansky, Krawietz, & Tamplin, 2011), suggesting that the creation of a new situation model may interfere with a previous one. Further evidence for this interference between separate situation models comes from studies examining the *fan effect* (Anderson, 1974), which is the increase in the response times or error rates as a result of an increasing number of associations between concepts. Research has shown that when multiple situation models are created by referring to the presence of an object at separate locations, this fan effect occurs (Radvansky, 2005; Radvansky, O'Rear, & Fisher, 2017). However, when various objects are described as being in the same location, this fan effect does not occur. This shows that the integration of information into an existing situation model requires less cognitive effort than when new situation models need to be created.

Many studies have shown that changes on any of the five dimensions as proposed by the event-indexing model requires the situation model to update, evidenced by the longer reading times when spatial (Radvansky & Copeland, 2006, 2010; Radvansky et al., 2011), temporal (Radvansky & Copeland, 2010), or changes in causality, protagonists, objects, or motivations occur (Zwaan, Radvansky, Hilliard, & Curiel, 1998). Moreover, a study by McNerney, Goodwin, and Radvansky (2011) showed that situation model updating occurs not only in brief sentences created by experimenters but also when reading an entire novel, suggesting that situation model updating occurs during language comprehension in a naturalistic context and not simply in the context of an experiment.

Although both the event segmentation theory and the event-indexing model state that model updating occurs when changes are made to any of the five dimensions we discussed in the previous section, Kurby and Zacks (2012) argue that each theory proposes a distinct mechanism by which this updating occurs. According to them, the event-indexing model assumes *incremental updating* in situation models after a change occurs in any of the five dimensions. This incremental updating means that the model is continuously updated. Conversely, the event segmentation theory suggests that updating generally occurs globally (Kurby & Zacks, 2012), meaning that new models are created at event boundaries. These event models are kept in a stable state that is resistant to updating, as this would interfere with the prediction processes inherent to the model. These predictions are consistently compared to what is happening in a narrative (Kurby & Zacks, 2012). Once these

predictions are no longer accurate and an increase in error is observed within the model, the model is abandoned and a new one is constructed. To summarize, the event-indexing model proposes an incremental updating mechanism, meaning that the model is continuously elaborated, while the event segmentation theory proposes a global updating mechanism, which argues that new models are created at event boundaries.

Are these two updating mechanisms mutually exclusive? Kurby and Zacks (2012) argue they might not be. Indeed, the mental representations of an ongoing narrative may be updated within one event (i.e., incremental updating) and may be updated entirely at event boundaries (i.e., global updating). Considering the fact that many studies have provided evidence for incremental updating or global updating, it seems natural to assume that both of these processes in fact exist (see Gernsbacher, 1997, for an overview). However, Kurby and Zacks (2012) argue that these processes have always been examined in isolation and that much of the evidence provided for incremental updating could in fact be interpreted as global updating occurring, and vice versa.

Kurby and Zacks (2012) found evidence of both incremental and global updating in an experiment in which participants performed think-aloud exercises where they typed their thoughts after finishing reading a clause and also had to segment the narrative into either short- or long-timescale events. Participants were more likely to mention characters, objects, space, and time when these changed in the narrative, illustrating the presence of incremental updating. Furthermore, event boundaries were significantly associated with the mention of characters, time, causation, and goal dimensions (but not for objects and space), providing evidence for global updating. Given that both global and incremental updating seem to occur in situation models, the authors conclude that neither the event segmentation theory nor the event-indexing model can independently explain how situation models are updated as they only consider one form of updating. Clearly, discovering whether the various dimensions that are tracked during language comprehension are updated using different updating mechanisms is an important next step for future research in this area.

Having concluded that the updating of situation models can occur both globally and incrementally, what can be said about where situation model construction takes place? Most models agree that situation models are built within working memory and that updating works via an interplay between working and long-term memory. Both the event segmentation theory and the event-indexing model state that working memory contains retrieval cues for long-term memory (Zacks, Speer, Swallow, Braver, & Reynolds, 2007; Zwaan & Radvansky, 1998). Situation models contain too much information to be stored and manipulated in short-term working memory alone, thus information in the narrative must be rapidly encoded into long-term memory (Zacks et al., 2007). This information can then easily be retrieved from long-term memory, as long as a part of the information is still available in working memory, with the help of retrieval cues. As such, in order for a situation model to be updated, a continuous interaction between working- and long-term memory processes is required.

