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Semantic knowledge attenuates age-related differences in event segmentation and episodic memory

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Abstract
While semantic and episodic memory may be distinct memory systems, their interdependence is substantial. For instance, decades of work have shown that semantic knowledge facilitates episodic memory. Here, we aim to clarify this interactive relationship by determining whether semantic knowledge facilitates the acquisition of new episodic memories, in part, by influencing an encoding mechanism, event segmentation. In the current study, we evaluated the extent to which semantic knowledge shapes how people segment ongoing activity and how such knowledge-related benefits in segmentation affect episodic memory performance. To investigate these effects, we combined data across three studies that had young and older adults segment and remember videos of everyday activities that were either familiar or unfamiliar to their age group. We found age-related differences in event-segmentation ability and memory performance, but only when older adults lacked semantic knowledge. Most importantly, when they had access to relevant semantic knowledge, older adults segmented and remembered information similar to young adults. Our findings indicate that older adults can use semantic knowledge to effectively encode and retrieve everyday information. These effects suggest that future interventions can leverage older adults' intact semantic knowledge to attenuate age-related deficits in event segmentation and episodic long-term memory.

Keywords Semantic knowledge · Episodic memory · Event segmentation · Cognitive aging

Introduction

Tulving (1972) made a distinction between two functionally separate memory systems: episodic memory and semantic memory. Episodic memory includes recollections of specific, personally experienced events and is largely served by an interplay between cortical activity representing sensory features and the binding of these features in the hippocampus (Rugg et al., 2015). Semantic memory includes our general knowledge of concepts and schematic representations from our accumulated experiences and is largely served by neural activity distributed across cortical regions of the brain (Renoult et al., 2019). While this distinction has been supported by behavioral, neuropsychological, and neuroimaging data, the two systems are functionally and anatomically intertwined (Renoult et al., 2019). For example, Burianova, McIntosh, and Grady (2010) propose that a large-scale functional network, including the left hippocampus, left lingual gyrus, and right caudate nucleus, underlies a unitary system of declarative memory that gives rise to semantic, episodic, and autobiographical memory retrieval. Clarifying the relationship between these two memory systems is important for understanding episodic memory failures. This is particularly important for people who experience greater issues with episodic memory, such as older adults.

Importantly, decades of research suggest that semantic knowledge improves episodic memory in young adults (e.g., Bransford & Johnson, 1972), older adults (e.g., Hess, 2005), and for experts within their knowledge domain (e.g., Chase & Simon, 1973). For example, subject matter experts, such as chess masters (Chase & Simon, 1973), beer experts (Valentin et al., 2007), and soccer players (Williams et al., 1993) are better able to remember new information within their domain of expertise. Similarly, both young and older adults are better able to remember information from ambiguous text passages when given context, such as a picture (Bransford & Johnson, 1972) or title (Miller et al., 2006) that allows them to draw upon relevant semantic knowledge. These knowledge-related benefits on episodic memory may be due, in part, to more

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efficient encoding processes (Anderson & Pichert, 1978; Chase & Simon, 1973; Miller et al., 2006; Reingold et al., 2001); however, little evidence indicates which encoding mechanisms are responsible.

In the current study, we evaluated an encoding mechanism, *event segmentation*, that is (1) associated with episodic memory performance and (2) presumably guided by semantic memory, based on theories of event cognition (Radvansky & Zacks, 2014). Specifically, we evaluated the extent to which semantic knowledge shapes the segmentation of episodic memory for everyday activities in both young and older adults. If semantic knowledge aids episodic memory performance by improving moment-to-moment encoding processes (Anderson & Pichert, 1978; Chase & Simon, 1973; Miller et al., 2006; Reingold et al., 2001), then knowledge-related benefits in the segmentation of continuous activity may account for the knowledge-related benefits observed in episodic memory performance.

Event segmentation

Over the course of a day, we encounter a continuous stream of information, yet later on, we remember this information in the form of discrete events. One encoding mechanism our perceptual system uses to make sense of continuous event information is event segmentation: the process of parsing continuous information into meaningful, discrete units. Event Segmentation Theory (Zacks et al., 2007) provides a framework for understanding how we engage in segmentation. Event Segmentation Theory proposes that current event information is represented in a working memory representation called an event model. The event model is informed by both bottom-up (sensory input) and top-down influences (semantic knowledge; relevant prior experiences). As information changes during a real-world event, our event model is updated to reflect the change, and it is at these points in time when individuals segment*,* perceiving a boundary between two events. In the lab, we operationalize event segmentation with the unitization task (Newtson, 1973), in which viewers are asked to press a button whenever they judge that one meaningful unit of activity ends and another begins. Importantly, viewers show high agreement in their segmentation behavior between and within viewers (Speer et al., 2003; Zacks et al., 2006).

What determines the perception of an event boundary? Event cognition theories propose different mechanisms: failures to predict the immediate future (Zacks et al., 2007); changes in context (Clewett et al., 2019); or when incoming information is less coherent (Gernsbacher, 1990). Regardless of the specific mechanism, relevant top-down influences, such as semantic knowledge, should influence how continuous information is segmented. For example, context and forewarning of an event change, and understanding of action-related goals has been found to aid segmentation (Newberry & Bailey, 2019; Pettijohn & Radvansky, 2016; Zacks, 2004).

