Open Psychology 2019; 1: 94–105 DE GRUYTER

Review Article

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Temporal Chunking Makes Life's Events More Memorable

https://doi.org/10.1515/psych-2018-0007
Received July 30, 2018; accepted October 21, 2018

Abstract: Declines in episodic memory accompany both healthy aging and age-related diseases, such as dementia. Given that memory complaints are common in the aging population, a wealth of research has evaluated the underlying mechanisms of these declines and explored strategy interventions that could offset them. In the current paper, we describe a newer approach to improving memory: event segmentation training. Event segmentation is an encoding strategy in which individuals parse continuous activity into meaningful chunks. The ability to segment activity is associated with later memory for the events, but unfortunately, this segmentation ability declines with age. Importantly, interventions designed to improve event segmentation have resulted in memory improvements for both young and older adults. We will review these past experiments as well as some new event segmentation training work that uses older adults' semantic knowledge to improve their segmentation and episodic memory. We believe that future research on event segmentation is a promising avenue for improving older adults' ability to remember everyday activities.

Keywords: cognitive aging, event segmentation, encoding strategy, memory, strategy training

Temporal Chunking Makes Life's Events More Memorable

"Honey, have you seen my keys?" "Whose birthday party did we go to last week?" "Did I turn off the stove?" Memory lapses such as these are one of the top complaints reported by older adults, and they often involve memory for everyday event information, such as remembering the name of a new acquaintance, information from a news program (West, Crook, & Barron, 1992), and which prescription medication to take on which day (Morrell, Park, & Poon, 1989). Our lives revolve around events; therefore, it is important to understand how we perceive, encode and remember event information, and whether age-related declines in these processes can be delayed, offset, or even improved. Recent event cognition research evaluating *event segmentation* offers a new approach to understanding how people encode complex events and provides a promising avenue for memory interventions. Event segmentation is an encoding strategy in which people parse, or segment, ongoing activity into discrete and meaningful units. The following sections outline the relevance and importance of event segmentation as an encoding strategy in the context of Event Segmentation Theory and they discuss methods for improving this encoding strategy, which may benefit populations such as older adults.

Article note: This article is a part of Topical Issue "Strategy Contributions to Cognitive Aging" edited by Beatrice G. Kuhlmann.

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Cognitive Decline in Healthy Aging

Changes in cognitive functioning are a common consequence of the natural aging process. However, not all cognitive processes get worse with age. While some processes, such as cognitive speed (e.g., Luszcz & Bryan, 1999; Salthouse, 1991), inhibition (e.g., Connelly, Hasher, & Zacks, 1991), and working memory (e.g., Miller et al., 1960), decline with age, other processes, such as semantic and procedural memory, remain intact (Park, Lautenschlager, Hedden, Davidson, Smith & Smith, 2002; Churchill, Stanis, Press, Kushelev, & Greenough, 2003). Each of these cognitive abilities serves an important role in how we perceive, perform, and remember everyday event information. For example, completing mental math at the grocery store, following a recipe, or driving to work are more difficult to execute when one has deficits in cognitive processes such as working memory.

In addition to changes in speed, inhibition and working memory, episodic long-term memory also declines with age (e.g., Spaniol, Madden, & Voss, 2006). Older adults often report concerns about their memory and they are justified: research has demonstrated age-related impairments on memory tasks that older adults might carry out in real-life, such as remembering stories (Johnson, Storandt, & Balota, 2003) and movies (Koutstaal, Schacter, Johnson, Angell, & Gross, 1998). Importantly, these tasks involve remembering information from events that occur frequently in our daily lives.