To summarize, although there is evidence to suggest that updating occurs both incrementally and globally (e.g., Kurby & Zacks, 2012), more studies are required to establish exactly at which points in a narrative updating occurs, and whether updating differs for the five dimensions that are tracked during the reading of a narrative (i.e., time, space, characters and objects, goals, and causation). Given that (changes in) situation models contain too much

information to be held temporarily in memory, working memory capacity and links with long-term memory are important for effective updating processes to occur. Here, the role of aging processes becomes particularly relevant as older adults may deal with situation model updating differently than young adults as a function of changes in their cognitive development.

## Situation Model Updating in Younger and Older Adults

The discussion of theories on situation model updating focused on the mechanisms responsible for this process. These theories differ with respect to how and when these updating processes take place. Relevant for this review is how these theories may explain (differential) situation model updating processes in younger and older adults, possibly as a result of differences in cognitive developments across the life span (Zacks, Hasher, & Li, 2000). For example, older adults experience declines in some cognitive domains which may have repercussions for their ability to process and update information when reading. At the same time, other cognitive abilities are preserved or continue to develop in older age which may affect language comprehension processes in a more positive sense (Radvansky & Dijkstra, 2007). Below, areas of cognitive decline and preservation in language comprehension in older adults are discussed in the context of research illustrating how this has been demonstrated empirically in cohort comparisons of younger and older readers. After the areas of cognitive decline and preservation, as well as their impact on situation model updating have been discussed, the focus will turn to the issue of how these findings may or may not support the models on situation model updating discussed above.

One known area of cognitive decline in older adults is speed of processing (Salthouse, 1996). Processing of information occurs at a slower speed in older relative to younger adults and accounts for a substantial portion of age-related decline on various cognitive tasks (Salthouse, 1996). In accordance with the *slowing hypothesis* (Salthouse, 1996), research has shown that older adults need more time to process ideas in propositionally dense sentences in a text and at clause boundaries where information from the sentence is updated (Payne & Stine-Morrow, 2014; Stine-Morrow & Hindman, 1994). The need to allocate more resources to the processing of more effort-demanding parts of a text could exhaust the available capacity to do so adequately (Kemper, Crow, & Kemtes, 2004). Indeed, older adults have shown marked declines in text processing ability, especially at the surface and textbase level (Radvansky, 1999; Radvansky, Zwaan, Curiel, & Copeland, 2001; Stine-Morrow, Lovelless, & Soederberg, 1996).

Another area of cognitive decline in older age has to do with a decrease in working memory capacity with increasing age (Salthouse & Babcock, 1991). Limitations in working memory capacity increase chances that recently processed sentences are forgotten and that the construction of a text representation is hindered (De Beni, Borella, & Carretti, 2007; Norman, Kemper, & Kynette, 1992). This was demonstrated in older adults reading texts with higher syntactical complexity (Norman et al., 1992) and when they were processing cognitively demanding text components, such as clause and sentence boundaries (Payne & Stine-Morrow, 2014).

Inhibitory processes are a third area of cognitive ability that declines with age (e.g., Radvansky, Zacks, & Hasher, 1996). Specifically, the *inhibition-deficit account* (Hasher & Zacks, 1988) has

been used to explain cognitive deficits in various tasks in older adults. According to this account, older adults are less able to prevent irrelevant information from entering working memory or to suppress information in working memory that is no longer relevant. Indeed, a study by Radvansky, Zacks, and Hasher (2005) found that older adults are less able to suppress information from competing situation models during a long-term memory retrieval task compared to young adults.

Given the impact of these age-related declines on textbase construction (Radvansky et al., 2001), text processing (Stine-Morrow & Hindman, 1994), and suppressing information, one would expect this to have a negative effect on situation model updating as well. As changes in events require more effort to incorporate these changes into an updated situation model according to the event-indexing model (Zwaan et al., 1995), situation model construction and updating should be more difficult for older adults than younger adults. A thorough review of the extant literature on this topic, however, reveals different results regarding age differences depending on the extent to which situation models are created and updated.