Consistent with this idea, subject matter experts show different patterns of event segmentation, such that experts identify fewer (Blasing, 2015) and more similar event boundaries (Levine et al., 2017; Newberry et al., 2021) compared to novices. These results suggest that semantic knowledge provides an organizational framework to understand and construct episodic memory representations for new events (Renoult et al., 2019). In contrast, other researchers have failed to find that semantic knowledge influences event segmentation (see Huff & Papenmeier, 2017, for a review). For instance, Hard et al. (2006) presented films to participants either forward or backward and found that participants identified similar event boundaries regardless of film direction. As such, event segmentation may predominantly be driven by bottom-up, perceptual changes in the activity (i.e., changes in movement), rather than top-down knowledge-based factors (Cutting et al., 2012; Huff & Papenmeier, 2017; Zacks, 2004). Further, the perception of event boundaries may activate semantic knowledge, rather than the reverse (Hard et al., 2006).

Event segmentation offers a framework for measuring the effectiveness of encoding processes in real time. Event boundaries are thought to serve as anchors in memory that help reduce retroactive interference by organizing ongoing activity into smaller chunks, or events (Radvansky, 2012; Radvansky & Zacks, 2014, 2017). Individuals who engage in more normative event segmentation (i.e., they identify boundary locations that most people identify) tend to have better memory for that activity at a later time (Bailey et al., 2013; Flores et al., 2017;Sargent et al., 2013 ; Zacks et al., 2006).

Some research suggests that everyday episodic memory failures in older adults may be due, in part, to deficient segmentation processes during encoding (Kurby & Zacks, 2019; though see Magliano et al., 2012, who found minimal age-related differences in segmentation). Cognitively healthy older adults tend to segment less normatively than do young adults (Kurby & Zacks, 2011), and they remember less event information than do young adults (Sargent et al., 2013). Nevertheless, older adults have better memory for the event when they segment effectively (Sargent et al., 2013; Zacks et al., 2006), and this is true even amongst older adults in the earliest stages of Alzheimer's disease (Bailey et al., 2013; Zacks et al., 2006).

In addition to the age-related deficits in segmentation ability, several other cognitive abilities important for understanding and effectively processing ongoing event information decline with age, such as working memory (e.g., Salthouse, 1994), processing speed (e.g., Salthouse, 1991), inhibition (e.g., Connelly et al., 1991), and perceptual processing (Andersen, 2012). Despite these cognitive declines, semantic knowledge remains intact with age (Dixon et al., 2003; Park et al., 2002). For example, older adults show preserved script knowledge (Light & Anderson, 1983; Umanath & Marsh, 2014) and vocabulary knowledge (Badham et al., 2016). In fact, when memory tasks involve familiar and meaningful stimuli for which older adults can rely upon their prior knowledge, age-related episodic memory deficits can be reduced or eliminated (Castel, 2005; see Umanath & Marsh, 2014, for a review).

In sum, segmentation ability is associated with many other cognitive abilities – e.g., working memory, processing speed, executive function, and semantic memory (Sargent et al., 2013). Most of these show marked age-related declines, with the exception of semantic memory. Given these declines, older adults may rely more upon prior knowledge to improve the efficiency of how everyday events are segmented and later retrieved than young adults.

Current study

In this study, we evaluated whether older adults are able to leverage their semantic knowledge to overcome age-related declines in segmentation and event memory. To investigate the effects of semantic knowledge on segmentation and memory, we manipulated the content of the everyday activities such that they were more or less familiar to young and older adults. We hypothesized that familiarity with an activity would lead to more effective segmentation in older adults, and that this knowledge-related benefit in segmentation would be associated with better episodic memory for the activity.

Method

For the current study, we combined data from three separate experiments within a federally funded grant that shared the same overall goal of assessing whether older adults can leverage their intact semantic knowledge to improve their event perception and memory. These experiments used the same age groups, knowledge manipulation, stimuli, overt segmentation, and memory tasks. However, it is important to note that these experiments were conducted at different times. Further, in addition to the overt segmentation task, two of the experiments contained other key measures of event perception (e.g., eye movements, fMRI BOLD activity) to address other research questions. Additional differences between studies are outlined in Table 1.

KSU Kansas State University, *KU* University of Kansas, *MMSE* Mini Mental State Exam

Table 1 Participant and procedural information by experiment

	Measure of event perception	Participant information	Procedure
Experiment 1 (Newberry, Pitts, Smith, & Bailey, unpublished)	· Overt segmentation task	· n = 20 young adults (11 females) ○ Recruited from KSU given course credit for participation · n = 19 older adults (13 females) ○ Recruited from Manhattan, KS community ○ Paid $10/h for participation	1. Segmentation practice task 2. Watch and segment video 3. 5-min distractor task 4. Memory tasks (2–4 repeated for four videos) 5. MMSE
Experiment 2 (Smith, Loschky, & Bailey, under review)	· Overt segmentation task · Eye-movement measures	· n = 31 young adults (16 females) ○ Recruited from KSU given course credit for participation · n = 30 older adults (16 females) ○ Recruited from Manhattan, KS community ○ Paid $10/h for participation	1. MMSE 2. Eye-tracker calibration 3. Practice video task 4. Passively watch video while eyes were tracked 5. 5-min distractor task 6. Memory tasks (3-6 repeated for four videos) 7. Watch and segment each video 8. Familiarity ratings
Experiment 3 (Smith, Brucks, Rogers, Martin, & Bailey, in prep)	· Overt segmentation task · fMRI/BOLD measures	· n = 25 young adults (18 females) ○ Recruited from KUMC ○ Paid $25/ hour for participation · n = 24 older adults (16 females) ○ Recruited from KU ADC ○ Paid $25/h for participation	1. MRI screening 2. Practice video 3. Passively watch 4 videos in MR scanner 4. Memory tasks (3-4 repeated for four videos) 5. Watch and segment each video 6. Familiarity ratings