Aging and Strategy Use

Given that these cognitive processes – particularly episodic memory – decline as we age, decades of research have investigated whether these declines could be explained by the strategic choices people make when they approach a task. That is, do young and older adults use different strategies when trying to learn new information, and if so, do these differences explain the age-related deficit in episodic memory performance? In fact, this research has demonstrated that older adults are less likely to implement effective strategies on free recall tasks (e.g., Hertzog, McGuire & Lineweaver, 1998; Zivian & Darjes, 1983), associative memory tasks (e.g., Dunlosky & Hertzog, 2001; Kausler, 1994; but see Kuhlmann & Touron, 2012), and arithmetic problems (Lemaire & Arnaud, 2008). Thus, older adults display a deficit in *strategy production*. What is more, they also have a deficit in *strategy utilization*, as further research has shown. That is, even when older adults report using effective strategies, they are unable to implement them as effectively as do younger adults (Kausler, 1994; Dunlosky & Hertzog, 1998; Lemaire & Arnaud, 2008; Naveh-Benjamin, Brav, & Levy 2007).

These deficits in strategy production and utilization led people to evaluate whether older adults can learn to use strategies more often and more effectively with practice. In fact, strategy training has been a popular approach to improving memory in older adults for decades. Research has evaluated techniques such as mnemonic training (e.g., Baltes & Kliegl, 1992; Kuhlmann & Touron, 2012) and categorization (e.g., Cavallini, Pagnin, & Vecchi, 2003; Rebok, Rasmusson, & Brandt, 1997). Other work has paired mnemonic training with metacognitive training (e.g., Dunlosky, Kubat-Silman, & Hertzog, 2003; McGillivray & Castel, 2011). Overall, these interventions have been fairly successful in terms of producing memory improvements in older adults (see Verhaeghan, Marcoen, & Gossens, 1992; Rebok, Carlson, & Langbaum, 2007) and maintaining those improvements over time (e.g., Ball et al., 2002).

While this important work has been quite successful in improving the trained tasks, it has demonstrated little improvement in everyday activities. Recently, however, research has begun to focus on more ecologically valid tasks that older adults may encounter in their daily lives, such as associative memory for medication interactions (Hargis & Castel, 2018), source memory for gender (Kuhlmann & Touron, 2017), prospective memory for naturalistic tasks (Rose, Rendell, Hering, Kliegel, Bidelman, & Craik, 2015), and memory for dynamic events (Bailey et al., 2013). In this paper, we will focus on the latter one: strategies people use to encode dynamic, everyday activities, namely, how people segment continuous activity into discrete events.

Event Segmentation Theory

Although we experience a continuous stream of information every day, we tend to remember our days in terms of discrete events. For example, if asked to recall what happened yesterday, one might say something like the following: "First, I got ready for the day, then I went to work. On the way home, I bought groceries, then I made dinner, and soon after I went to bed." If probed further, one would be able to break each of these major events into sub events. For instance, the "getting ready for work" event could be broken into smaller sub-events such as taking a shower, getting dressed and brushing teeth. This example poses an intriguing question: How do continuous events get stored as discrete memories?

Event segmentation theory (EST; Zacks et al., 2007) provides an explanation for how memory is constructed around discrete events. According to EST, the brain naturally parses incoming information into meaningful units. To understand what is happening around us, we construct an event model, which is a working memory representation of what is currently happening (e.g., making dinner). Information from the environment (e.g., motion, light) and long-term memory (e.g., semantic knowledge, prior experience) are integrated to build the event model, which is used to make predictions about what will happen next. When the activity changes (e.g., eating dinner), our event model no longer reflects what is currently happening and our predictions about what will happen next become less accurate. When this occurs, we are forced to update our model. It is at these points in time, when an event changes and the event model is updated, that people typically perceive an event boundary (Zacks et al., 2007). Let's map this onto another real-life example.