When situation models are created at a sentence level, age-related slowing in processing the information may occur, yet working memory may not be overly taxed in older adult because a limited amount of information has to be processed. Consequently, similar situation models may be constructed by younger and older adults. This issue was examined in a sentence-picture verification task in which participants read a sentence about an object (i.e., an eagle in the air) that was followed by a visual depiction of the object that either matched the implied shape of the object (e.g., an eagle with wings outstretched) in the sentence or mismatched (e.g., an eagle with the wings folded) with it (Dijkstra, Yaxley, Madden, & Zwaan, 2004). Generally, if readers create a situation model of the sentence, then the implied shape of the object matters and should result in faster response times for matching pictures than for mismatching pictures (Stanfield & Zwaan, 2001). The results indicated that older readers not only demonstrated a similar facilitation for the match effect as young adults, but even demonstrated a larger slowdown of responses when the picture mismatched, even when the variability in responses time was controlled for. Older adults had longer response latencies than younger adults overall, but similar performance on the comprehension questions as younger adults supporting the idea of a similar situation model construction.

Possibly, longer reading times for the sentences in older adults allowed them to build a more elaborate situation model that would be protected from overwriting by a mismatching picture. This coincides with a differential allocation of time in older adults in sentence comprehension studies where older adults spent more time at clause boundaries to comprehend the text (Kemper et al., 2004). Presumably, older adults have different strategies when creating situation models, compensating for declines in slowing and working memory capacity by allocating more resources to process the text where it is needed most (i.e., comparing the implied shape of the sentence with the picture presented after the sentence) to comprehend these texts effectively.

Would this lack of age difference regarding situation model construction hold for the same task but in a setting that taxes working memory to a greater extent? This issue was examined in another study using the sentence-verification task in younger and older adults but with participants listening to the sentences over headphones and naming the pictures that appeared after the sentence (Madden & Dijkstra, 2009). Here, the task could be considered

more effortful because it required a more active response (i.e., naming the object) and the maintenance of the processed information from auditory information in working memory. The results again demonstrated a greater match effect in older adults despite the more taxing demands on working memory. Moreover, the match effect was larger in older adults with a higher working memory span than young adults with a higher working memory span. Again, older adults seemed to allocate more resources of their working memory capacity to maintain and update relevant information for the situation model. Why did higher task demands not have a negative effect on the performance of older adults? Possibly, the situation model that high span older adults created from their allocation of resources to a single sentence was even more difficult to override with a mismatching picture than the model created by low span older adults or young adults.

The results of these two studies suggest no age differences in situation model creation, not even when working memory capacity is taxed to a greater extent. In terms of the distinction between constructed and integrated situation models, these results imply that there is no age impairment for the construction of situation models. If anything, older adults are at an advantage for the construction of difficult-to-overwrite situation models, as they illustrated a larger slowdown in responses for mismatching than matching pictures. The question is whether this would also be true for integrated situation models as they not only require more working memory capacity to keep track of changes in the situation but also need to maintain links with the current situation model and long-term memory. We will discuss several studies below that looked into potential age differences regarding updating processes when one of the dimensions that are part of the event-indexing model (Zwaan et al., 1995), such as time, location, objects, or characters, changed and required updating of situation models.

One of the early studies on situation model updating focused on answers to probes about narratives that varied in distance from the protagonist. Older adults answered probes about objects in a room (e.g. shelves in the library) that were distant from a protagonist in narratives more slowly than objects in a room that were closer to the protagonist. Moreover, this distance effect was larger for older than for younger adults (Morrow, Leirer, Altieri, & Fitzsimmons, 1994). In a follow-up experiment, Morrow, Stine-Morrow, Leirer, Andrassy, and Kahn (1997) had younger and older participants again read narratives about a protagonist who moved through space, which resulted in varying distances of objects in those spaces. Reading times rather than probe times were assessed and again showed slowing in both age groups when the objects in a room were more distant from the protagonist, and again there was a larger slowdown in the older age group. Moreover, older adults with better reading comprehension of the narratives showed more slowing for sentences when updating required the integration of earlier information into the model. Both younger and older adults successfully managed to update the situation model, but this came at a cost for older adults. Only by slowing down in reading time were they able to update their situation model, yet their comprehension ability is the same as that of their younger counterparts.

Research on updating processes of other dimensions of the event-indexing model, such as time and goal completion, also showed longer reading times in older adults relative to younger adults when there were shifts in these dimensions. Radvansky, Copeland, Berish, and Dijkstra (2003) examined potential age differences in temporal updating in situation models. Young adults and older adults read narratives with either short (a moment later)

or long time-shifts (a day later). Presumably, a short time shift requires little updating of the situation model, whereas a long time shift requires substantial updating, which should be noticeable in the response times. For example, a wall that is being painted does not look very different a moment later, but it will look entirely different a day later when one assumes the painting continued for some time. Indeed, this substantial updating was reflected in longer reading times in younger and older adults for the narratives that contained a longer time shift. The size of the effect was larger in older adults, again suggesting more sensitivity to the situation model updating manipulation among older adults.