Common methods across experiments

Participants

All three experiments included young adults (aged 18–28 years) and older adults (aged 65–85 years). Table 2 provides demographic information for all experiments.

To screen for cognitive impairment, all older adults completed a thorough phone screening to exclude for a wide range of neurological disorders (e.g., Huntington's disease, Parkinson's disease) and neurological damage (e.g., due to stroke, seizures, concussions). These older adults also completed two dementia screening measures over the phone: The Short Blessed dementia test (score < 7; Katzman et al., 1983) and the AD8 (score < 2; Galvin et al., 2005). Only older adults who met all criteria based on the phone screening were invited to participate in an experiment. Both young and older participants also completed the Mini Mental State Exam (MMSE). Data from individuals who scored less than 24 were excluded from analyses (n = 1 older adult in Experiment 1). Each experiment was approved by Kansas State University's Institutional Review Board.

Materials

All three experiments used the same videos of everyday activities, event memory tests, and measure of event segmentation. Studies 1 and 2 also included several psychometric measures to serve as filler tasks between encoding and retrieval of the activities.

Table 2 Demographic information by experiment

Measure (construct)	Young adult		Older adult		*t* value	*p*
	M	*SE*	*M*	*SE*		
Experiment 1						
Age, y	18.90	0.18	72.10	1.22		
MMSE	29.20	0.25	28.95	0.25		
Years of education	13.05	0.15	17.50	0.67	6.47	<.001
Experiment 2						
Age, y	19.09	0.91	69.55	0.30		
MMSE	29.12	0.36	29.16	0.20		
Years of education	13.17	0.21	16.69	0.45	1.59	0.12
Experiment 3						
Age, y	24.20	0.56	77.04	1.03		
Years of education	17.40	0.29	16.48	0.65	1.30	0.20

Note. The Mini Mental State Exam (MMSE) was not used in Experiment 3 because older adults in this study were given the more extensive Clinical Dementia Rating Scale (Morris, 1997) and received a score of 0, signifying that they had no signs of dementia

Videos of everyday activities We used four videos shot at a rate of 25 frames/s. These videos depicted activities that are targeted to be more and less familiar to older and young adults (Fig. 1). As indicated in the *Materials* ("Self-reported knowledge ratings") section, two of the videos were more familiar to older adults (planting a pot of flowers: duration = 297 s; balancing a checkbook: duration = 258 s) than to young adults. Older adults tend to provide more normative scripts for these activities than young adults (Rosen et al., 2003; Smith et al., 2020). Likewise, the remaining two videos were more familiar to young adults (installing a printer: duration = 148 s; setting up a video game console: duration = 267 s) than to older adults. The older and young adult videos were used in prior studies examining the effect of knowledge on event encoding (Smith et al., 2020; Smith et al., under review). Participants also watched a practice video of an individual building a boat from Duplo blocks (duration = 155 s; Zacks et al., 2006).

Everyday memory measures We assessed episodic memory for each video using three different measures. The measures included free recall, recognition, and temporal order memory, and the participants always completed these measures in this order.

Free recall A blank text box appeared on screen after the filler tasks were completed for each video. Participants were instructed to freely recall (i.e., type) as much information as they could remember from the video they just watched. No other prompts were given. Free recall was scored based on the number of actions recalled from the video using the action-coding system (ACS; Schwartz et al., 1991; Smith et al., 2020). The ACS organizes action sequences into a goal hierarchy, in which basic actions involved in completing subgoals are termed A1 units (i.e., pick up the power supply box, connect the power cable into the power supply box, insert the power supply into the xbox's power port, and then connect the power cable to an outlet.) and higher-level goals that encompass many A1s are termed A2 units (i.e., connect the xbox to a power outlet). Each video was first broken down into its component A1s and then grouped into A2 units. Multiple coders scored the data. After receiving training from one of the lead researchers, each coder scored data from ten participants, blind to the age of the participants, for each video to ensure reliability across coders (average inter-rater Kappa across coders = 0.84 for A1 units and average inter-rater Kappa across coders = 0.89 for A2 units). Once an acceptable baseline (Kappa = 0.75) had been met, each coder was assigned to score all of the recall responses for a particular video. The number of correctly recalled actions was divided by the total number of units in the video to make the dependent measure: proportion of A1/A2 units correctly recalled. Of note, recall scored using the ACS was strongly correlated with

Fig. 1 Event stimuli. Stills taken from each of the four experimental movies. Stills from (**a**) planting a pot of flowers and (**b**) balancing a checkbook were taken from the older adult videos. Stills from (**c**) setting up a video game console and (**d**) installing a printer were taken from the young adult videos

normalized word count (r = .70 for A1 and r = .64 for A2 units), a method of scoring free-recall data reported in Flores et al. (2017).