Imagine you watch a woman doing laundry at a laundromat. She takes a white sock from a basket full of clothing and places it onto the table. Next, she takes a dark T-shirt and places it onto another area of the table. As you watch this activity unfold, the perceptual information in the environment such as the clothes, the machines, the movements of the person doing her laundry as well as your own prior knowledge relevant to doing laundry (e.g., clothes need to be sorted before they are placed into the machine) will be used to build an event model representing the current activity. After she places the dark shirt in a pile, what will happen next? It is likely that the woman will continue to sort the basket of clothes into separate piles. The perceptual and semantic information represented in the event model will be used to make predictions about future actions. As long as the activity remains predictable, the event model remains fairly stable in working memory. However, imagine that she places the last piece of clothing into the pile which indicates that the "sorting laundry" event is finished. What will she do next? She could start putting the darker clothing items into a washing machine or she could walk over to the change machine to get some coins. At this point, your "sorting laundry" event model will not help you make accurate predictions about what will happen next; therefore, to understand the current activity, you must update your event model to reflect the new event. Assume she begins loading a pile of laundry into a washing machine, the new event model should now reflect the current perceptual information as well as any relevant background knowledge associated with washing clothes. According to EST, the points at which the activity changes and new event models are constructed are when people typically segment the activity and perceive an event boundary.

Segmentation: An Encoding Strategy

Although memories may be segmented or reorganized at retrieval (Hohman et al., 2013), several studies have demonstrated that segmentation is a natural, spontaneous process that occurs at encoding. Zacks et al. (2001) had participants passively watch videos of everyday activities, such as making the bed and ironing a shirt, while brain activity was recorded in an fMRI scanner. After the passive viewing, the participants watched the videos again outside the scanner and they were asked to segment the activity by pressing a button each time they believed one unit of activity had ended and a new unit had begun (based on methods introduced by Newtson, 1973). Zacks et al. (2001) observed transient increases in activation in a network of brain regions at points in the videos that participants later identified as event boundaries. This finding indicates that people spontaneously deconstruct activity into events as they are encoding it, even without instruction to do so.

Importantly, we consider event segmentation to be an encoding strategy because the perceived event boundaries serve as anchors in memory – they help people chunk complex activity into meaningful events. In fact, information that occurs at event boundaries is better remembered than information from the middle of an event (e.g., Newtson & Engquist, 1976; Swallow, Zacks, & Abrams, 2009). Further, when event boundary information is removed from a film, the ability to recall the activity declines (Schwan & Garsoffky, 2004).

Event boundaries are often, but not always, perceived when various features of the event change (e.g., new characters are introduced, a new goal is instated, the situation moves to a new spatial location). People tend to agree about when event boundaries occur during an activity, and the perception of these boundaries shows reliable test-retest reliability within individuals even up to one year later (Speer, Swallow, & Zacks, 2003). While people tend to agree on where to segment an activity, there are important individual differences that predict long-term memory for the activity. In a large-scale individual differences study, Sargent et al. (2013) had 208 participants between the ages 20-79 years segment and later remember movies of everyday activities. The participants also completed psychometric tests, including measures of working memory, episodic memory, perceptual speed, and general knowledge. The researchers found that an individuals' ability to segment an activity is related to their memory for the activity. That is, people who are better able to identify event boundaries during encoding are also better able to remember the activity at a later time. Further, Sargent et al. (2013) discovered that event segmentation ability still predicted memory performance, even after accounting for the participants' age, working memory, episodic memory, processing speed and general knowledge performance. That is, event segmentation is a unique and important predictor of memory for everyday activities for people across the lifespan.

However, some questions still remained as to (1) whether segmentation can only occur spontaneously or whether it can also be under one's volitional control, (2) whether segmentation ability is only associated with better memory or whether normative segmentation improves memory, and (3) how long the relationship between segmentation and memory lasts. Zacks et al.'s (2001) neuroimaging study provides an answer for the first question. As described above, they found that a network of brain regions responded at event boundaries during the passive viewing of the videos, which indicates that people spontaneously segment during perception. However, they also found that this brain network showed an even larger response at event boundaries when people were instructed to *actively* segment the videos while in the scanner. Such a result indicates that attending to the structure of an event through an overt segmentation task modulates brain response, and thus, it may also influence memory.