Goal completion was examined among younger and older readers in a study by Radvansky and Curiel (1998). Younger and older participants read a narrative that contained a goal that the protagonist obtained, failed to obtain, or had a neutral outcome. Response times to probe questions about the goal revealed that the availability of the goal decreased, as indicated by longer response times, equally in younger and older readers for the completed goal relative to the failed goal. Both age groups showed similar differences in response times and were therefore equally sensitive to the manipulation. In contrast to the other studies discussed above, the slowdown in response time in Radvansky and Curiel's (1998) study was not greater for older than young adults. Apparently, it depends on the dimension of the event-indexing model that changed, location, time, or goal completion, whether or not updating occurs differently for younger versus older readers.

Based on the studies that tested predictions from the event-indexing model in a younger and older population, we can conclude that they hold equally well for both age groups. In general, younger and older adults demonstrate similar updating and integration ability of the situation model in narratives (Morrow et al., 1994; Morrow, Stine-Morrow, Leirer, Andrassy, & Kahn, 1997; Radvansky, Copeland, Berish, & Dijkstra, 2003; Radvansky & Curiel, 1998; Radvansky et al., 2001) despite stronger demands on available memory capacity to do so in older adults. Stronger age effects as reflected in longer reading or response times may be due to the establishment of more elaborate situation models based on more extensive reading experiences. Rather than having more difficulty establishing links between the current and integrated situation model and with long-term memory in older adults, their extensive reading experiences may actually help them to accomplish this. The ability to establish and maintain integrated situation models may also be due to a stronger emphasis on global and top-down text processing strategies relative to young adults who may focus more on surface-based and bottom-up processing. These successful strategies in older adults to deal with more effortful task demands at a global level may be a way to compensate for age-related declines at the lower surface or textbase level (Stine-Morrow, Morrow, & Leno, 2002). For some changes in dimensions (location, time), this may be easier than for other changes (goal), hence the lack of stronger age effects there.

As stated earlier, updating processes along one dimension of the situation model is consistent with incremental updating. The event-indexing model supports the idea of continuous, incremental updating as demonstrated in longer reading and response times for manipulated dimensions in the narrative. As a whole, incremental updating appears intact in older adults, as seen by adequate situation model construction and updating ability when changes in location, time, and goals occur as long as sufficient processing time is allocated to allow this form of updating to occur. Stronger match effects in the picture-verification tasks discussed earlier (Dijkstra

et al., 2004; Madden & Dijkstra, 2009) can also be considered as a form of incremental updating when a picture is compared with the mental representation of the implied shape of an object in the preceding sentence.

The question is how far this goes. Will older adults still be able to update their situation model when more extensive updating of the situation model is required? A study examining the *fan effect* (Radvansky, Zacks, & Hasher, 1996) demonstrated that, even though both older and younger adults could easily integrate information into a single situation model when reading sentences describing different objects in the same location (e.g., a potted palm and a bulletin board at an airport), age differences occurred when the same object was described to be in different locations (e.g., a potted palm in an airport, hotel, and restaurant). Because multiple situation models had to be constructed to represent objects in different locations, global updating was necessary and interference occurred during retrieval. Older adults suffered more from this interference as seen by the larger fan effect. It is therefore plausible that, when event boundaries are perceived and global updating has to occur (as predicted by the event segmentation theory), older adults may have more difficulty doing so.

This assumption is supported by the results of a study that required the construction of multiple situation models and global updating with regard to changes in characters in a narrative. Noh and Stine-Morrow (2009) demonstrated that older participants had more difficulty than younger adults in accessing previously mentioned protagonists in a narrative after a new one was introduced. This happened even though older adults over-allocated processing time to instantiate the first character in a narrative. As was the case in the previous study (Radvansky et al., 1996), multiple situation models had to be constructed to keep track of all protagonists in the narrative. This required global updating to create a new situation model that still contains all relevant information of the older model. Possibly, due to constraints to their working memory capacity, older readers had difficulty to allocate sufficient resources to characters introduced later in a narrative in an effort to maintain representations of characters that were introduced earlier. Their difficulty in doing so reflects a deficit in global updating among older adults.