Recognition Recognition memory was assessed using a two-alternative forced choice test. There were 20 trials per video, each containing a target image and a distractor image, presented side by side. Target images always came from the videos that participants watched, and distractor images always came from similar, but different, videos that contained the same actors and objects and were in the same spatial location. Participants responded by selecting the image they believed came from the video they watched. Order of presentation of the image pairs was the same for each participant. Target and distractor images appeared equally often on the left and right sides of the screen. Correct responses were scored as 1 and incorrect responses were scored as 0. Cronbach's alpha for recognition memory was acceptable across experiments (α = 0.73 in Experiment 1, 0.69 in Experiment 2, and 0.71 in Experiment 3). We used the proportion of correct responses for each participant for each video as the dependent measure.

Order memory The order memory task differed between experiments and, thus, will not be included in the analyses. The specific methods for each experiment are described in the Online Supplementary Materials and sample stimuli are provided on our Open Science Framework page (https://osf.io/h4wy9/).

Segmentation We used the unitization task (Newtson, 1973) to measure where participants perceived event boundaries in each video. While watching the videos, participants were asked to identify whenever "one meaningful unit of activity ends and another begins." Participants were instructed to press the spacebar on a keyboard to indicate these units. They were not given examples of how the videos could be broken down into segments.

To assess segmentation behavior, we calculated two dependent measures: *segmentation count* and *segmentation agreement*. Segmentation count refers to the number of times an individual segmented the activity, or put differently, it is the number of perceived events. Segmentation agreement is the extent to which an individual's perceived event boundaries align with the boundaries perceived by a reference group. We used two groups as the reference. Responses from participants were compared to normative boundaries identified to their own-age group and to the other-age group (see Newberry & Bailey, 2019, for similar methods).

To calculate agreement, we recorded each frame number when participants pressed the button to indicate an event boundary. The likelihood of two participants segmenting at the exact same frame is very low even if they both perceive the same boundary between two actions in the video. Thus, we fit a 1-s (25-frame bandwidth; Kurby & Zacks, 2011) Gaussian

Kernel function to each participant's button presses for each video, so that each frame number in each video for each participant was associated with a probability ranging from 0 to 1 (Newberry et al., 2021). The main advantage of our agreement calculation method over other methods (Kurby & Zacks, 2011) is statistical. It allows us to treat the timing of the button press marking a boundary as probabilistic rather than categorical. Next, we averaged the event boundary probabilities of each frame across the young and older adults to get the normative event boundaries identified from young and older adults. Finally, we correlated each individual's segmentation probabilities with the normative boundaries identified by either their own age group (e.g., older adults correlated with older adult boundaries) or the other age group (e.g., older adults correlated with young adult normative boundaries) to investigate if young and older adults agreed more with their own group than the other group. This allowed us to test whether within-group segmentation was more similar when the group had knowledge of the activity versus when they did not. A leave-one-out procedure was used to calculate agreement between each participant and their own group so that each participant's own probabilities were not included in the normative distribution of their own group. This procedure was independently repeated for each of the three experiments. Each participant received eight segmentation agreement scores: two correlation values (reference = own age group; reference = other age group) for each of the four videos. We also calculated agreement using segmentation responses from all of the participants from each of the experiments to determine the normative boundaries. Results from those analyses are reported in the Online Supplementary Materials

Self-reported knowledge ratings Participants in Experiments 2 and 3 were asked to report their subjective familiarity with each of the activities at the end of the experiment. Participants were presented with a pair of activities (e.g., balancing a checkbook vs. installing a printer) and were then asked to select the activity for which they were more familiar. If the participant selected an older adult activity, then we coded the response as a 1, and a 0 if the participant indicated they were more familiar with the young adult activity. They completed this process for all six pair combinations. We fit a logistic mixed-effects model to assess if older and young adults differed in their self-reported familiarity with the different activities. The age group of the participant was treated as a fixed effect and the experiment and subject were treated as random effects. Older adults ($M = 0.98$, $SE = 0.01$) were significantly more likely than young adults ($M = 0.30$, $SE = 0.07$) to select an older adult activity, $B = -4.57$, $SE = 0.62$, $z = -7.33$, $p < .001$. When we flipped how responses were coded so that selecting a young adult activity received a 1 and an older adult activity received a 0, we found that young adults ($M = 0.70$, $SE = 0.07$) were significantly more likely than older adults ($M = 0.02$, $SE = 0.01$) to select a young adult activity, $B = 4.57$, $SE = 0.62$, $z = 7.33$, $p < .001$. Participants also reported how long it had been since they performed the activity, and how often they perform it. Older adults reported that they rarely set up a game console or printer and young adults reported that they rarely balanced a checkbook or planted flowers. See Online Supplementary Materials for raw values.

Psychometric measures After viewing each video, participants in Experiments 1 and 2 completed various psychometric measures. These psychometric measures assessed script knowledge (script generation, script sequencing), general semantic knowledge (category fluency, Boston Naming Test, Shipley-Hartford vocabulary), working memory (Operation Span, Reading Span), and processing speed (letter comparison, pattern comparison, Digit Symbol Substitution). Since these measures were included as filler tasks between encoding and retrieval of the activities in the videos and are not central to our hypotheses, these data are not reported here, but can be found in the Online Supplementary Materials.