Flores, Bailey, Eisenberg & Zacks (2017) designed a series of experiments to more directly address the questions raised about the nature of the segmentation-memory relationship: Is segmentation under a viewer's volitional control? Is it causal? If so, how long will the effects of segmentation last? Specifically, they evaluated whether memory is improved by the overt act of segmenting. In this study, the participants watched videos of everyday activities and were instructed to either 1) segment or 2) watch the videos passively. The participants completed a series of memory tests after a delay of 10 minutes, one day, one week, and one month. First, the segmentation group outperformed the control group when memory was tested immediately, and these improved scores were maintained over a one-month delay. Importantly, in addition to the main effect of group on memory performance, they found that better event segmentation ability was associated with better long-term memory for the activities, replicating previous work. This study demonstrated that instructing people to pay attention to the structure of an activity resulted in better long-term memory representations, and it provided crucial evidence that event segmentation is a viable encoding strategy for improving memory for dynamic events.

Aging and segmentation

Unfortunately, though, older adults tend to segment events less normatively than young adults (Zacks et al., 2006). Further, older adults with mild Alzheimer's dementia segment even less normatively than cognitively healthy older adults (Bailey et al., 2013). Such results indicate that age-related differences in memory for everyday activities may be due, at least in part, to older adults' inability to properly chunk events. In these studies, event segmentation ability has been measured by comparing each individual's segmentation behavior with a normative sample of segmentation, a measure called *segmentation agreement* (Kurby & Zacks, 2011). Bailey et al. (2013) observed that higher segmentation agreement was associated with better memory performance, even in individuals who clearly suffered from episodic memory impairments. In sum, older adults do not segment as normatively as young adults, but those who do also exhibit better memory for the activity even if they are in the early stages of Alzheimer's disease.

Changes in event segmentation ability are likely to occur due to several age-related changes in the brain. For instance, age-related changes in the prefrontal cortex, such as reductions in volume (Raz et al., 1997), synaptic density and dendritic arborization (Liu, Erickson, & Brun, 1996) may explain age-related deficits in task performance that rely on the PFC (i.e., attentional control and working memory). Given that event models presumably are working memory representations, changes in working memory ability partially account for age-related deficits in event segmentation, including the ability to construct and update event models during encoding as well as ignore distracting and non-relevant sensory information (Darowski, Helder, Zacks, Hasher, & Hambrick, 2008). In addition to working memory, the PFC is thought to guide organizational processing during encoding (Petrides & Milner, 1982), perhaps because ventrolateral PFC helps select goal-relevant information during event encoding (see Blumenfeld & Ranganath, 2007). In fact, patients with PFC lesions are unable to implement organizational encoding strategies (e.g., Hirst & Volpe, 1988). Thus, age-related changes in the PFC may partially explain why older adults have trouble remembering events.

Up to this point, we have discussed how event segmentation occurs during encoding (e.g., Zacks et al., 2001) and how differences in segmentation ability predict memory (Sargent et al., 2013). Although people naturally use this strategy, instructions to segment an activity further improve memory for up to one month later (Flores et al., 2017). Finally, neurophysiological and cognitive changes that emerge in later adulthood partially explain the age-related deficits in segmentation (Bailey et al., 2013; Kurby & Zacks, 2011; Zacks et al., 2006). Even though event segmentation research over the past two decades has provided important insights into age-related changes in perception and memory, many questions still remain unanswered. In the next section, we will discuss some work that has implemented various interventions in an attempt to improve memory, and particularly, older adults' memory, for everyday activities.

Improving Segmentation and Subsequent Memory

As discussed above, in situations where older adults show a deficit in strategy production or utilization, research has evaluated whether strategy interventions can help. The same is true of the event segmentation literature. Given that normative event segmentation is associated with better memory and that older adults demonstrate worse segmentation ability, it seems only natural that improving segmentation ability ought to improve subsequent memory. In fact, the previous research provides evidence suggesting that this is exactly the case.