This does not necessarily mean that older adults always have difficulty with global updating processes. Results of a study by Radvansky, Pettijohn, and Kim (2015) suggest that under certain circumstances, older adults are equally capable of updating their situation models globally (i.e., at event boundaries). In their study, both young and older adults had to move an object in a virtual environment, either within the same room or through a doorway. The results found a location updating effect as seen by participants' increased forgetting when an event boundary was crossed, suggesting global updating. Importantly, the effect sizes were similar for both age groups, suggesting that older adults do not have more difficulty updating their situation model at event boundaries compared to young adults.

The ability in older adults to update situation models globally in a similar manner as younger adults is further supported by a study on event segmentation by Magliano, Kopp, McNeerney, Radvansky, and Zacks (2012), who had young and older participants segment either text-based or visually based narratives into separate events. They found that both older and young adults were similarly sensitive to situational changes resulting in good between-group segmentation agreement. However, older adults tended to create smaller segments in a narrative than younger adults. Possibly, older

adults perceived event boundaries with fewer situational changes than younger adults. This is less taxing on their resources and helps older adults to update their situation model adequately. Although more research is needed to test this, it could suggest that older adults indeed tend update their situation models globally more often than young adults, possibly as a strategy to avoid placing heavy demands on their working memory capacity. Differential age differences with regard to global updating in different studies could be due to the extent to which how much updating is required to construct integrated situation models and how older adults may use strategies to do so. To assess whether this happens, changes within and beyond event boundaries have to be examined systematically in younger and older adults.

Bailey and Zacks (2015) did just that by controlling for changes in characters and locations in narratives. They found that, although older adults generally read more slowly than young adults, they had faster reading times for a probe that followed no change in the text than for a probe that followed a change in the text, which is indicative of global updating. Young adults, however, did not show such differences in changes for the probes. This suggests that, when changes occur in a narrative, for example, a character moving from the kitchen to the basement, older readers are not only slower when responding to probes about the basement but also to probes about the character (e.g., a change in hairdo), when compared to control probes. In other words, older adults do not only update the element that changes in the situation (location), which suggests incremental updating, but also to elements that did not change but are part of the new situation, which suggests global updating. No clear support for either incremental or global updating processes was found for young adults. It seems that older adults strategize their resources to allocate them where they are most needed and are thus able to successfully update their situation model.

## Conclusion

Research on cognitive aging over the past several decades has often focused on declines in cognitive functioning (Zacks et al., 2000; Norman et al., 1992). Given that the updating mechanism of situation models appears to rely on the interaction between working memory and long-term memory, it is possible that this interaction is mediated by aging processes. Therefore, it would be reasonable to assume that the construction of situation models should be more difficult in older adults who have reduced working memory capacity relative to young adults, as the requisite linking between the current and integrated situation model would require more effort than if information was simply maintained in the current situation model.

Interestingly, several studies have shown that, even when controlling for the longer reading times, older adults still create mental representations during text comprehension both for shorter and longer texts (Dijkstra et al., 2004; Madden & Dijkstra, 2009; Morrow et al., 1994, 1997; Radvansky et al., 2001, 2003; Radvansky & Dijkstra, 2007). Furthermore, these findings support the notion that the constructed situation model can be more elaborate in older adults than in young adults, thus providing protection against contradictory (or mismatching) information. Perhaps most importantly, however, are the findings that younger and older adults appear to demonstrate similar capacities for updating and integrating information in the situation model, albeit that older adults do this more slowly.

We can draw the following conclusions from our discussion of situation model updating in younger and older adults. First, updating occurs when there is a change in the situation of the events described in a text. In the event-indexing model, this change can be along one dimension (Zwaan & Radvansky, 1998), such as location, time, or goals, or in the event segmentation theory along several dimensions (Kurby & Zacks, 2012). In both cases, updating occurs but the difference is whether only the new dimension is being updated (continuously in incremental updating) or all information is being updated (global updating). Older adults are able to update their situation model globally (Bailey & Zacks, 2015; Radvansky et al., 2015), but not always. When multiple situation models have to be created, for example, when objects are described in different locations, or when multiple characters are introduced in a narrative, updating processes may be too taxing on available working memory capacity in older adults to do so (Noh & Stine-Morrow, 2009; Radvansky et al., 1996). Future research could look into this matter more closely by examining the point at which updating in older adults no longer can be compensated for by allocating resources to the task. For example, what happens when older adults are not able or allowed to allocate more attentional resources to certain parts of the texts. Are they still able to construct and update situation models adequately then?