Design

In all three experiments, a 2 (Age Group: Young vs. Old) × 2 (Activity Type: Young Adult Activities vs. Older Adult Activities) mixed design was used. Age Group was a between-subject variable and Activity Type was a within-subject variable.

Results

Approach

All of the analyses were conducted in R (version 4.0.1). Mixed effects models were specified using the lme4 library (Bates et al., 2015). Degrees of freedom were corrected with a Kenward-Roger correction (Kenward & Roger, 1997), and p values for Linear Mixed Models were estimated using the afex library (Singmann et al., 2016). The emmeans library was used to obtain least-squared means and their corresponding standard errors, and to probe significant interactions (Russell, 2019). We determined the random effect structure of each model by testing a variety of models with different random effect structures, and we retained the model with the lowest Akaike Information Criterion (AIC; Matuschek et al., 2017). Model selection was done separately for each dependent measure. We assume that the experiments we conducted, the subjects within each experiment, and the videos we used are each a random sample from the population of all experiments, subjects, and videos. Therefore, subject and video were included in each of the analyses as random intercept effects. In addition, we also allowed the main effect of activity type (young adult activity vs. older adult activity) to vary for each subject as a random slope effect. Age group and activity type were dummy coded as a 1 for young adults and a 0 for older adults prior to entry into the analyses.

Segmentation analyses

We first evaluated whether age and familiarity influenced the number of event boundaries perceived in the videos (i.e., segmentation count) followed by whether age and familiarity influenced the extent to which people perceived similar event boundaries (i.e., segmentation agreement). Twenty-three total observations (4% of the total observations) were removed from the segmentation count and agreement analyses because participants failed to press the button in those videos (seven observations were from older adults). This failure to follow instructions resulted in the removal of six observations from Experiment 1 (1 Planting flowers; 1 Balancing a checkbook; 3 Installing a printer; 1 Setting up a game console), eight observations from Experiment 2 (2 Planting flowers; 2 Balancing a checkbook; 2 Installing a printer; 2 Setting up a game console), and nine observations from Experiment 3 (2 Planting flowers; 2 Balancing a checkbook; 2 Installing a printer; 3 Setting up a game console).

Segmentation count

A Poisson mixed-effects model was used to predict the number of times each participant segmented in each video as a function of age group, activity type, and their interaction. As shown in Fig. 2, young adults perceived more events in the videos compared to the older adults, but this did not differ based on prior knowledge. Specifically, there was a significant main effect for age group, $B = 0.23$, $SE = 0.09$, $z = 2.44$, $p = .01$, such that young adults ($M = 12.72$, $SE = 1.37$) segmented significantly more frequently than older adults ($M = 9.91$, $SE = 1.08$). We did not observe a significant main effect for activity type [Young Adult Activities ($M = 9.95$, $SE = 1.30$); Older Adult Activities ($M = 12.66$, $SE = 1.63$)], $B = -0.26$, $SE = 0.17$, $z = -1.53$, $p = .13$, or a significant interaction between activity type and age group, $B = 0.05$, $SE = 0.05$, $z = 0.91$, $p = .37$.

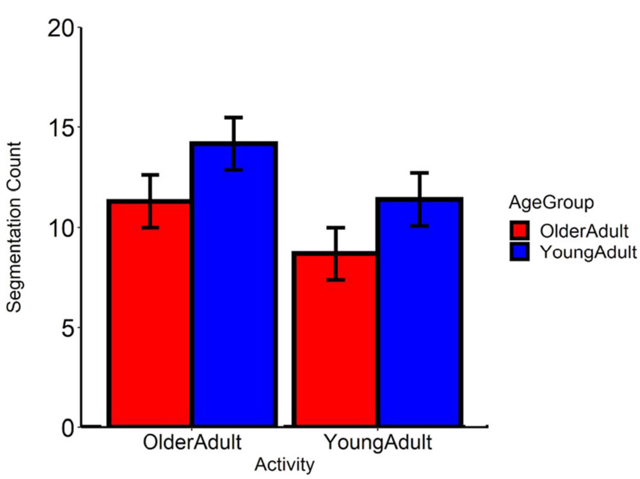

Fig. 2 Segmentation count as a function of age group and activity type. Young adults identified more boundaries than older adults

Segmentation agreement

We used a linear mixed-effects model to predict segmentation agreement from the age group of the participants, activity type, the group that was treated as the reference (own vs. other), and their interactions. As shown in Fig. 3, we did not observe a significant effect for the age group [Young Adults ($M = 0.17$, $SE = .02$); Older Adults ($M = 0.17$, $SE = .02$)], $B = 0.02$, $SE = 0.02$, $t(292) = 1.08$, $p = .28$, activity type [Young Adult Activities ($M = 0.18$, $SE = .03$); Older Adult Activities ($M = 0.16$, $SE = .03$)], $B = -009$, $SE = 0.03$, $t(4.42) = -0.38$, $p = .72$, or the reference group factors, [Own Group ($M = 0.18$, $SE = .02$); Other Group ($M = 0.16$, $SE = .02$)], $B = 0.007$, $SE = 0.013$, $t(870) = 0.54$, $p = .59$. However, segmentation agreement did depend on the activity type and the group that was treated as the reference, $B = 0.06$, $SE = 0.02$, $t(870) = 3.29$, $p = .001$. Specifically, as shown in Fig. 3, older and young adults agreed significantly more with their own age group (M