Most of the work on event segmentation training has focused on making event boundaries more salient given that they serve as important anchors in memory. For instance, Boltz (1992) attempted to emphasize event boundaries by manipulating the placement of commercial breaks throughout a television episode. She evaluated the effect of commercials placed at event boundaries, commercials placed in the middle of an ongoing event, and no commercials on long-term memory for activity in the television episode. Boltz (1992) found that memory benefitted from commercials placed at event boundaries (compared to the no-commercial control condition) and it was impaired from commercials placed in the middle of an event. Conversely, when event boundaries are removed from a film during encoding, overall comprehension and recall suffers (Schwann & Garsoffky, 2004). The results from both of these studies indicate that encoding information effectively at event boundaries directly relates to memory for those events.

In another recent experiment, Gold, Zacks, and Flores (2016) examined whether another type of event segmentation intervention could reduce the age-related deficit in memory for everyday activities. They used perceptual cueing to draw individuals' attention towards specific parts of a movie (i.e., event boundary or event middle) in the form of a bell sound, an arrow, and a brief slowing of the movie. Interestingly, people who were cued at event boundaries showed increased recognition and recall over people in the control condition, and both young and older adults benefitted from this cueing intervention. Thus, even though the intervention did not eliminate the age-related deficit in memory, cueing the event boundaries and essentially forcing the participants to effectively segment the activities resulted in improved memory for everyone.

Semantic knowledge as a resource for older adults

To date, the research that has evaluated methods of improving segmentation ability has focused primarily on using external cues to emphasize event boundaries (e.g., commercials, presentation speed). However, EST suggests that in addition to perceptual information, segmentation should be influenced by conceptual factors, such as prior experience and semantic knowledge. This is a particularly exciting intervention avenue for older adults because semantic knowledge (i.e., knowledge of general facts and information) tends to be maintained or even improved with age (Park et al., 2002). Given that other cognitive processes such as working memory and episodic memory decline, older adults may rely upon their intact semantic knowledge to help them encode and remember everyday activities. The previous research has shown that indeed older adults tend to use knowledge to fill in the gaps when they fail to retrieve episodic information (e.g., using stereotypes; Radvansky, Copeland, & von Hippel, 2010). Further, they are more likely to remember information such as grocery prices when it is consistent with their prior knowledge (Castel, 2005). Since semantic knowledge appears to be more resistant to age-related declines, it may be useful as a resource to improve segmentation and memory.

Thus, in recent work from our lab, we have begun to more directly investigate the role of semantic knowledge for improving segmentation and memory in younger and older adults. In a series of studies, we have evaluated the influence of semantic knowledge on different measures of segmentation and memory ability. More specifically, knowledge was operationalized as the degree to which older and younger adults produced normative scripts of different types of daily activities, and we termed this "familiarity". Previous work has identified that young and older adults produce different quality scripts for various activities (Rosen et al., 2003). Based on these data, we chose activities for which older adults had more normative scripts (e.g., balancing a checkbook, gardening, ironing a shirt) and activities for which young adults had more normative scripts (e.g., playing a video game, setting up a new printer).

In one study, young and older adults completed an overt measure of event segmentation (i.e., the button pressing measure described above) on various activities for which they produced more or less normative script data (Newberry, Smith, & Bailey, 2018). They also completed a series of event memory measures for the activities, such as free recall, recognition, and temporal order, as well as a battery of psychometric assessments for processing speed, working memory and general knowledge. We hypothesized that when people are familiar with an activity and have a similar knowledge base (i.e., have more normative scripts), they should be better able to detect when important event boundaries occur and should, therefore, agree more on the locations of those boundaries, compared to activities for which they have little or no knowledge (i.e., less normative, or more idiosyncratic, scripts). Interestingly, this knowledge intervention did not benefit older adults' segmentation agreement. That is, despite having more normative scripts for certain activities, older adults still had lower segmentation agreement compared to young adults (see Figure 1). However, individual differences in processing speed partially accounted for the age-related deficit in segmentation agreement.