Secondly, older adults appear to be able to construct and integrate situation models along one or several dimensions as well as young adults but generally need more time for this, even if they have a higher working memory span. Situation model updating ability in older adults may be a way to compensate for needing to allocate more effort there (i.e., due to text complexity or task demand) where it is needed most. Only when they are able to allocate more resources to that task can they maintain successful updating performance. As described above, there may be limit the extent to which they are able to do that. Future studies could focus more specifically on how older adults utilize their extensive reading experiences to draw resources from long-term memory to construct and update a situation model. Older adults could be better at removing less relevant information from their situation models which would contradict in inhibitory deficit account (Bailey & Zacks, 2015). Alternatively, older adults could utilize different strategies relating to other goals when reading a narrative, or different self-regulatory activities, relative to young adults (Stine-Morrow, Miller, & Hertzog, 2006).

Apart from more research on incremental and global updating processes in younger and older readers, future research could incorporate insights from related domains. For example, language comprehension research from an embodied cognition perspective could be relevant to examine situation model updating from a different angle. Embodied cognition research has shown examples of how sensorimotor activation facilitates reading and updating processes (Dijkstra & Post, 2015). In a study on motor resonance, sensibility judgments about sentences by turning a knob clockwise or counterclockwise were faster when the manual response to the sentence was in the same rotation direction as the manual action described by the sentence (Zwaan & Taylor, 2006). Research on situation model updating could build on these findings by exploring different ways to examine updating processes in situation models in different age groups. Sensorimotor manipulations could be employed to see if older adults benefit differentially from such manipulations when they construct and update their situation model. For example, rotate a knob to move forward in a text that in which rotation is an important element in situation model construction could facilitate


updating of a situation model, pressing a space bar faster when reading about a character speeding up in a narrative, and could facilitate updating processes as well. The interesting question here would be to assess whether sensorimotor facilitation would occur both for incremental and global updating processes.

To conclude, situation model updating is a process supporting language comprehension and appears to remain intact during aging, despite the declines in other cognitive processes. After a period in which research more heavily focused on the negative aspects of aging in relation to cognitive functions, evidence converges toward preserved abilities in aging and reading comprehension and how older adults successfully allocate their resources to maintain these skills.

## Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

## ORCID iD

Katinka Dijkstra  <https://orcid.org/0000-0002-3486-0661>

## Notes

1. Older adults are defined here as healthy adults aged 60 and above without diagnoses of memory impairments.
2. We define younger readers as adults, generally between the ages of 18 and 30 years.
3. This means that certain theories, such as the memory-based text processing view (see McKoon, Gerrig, & Greene, 1996), the RI-Val model (Cook & O'Brien, 2014), and the event horizon model (Radvansky, 2012), are not part of this review.

## References

- Anderson, J. (1974). Retrieval of propositional information from long-term memory. *Cognitive Psychology*, 6, 451–474. doi:10.1016/0010-0285(74)90021-8
- Bailey, H. R., & Zacks, J. M. (2015). Situation model updating in young and older adults: Global versus incremental mechanisms. *Psychology and Aging*, 30, 232–244. doi:10.1037/a0039081
- Cook, A. E., & O'Brien, E. J. (2014). Knowledge activation, integration, and validation during narrative text comprehension. *Discourse Processes*, 51, 26–49. doi:10.1080/0163853X.2013.855107
- De Beni, R., Borella, E., & Carretti, B. (2007). Reading comprehension in aging: The role of working memory and metacomprehension. *Aging, Neuropsychology, and Cognition*, 14, 189–212. doi:10.1080/13825580500229213
- Dijkstra, K., & Post, L. (2015). Mechanisms of embodiment. *Frontiers in Psychology*, 6, 1–11. doi:10.3389/fpsyg.2015.01525
- Dijkstra, K., Yaxley, R. H., Madden, C. J., & Zwaan, R. A. (2004). The role of age and perceptual symbols in language comprehension. *Psychology and Aging*, 19, 352–356. doi:10.1037/0882-7974.19.2.352
- Gernsbacher, M. A. (1997). Two decades of structure building. *Discourse Processes*, 23, 265–304. doi:10.1080/01638539709544994
- Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. *Psychology of Learning and Motivation*, 22, 193–225. doi:10.1016/S0079-7421(08)60041-9
- Hoeben Mannaert, L. N., Dijkstra, K., & Zwaan, R. A. (2019). How are mental simulations updated across sentences? *Memory & Cognition*, 47, 1201–1214. doi:10.3758/s13421-019-00928-2