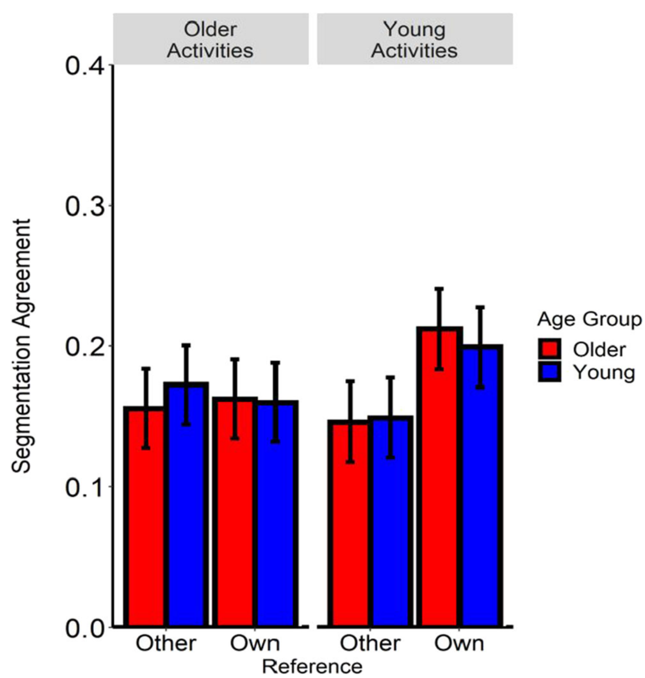

Fig. 3 Least square means for segmentation agreement as a function of the activity type, reference group, and age group. Agreement was significantly better in the young adult activities when participants' own group was used as the reference. Error bars correspond to plus or minus 1 standard error of the mean

= 0.21, *SE* = .03) than with the other age group (*M* = 0.15, *SE* = .03) in the young adult activities, *B* = -0.06, *SE* = 0.009, *t*(869) = -6.55, *p* < .001, but the groups of participants identified similar event boundaries in the older adult activities, [Own Group (*M* = 0.16, *SE* = .03); Other Group (*M* = 0.16, *SE* = .03)], *B* = 0.003, *SE* = 0.009, *t*(869) = 0.32, *p* = .94 (Bonferroni-corrected p values). Thus, participants disagreed when older adults lacked relevant knowledge, but they identified similar event boundaries when older adults had relevant knowledge. Interestingly, these knowledge-related effects on segmentation agreement were observed despite the fact that knowledge did not affect the *number* of perceived events. None of the other interactions were statistically significant.

We ran two exploratory analyses to better understand these findings. First, we evaluated changes in segmentation agreement, as a function of continuous age, within the older adult sample. In this analysis, segmentation agreement declined as the age of the participant increased. Second, we explored differences in the locations at which participants segmented, based on age group and knowledge of the activity. In general, both older and young adults tended to mark boundaries when goals of the actor in the videos were completed. However, we found some evidence that boundary locations did not align with goal endings when older adults lacked knowledge of the activity (see Online Supplementary Materials).

Memory

Free recall

We also analyzed how knowledge impacted free recall memory. Some of the participants wrote about information that was unrelated to the video when performing the free-recall task, such as describing an entirely different type of event. We removed 22 such observations (4% of the total number of observations) from the data: 15 observations from Experiment 1 (4 Planting flowers; 2 Balancing a checkbook; 5 Installing a printer; 4 Setting up a game console), four from Experiment 2 (0 Planting flowers; 1 Balancing a checkbook; 1 Installing a printer; 2 Setting up a game console), and three from Experiment 3 (0 Planting flowers; 1 Balancing a checkbook; 1 Installing a printer; 1 Setting up a game console). We conducted two different analyses on recall. We first assessed the effect of knowledge on the proportion of A1 actions recalled and then its effect on the proportion of A2 actions correctly recalled. Age group, activity type, and their interaction were treated as fixed effects of the proportion of recalled actions. The analysis of A2 units recalled contained the experiment, participant, and video at their intercepts as random effects as well as the within-subject manipulation of activity type, which was allowed to vary for each subject as a random effect. The analysis of A1 units contained the same random effects except for the by-participant slope effect due to failures in model convergence.

As evident in Fig. 4, young adults (*M* = 0.19, *SE* = 0.01) recalled significantly more A1 units than older adults (*M* = 0.13, *SE* = 0.01), *B* = 0.03, *SE* = 0.01, *t*(233) = 3.41, *p* < .001, replicating previous findings (Sargent et al., 2013; Smith, Newberry, & Bailey, 2020). Recall did not significantly differ between older (*M* = 0.17, *SE* = 0.02) and young adult (*M* = 0.16, *SE* = 0.02) activities, *B* = -0.04, *SE* = 0.03, *t*(2.15) = -1.35, *p* = 0.30; however, young and older adults differed in the amount they successfully recalled from each activity, *B* = 0.05, *SE* = 0.01, *t*(427.84) = 4.91, *p* < .0001. We probed this significant interaction and found that young adults recalled significantly more A1 units than older adults in both the older adult activities [Young Adults (*M* = 0.19, *SE* = 0.02); Older Adults (*M* = 0.15, *SE* = 0.02)], *B* = -0.03, *SE* = 0.01, *t*(231) = -3.41, *p* = .002 and the young adult activities [Young Adults (*M* = 0.20, *SE* = 0.02); Older Adults (*M* = 0.12, *SE* = 0.02)], *B* = -0.08, *SE* = 0.01, *t*(238) = -7.96, *p* < .0001; but the difference in recall of A1s was larger in the young adult activities. Older