Importantly, though, we replicated the previous work and showed that segmentation agreement predicts memory performance (Bailey et al., 2013; Flores et al., 2017; Sargent et al., 2013). That is, both younger and older adults who exhibited higher segmentation agreement also exhibited better memory for the everyday events (older adults' $r = .14$; young adults' $r = .38$; see Figure 2). Replicating the positive relationship between segmentation ability and memory, across different samples of individuals and various stimuli, provides more evidence that normative event segmentation, as an encoding strategy, is associated with better memory. In the future, we plan to replicate this study using a purer manipulation of familiarity, such as controlling for exposure to different activities in a laboratory setting (i.e., novelty).

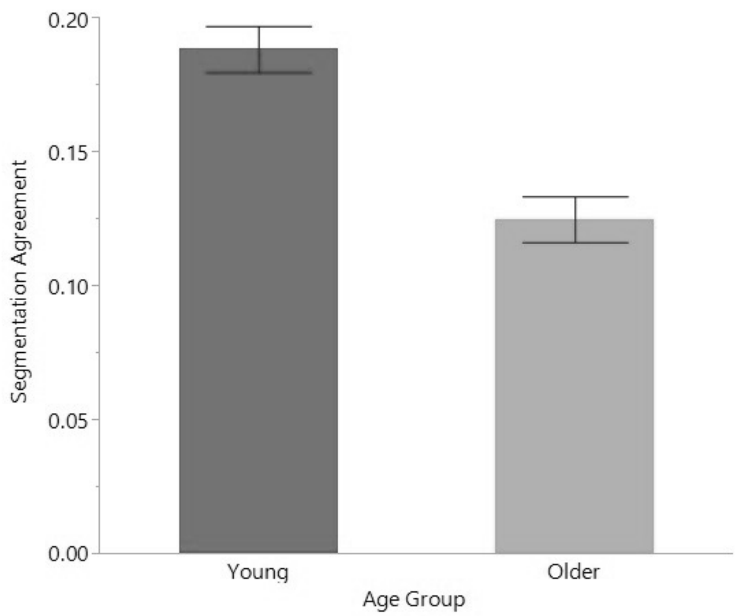

Figure 1. Segmentation agreement for young and older adults from Newberry, Smith, & Bailey (2018). Error bars represent standard error of the mean.

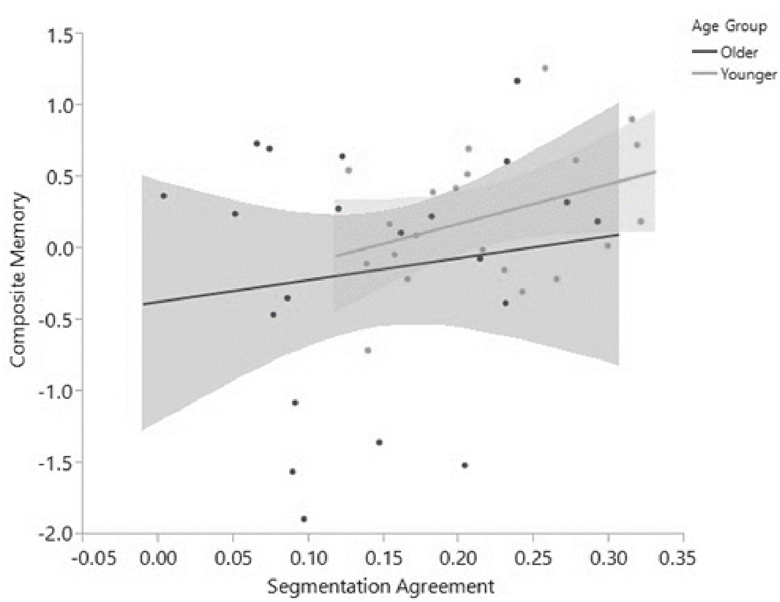

Figure 2. Segmentation ability predicts event memory for young and older adults (Newberry, Smith, & Bailey, 2018). The lines represent best-fit lines for each age group. Shaded portions of the figure represent confidence interval for the slope of the line.