- Kemper, S., Crow, A., & Kemtes, K. (2004). Eye-fixation patterns of high-and low-span young and older adults: Down the garden path and back again. *Psychology and Aging, 19*, 157–170. doi:10.1037/0882-7974.19.1.157
- Kurby, C. A., & Zacks, J. M. (2008). Segmentation in the perception and memory of events. *Trends in Cognitive Sciences, 12*, 72–79. doi:10.1016/j.tics.2007.11.004
- Kurby, C. A., & Zacks, J. M. (2012). Starting from scratch and building brick by brick in comprehension. *Memory & Cognition, 40*, 812–826. doi:10.3758/s13421-011-0179-8
- Madden, C. J., & Dijkstra, K. (2009). Contextual constraints in situation model construction: An investigation of age and reading span. *Aging, Neuropsychology, and Cognition, 17*, 19–34. doi:10.1080/13825580902927604
- Magliano, J., Kopp, K., McNerney, M. W., Radvansky, G. A., & Zacks, J. M. (2012). Aging and perceived event structure as a function of modality. *Aging, Neuropsychology, and Cognition, 19*, 264–282. doi:10.1080/13825585.2011.633159
- McKoon, G., Gerrig, R. J., & Greene, S. B. (1996). Pronoun resolution without pronouns: some consequences of memory-based text processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*, 919–932. doi:10.1037/0278-7393.22.4.919
- McNerney, M. W., Goodwin, K. A., & Radvansky, G. A. (2011). A novel study: A situation model analysis of reading times. *Discourse Processes, 48*, 453–474. doi:10.1080/0163853X.2011.582348
- Morrow, D. G., Leirer, V. O., Altieri, P., & Fitzsimmons, C. (1994). Age differences in creating spatial models from narratives. *Language and Cognitive Processes, 9*, 203–220. doi:10.1080/01690969408402116
- Morrow, D. G., Stine-Morrow, E. A., Leirer, V. O., Andrassy, J. M., & Kahn, J. (1997). The role of reader age and focus of attention in creating situation models from narratives. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 52*, P73–P80. doi:10.1093/geronb/52B.2.P73
- Noh, S. R., & Stine-Morrow, E. A. (2009). Age differences in tracking characters during narrative comprehension. *Memory & Cognition, 37*, 769–778. doi:10.3758/MC.37.6.769
- Norman, S., Kemper, S., & Kynette, D. (1992). Adults' reading comprehension: Effects of syntactic complexity and working memory. *Journal of Gerontology, 47*, 258–265.
- Payne, B. R., & Stine-Morrow, E. A. L. (2014). Adult age differences in wrap-up during sentence comprehension: Evidence from ex-Gaussian distributional analyses of reading time. *Psychology & Aging, 29*, 213–228. doi:10.1037/a0036282
- Radvansky, G. A. (1999). Aging, memory, and comprehension. *Current Directions in Psychological Science, 8*, 49–53. doi:10.1111/1467-8721.00012
- Radvansky, G. A. (2005). Situation models, propositions, and the fan effect. *Psychonomic Bulletin & Review, 12*, 478–483. doi:10.3758/BF03193791
- Radvansky, G. A. (2012). Across the event horizon. *Current Directions in Psychological Science, 21*, 269–272. doi:10.1177/0963721412451274
- Radvansky, G. A., & Copeland, D. E. (2006). Walking through doorways causes forgetting: Situation models and experienced space. *Memory & Cognition, 34*, 1150–1156. doi:10.3758/BF03193261
- Radvansky, G. A., & Copeland, D. E. (2010). Reading times and the detection of event shift processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 36*, 210–216. doi:10.1037/a0017258
- Radvansky, G. A., Copeland, D. E., Berish, D. E., & Dijkstra, K. (2003). Aging and situation model updating. *Aging, Neuropsychology, and Cognition, 10*, 158–166.
- Radvansky, G. A., & Curiel, J. M. (1998). Narrative comprehension and aging: The fate of completed goal information. *Psychology & Aging, 13*, 69–79.
- Radvansky, G. A., & Dijkstra, K. (2007). Aging and situation model processing. *Psychonomic Bulletin & Review, 14*, 1027–1042. doi:10.3758/BF03193088