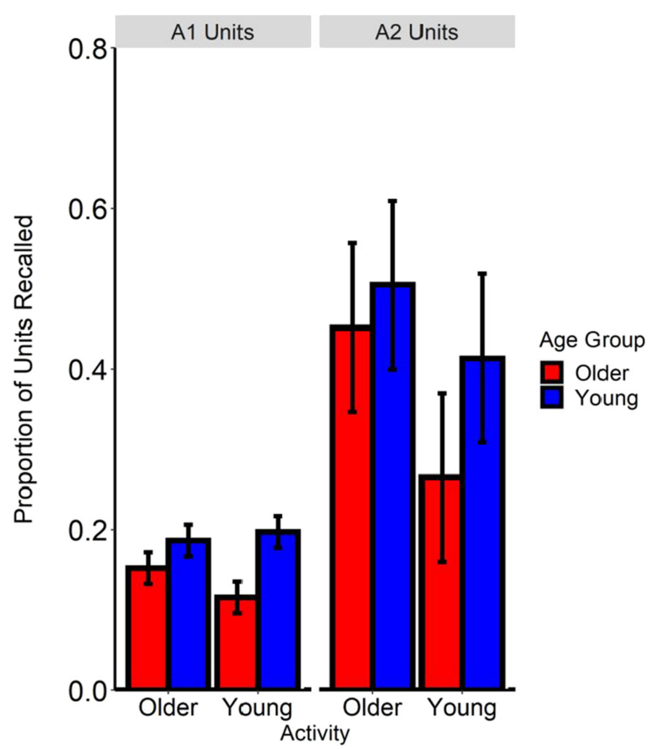

Fig. 4 Least-square means for the proportion of A1 and A2 units recalled as a function of activity type and age group. Young adults recalled significantly more information than older adults in both activities; however, the difference was larger in the young adult activities. Error bars correspond to 1 plus or minus standard error to the mean

adults recalled fewer A1 action units when they lack knowledge of the activity.

We observed analogous effects for recall of A2 units. Again, young adults (*M* = 0.46, *SE* = 0.07) recalled significantly more A2 units than older adults (*M* = 0.36, *SE* = 0.07), *B* = -0.05, *SE* = 0.01, *t*(146.68) = -6.25, *p* <.0001. As before, we did not observe a significant effect for the activity type [Young adult activities (*M* = 0.34, *SE* = 0.11); Older adult activities (*M* = 0.48, *SE* = 0.11)], *B* = 0.07, *SE* = 0.07, *t*(2.00) = 0.94, *p* = .45; however, we did find a significant interaction between age group and activity type, *B* = 0.02, *SE* = 0.004, *t*(147.57) = 5.35, *p* < .0001. Consistent with recall of A1 units, young adults recalled significantly more A2 units than older adults in both the older adult [Young Adults (*M* = 0.51, *SE* = 0.11); Older Adults (*M* = 0.45, *SE* = 0.11)], *B* = -0.05, *SE* = 0.02, *t*(148) = -2.77, *p* = .01 and young adult activities [Young Adults (*M* = 0.41, *SE* = 0.11); Older Adults (*M* = 0.27, *SE* = 0.11)], *B* = -0.15, *SE* = 0.02, *t*(147) = -8.41, *p* < .0001, but the difference was larger in the young adult activities. Again, older adults recalled fewer A2 action units than young adults when they lack relevant knowledge. For this analysis, however, recall memory did not change as a function of continuous age (see Online Supplementary Materials).

Recognition

We used a linear mixed-effects model to predict recognition accuracy from the fixed effects of age group, activity type, and their interaction. As shown in Fig. 5, we did not find a significant main effect for age group [Young Adults (*M* = 0.82, *SE* = .02); Older Adults (*M* = 0.76, *SE* = .03)], *B* = 0.34, *SE* = 0.29, *t* = 1.75, *p* = .24, activity type [Young Adult Videos (*M* = 0.80, *SE* = .02); Older Adult Videos (*M* = 0.79, *SE* = .02)], *B* = 0.08, *SE* = 0.28, *t* = 0.29, p = .77, or a significant interaction between activity type and age group, *B* = -0.05, *SE* = 0.41, *t* = -0.12, *p* = .91. These results suggest that there are no age-related differences in recognition accuracy and that prior knowledge did not benefit recognition performance.

Does the relationship between semantic knowledge and episodic memory depend on segmentation agreement?