In another study, we used a covert measure of event segmentation: dwell time (Smith, Newberry, & Bailey, 2018). To assess dwell time, still frames were taken from every second in each of the videos used in Newberry et al. (2018). These images were then put into a self-paced slideshow and the participants were instructed to view the slideshow and try to remember the activity for later memory tests. We recorded the time spent dwelling on each image. The previous work using dwell time as a measure of event segmentation has consistently found that people spend longer looking at images taken from event boundaries as compared to images taken from the middle of an event, something referred to as the *boundary advantage* (Hard, Recchia, & Tversky, 2011). Therefore, we evaluated (1) whether older adults also demonstrate the boundary advantage, (2) whether the boundary advantage is moderated by familiarity (i.e., degree to which a person's script for an activity is normative), and (3) whether dwell time predicts memory. In other words, when people are familiar with an activity, they should be better able to detect when important event boundaries occur. Therefore, they should spend more time dwelling on images containing event boundary information versus non-boundary information, especially compared to when they are viewing activities for which they are less familiar. Further, if they use a more effective encoding strategy (e.g., spending more time on images containing event boundary information), then they should also better remember the activity.

In this study, knowledge did benefit older adults' processing of event structure. Specifically, older adults showed a larger boundary advantage on the activities that they were more familiar with, compared to the activities that were less familiar and compared to younger adults (see Figure 3). It is worth noting, the participants' dwell time patterns predicted memory. That is, those individuals who slowed down to better encode event boundary information were also better able to remember the entire activity (Figure 4). These results provide some initial evidence that knowledge may improve older adults' ability to perceive, segment and remember information about everyday activities.

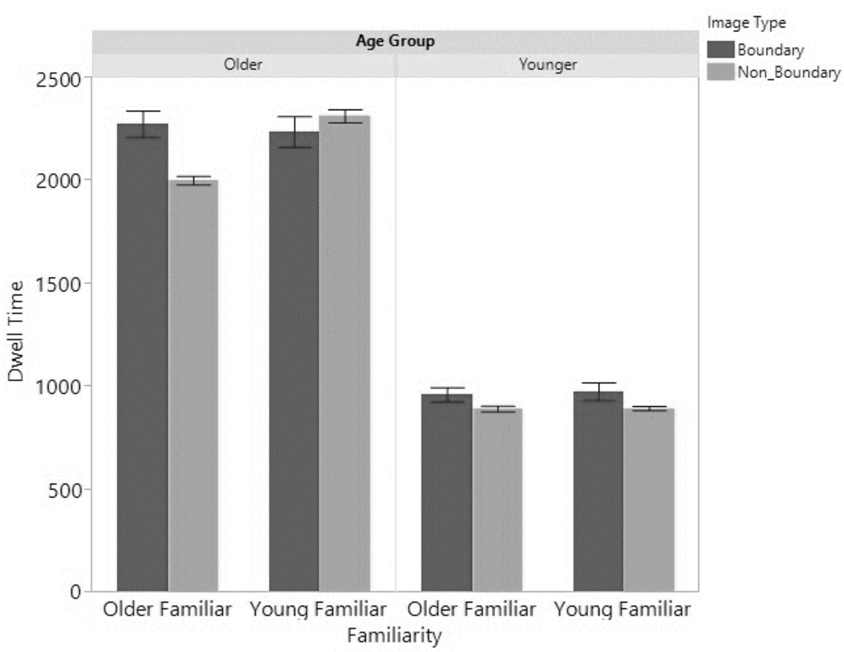

Figure 3. Mean dwell time spent on images containing event boundary or non-boundary information plotted by familiarity and age group from Smith, Newberry, & Bailey (2018). Error bars represent 95% confidence intervals.