- Radvansky, G. A., Krawietz, S. A., & Tamplin, A. K. (2011). Walking through doorways causes forgetting: Further explorations. *The Quarterly Journal of Experimental Psychology, 64*, 1632–1645. doi:10.1080/17470218.2011.571267
- Radvansky, G. A., O'Rear, A. E., & Fisher, J. S. (2017). Event models and the fan effect. *Memory & Cognition, 45*, 1028–1044. doi:10.3758/s13421-017-0713-4
- Radvansky, G. A., Pettijohn, K. A., & Kim, J. (2015). Walking through doorways causes forgetting: Younger and older adults. *Psychology and Aging, 30*, 259–265. doi:10.1037/a0039259
- Radvansky, G. A., & Zacks, J. M. (2011). Event perception. *Wiley Interdisciplinary Reviews: Cognitive Science, 2*, 608–620. doi:10.1002/wcs.133
- Radvansky, G. A., Zacks, R. T., & Hasher, L. (1996). Fact retrieval in younger and older adults: The role of mental models. *Psychology and Aging, 11*, 258. doi:10.1037/0882-7974.11.2.258
- Radvansky, G. A., Zacks, R. T., & Hasher, L. (2005). Age and inhibition: The retrieval of situation models. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 60*, P276–P278. doi:10.1093/geronb/60.5.P276
- Radvansky, G. A., Zwaan, R. A., Curiel, J. M., & Copeland, D. E. (2001). Situation models and aging. *Psychology and Aging, 16*, 145–160. doi:10.1037/0882-7974.16.1.145
- Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review, 103*, 403–428.
- Salthouse, T. A., & Babcock, R. L. (1991). Decomposing adult age differences in working memory. *Developmental Psychology, 27*, 763–776.
- Stanfield, R. A., & Zwaan, R. A. (2001). The effect of implied orientation derived from verbal context on picture recognition. *Psychological Science, 12*, 153–156. doi:10.1111/1467-9280.00326
- Stine-Morrow, E. A. L., & Hindman, J. (1994). Age differences in reading time allocation for propositionally dense sentences. *Aging, Neuropsychology, and Cognition, 1*, 2–16.
- Stine-Morrow, E. A. L., Loveless, M., & Soederberg, L. (1996). Resource allocation in on-line reading by younger and older adults. *Psychology and Aging, 11*, 475–486.
- Stine-Morrow, E. A. L., Miller, L. M. S., & Hertzog, C. (2006). Aging and self-regulated language processing. *Psychological Bulletin, 132*, 582–606. doi:10.1037/0033-2909.132.4.582
- Stine-Morrow, E. A. L., Morrow, D. G., & Leno, R. (2002). Aging and the representation of spatial situations in narrative understanding. *Journals of Gerontology, 57B*, P291–P297.
- Van Dijk, T. A., & Kintsch, W. (1983). *Strategies of discourse comprehension*. New York, NY: Academic Press.
- Zacks, R. T., Hasher, L., & Li, K. Z. H. (2000). Human memory. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 293–357). Mahwah, NJ: Lawrence Erlbaum Associates Publishers.
- Zacks, J. M., Speer, N. K., Swallow, K. M., Braver, T. S., & Reynolds, J. R. (2007). Event perception: A mind-brain perspective. *Psychological Bulletin, 133*, 273–293. doi:10.1037/0033-2909.133.2.273

- Zwaan, R. A., Langston, M. C., & Graesser, A. C. (1995). The construction of situation models in narrative comprehension: An event-indexing model. *Psychological Science*, 6, 292–297. doi:10.1111/j.1467-9280.1995.tb00513.x
- Zwaan, R. A., & Radvansky, G. A. (1998). Situation models in language comprehension and memory. *Psychological Bulletin*, 123, 162–185. Retrieved from <http://psycnet.apa.org/buy/1998-00120-003>
- Zwaan, R. A., Radvansky, G. A., Hilliard, A. E., & Curiel, J. M. (1998). Constructing multidimensional situation models during reading. *Scientific Studies of Reading*, 2, 199–220. doi:10.1207/s1532799xssr0203\_2
- Zwaan, R. A., & Taylor, L. J. (2006). Seeing, acting, understanding: Motor resonance in language comprehension. *Journal of Experimental Psychology*, 135, 1–11. doi:10.1037/0096-3445.135.1.1