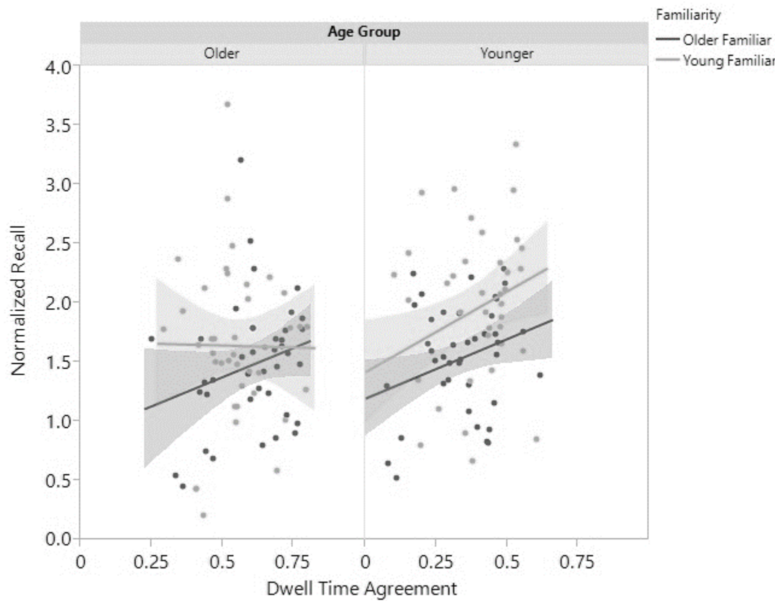

Figure 4. Dwell time agreement predicting recall for young and older adults plotted by familiarity from Smith, Newberry, & Bailey (2018). "Older familiar" refers to the activities for which older adults produced more normative scripts. "Young familiar" refers to the activities for which young adults produced more normative scripts. The lines represent best-fit lines for each age group. Shaded portions of the figure represent confidence interval for the slope of the line.

Conclusions and Future Directions

Individuals differ in their ability to encode event information and the effectiveness of this ability has consequences for memory. Those who are better able to employ the segmentation strategy at encoding are better able to remember events at later times, regardless of age (Bailey et al., 2013; Newberry et al., 2018; Smith & Bailey, 2018; Zacks et al., 2006) or other pre-existing cognitive abilities (Sargent et al., 2013). Despite this, segmentation ability tends to be worse in older adults, suggesting that it may be a contributing factor to the commonly observed deficits in episodic memory. Thus, it is imperative that we better understand how event segmentation operates as an encoding strategy when people are learning new information, and how this strategy can be improved.

It is important to note here that event segmentation does occur spontaneously (Zacks et al., 2001). Similarly, other encoding strategies such as mental imagery can occur in a ballistic, involuntary manner in response to certain stimuli (Kok, Failing, & de Lange, 2014; Pearson & Westbrook, 2015). However, despite the fact that segmentation occurs spontaneously during normal event perception, various interventions have been shown to improve one's segmentation ability - just as the previous mnemonic interventions have been shown to increase the use of mental imagery (Dunlosky, Hertzog, & Powell-Moman, 2005). Thus, we believe that, under certain circumstances, people may have volitional control over how they segment information. However, more work is still needed to better understand this strategic control.

Future research on this topic could take a number of different directions. For example, the influence of other top-down manipulations, such as experience and expertise, on segmentation, memory, and aging should be evaluated. Another line of research could further evaluate the relationship between event segmentation and memory. We know that normative segmentation is associated with better memory, and there is some initial evidence to suggest it has a causal influence on memory (Flores et al., 2017; Gold et al., 2016), but future work could further evaluate this relationship. How does this strategy specifically affect the long-term representations of events? We currently assume that these event models are more normatively, and perhaps more hierarchically, organized in long-term memory. If so, this organization should further improve with knowledge and experience. Many important questions remain, concerning the issue of how segmentation improves memory. If answered, they would aid the general understanding of how dynamic, real-world activity is encoded and they would help inform the development of successful segmentation training, particularly in older adults. Finally, some work has already shown that individuals who are better at segmenting activities are also better at performing activities (Bailey, Kurby, Giovannetti, & Zacks, 2013). Thus, future work could investigate whether segmentation training can improve older adults' ability to execute everyday tasks, which is a critical factor for maintaining an independent lifestyle.

Acknowledgements: This project was supported by a grant from the National Institute of General Medical Science GM113109 of the National Institutes of Health.

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