We next evaluated the extent to which segmentation agreement predicted the proportion of A1 and A2 units that participants successfully recalled. It is possible that individuals may only get the knowledge-related benefit on memory performance when they can use their knowledge to help them encode the information more efficiently. If so, segmentation agreement may predict memory performance more strongly when the activity is familiar. Alternatively, it is possible that segmentation agreement only predicts event memory when

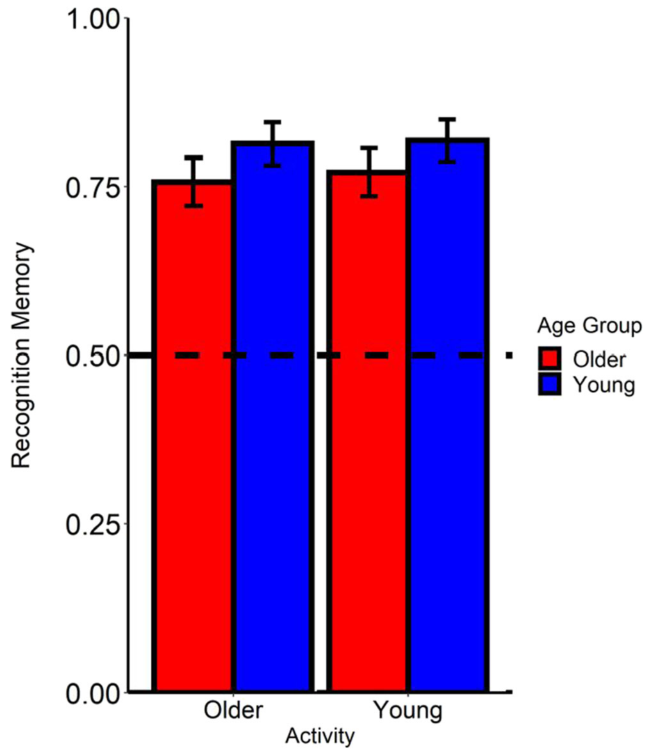

Fig. 5 Least square means for recognition memory performance as a function of the activity type and age group. Error bars correspond to 1 plus or minus standard error to the mean. The dashed line at 0.50 corresponds to chance level performance

the activity is unfamiliar (Newberry et al., 2021; Smith et al., 2020). Observers may be able to rely on their prior knowledge to help fill in the gaps of their memory when the activity is familiar, and they may rely on how the information was encoded when the activity is unfamiliar.

We first used a linear mixed-effects model to predict the proportion of A1 units that participants successfully recalled from the fixed effects of age group, activity type, segmentation agreement with their own group, and their interactions (Fig. 6). Agreement was centered at its mean before it was entered into the analysis to reduce nonessential multicollinearity between the predictors. Consistent with the previous analysis of free recall, we observed a significant effect for age group, *B* = 0.03, *SE* = 0.01, *t*(107.42) = 2.96, *p* = .004; but not for activity type, *B* = -0.04, *SE* = 0.02, *t*(2.61) = -1.72, *p* = .21. Again, we found that young adults recalled significantly more A1 units in the young adult activities. This was evident from a significant interaction between age group and activity type, *B* = 0.05, *SE* = 0.01, *t*(146.27) = 4.68, *p* < .0001. Segmentation agreement was a significant positive predictor of the proportion of A1 units recalled, *B* = 0.19, *SE* = 0.04, *t*(342.23) = 4.71, *p* <.001, consistent with past research (e.g., Sargent et al., 2013), and it was a better predictor in the older adult activities, *B* = -0.13, *SE* = 0.06, *t*(484.31) = -2.24, *p* = .03. Segmentation agreement was also a better predictor for older adults compared to young adults as evident from a significant interaction between segmentation agreement and age group, $B = -0.22$, $SE = 0.06$, $t(355.94) = -3.89$, $p < .001$. Importantly, we also found a significant three-way interaction between agreement, age group, and activity type, $B = 0.21$, $SE = 0.08$, $t(483.79) = 2.55$, $p = .01$ (Fig. 6).

We probed this three-way interaction and found that segmentation agreement predicted free recall when participants were familiar with the activity, both when older adults viewed the older adult videos [Young Adult Videos: $B = 0.06$, $SE = 0.04$, 95% CI = (-0.02, 0.14); Older Adult Videos: $B = 0.19$, $SE = 0.04$, 95% CI = (0.11, 0.27)], and when young adults viewed the young adult videos [Young Adult Videos: $B = 0.05$, $SE = 0.04$, 95% CI = (0.03, 0.13); Older Adult Videos: $B = -0.03$, $SE = 0.04$, 95% CI = (-0.11, 0.05)], and this effect was stronger amongst the older adults.

We observed analogous effects when we analyzed the proportion of A2 units successfully recalled using the same predictors as those used when we looked at A1 units (see Fig. 6). We observed a significant main effect for age group, $B = 0.04$, $SE = 0.02$, $t(142.82) = 2.49$, $p = .01$; but not activity type, $B = -0.19$, $SE = 0.14$, $t = -1.34$, $p = .31$. Again, we observed a significant interaction between age group and activity type, $B = 0.09$, $SE = 0.02$, $t(143.65) = 5.29$, $p < .001$. More importantly, segmentation agreement positively predicted the proportion of A2 units recalled, $B = 0.35$, $SE = 0.08$, $t(386.64) = 4.46$, $p < .0001$, and it did so better in the older adult activities, $B = -0.32$, $SE = 0.11$, $t(490.50) = -2.93$, $p = .004$ and in older adults, $B = -0.37$, $SE = 0.11$, $t(397.32) = -3.43$, $p < .001$. Importantly, we again observed a significant three-way interaction between

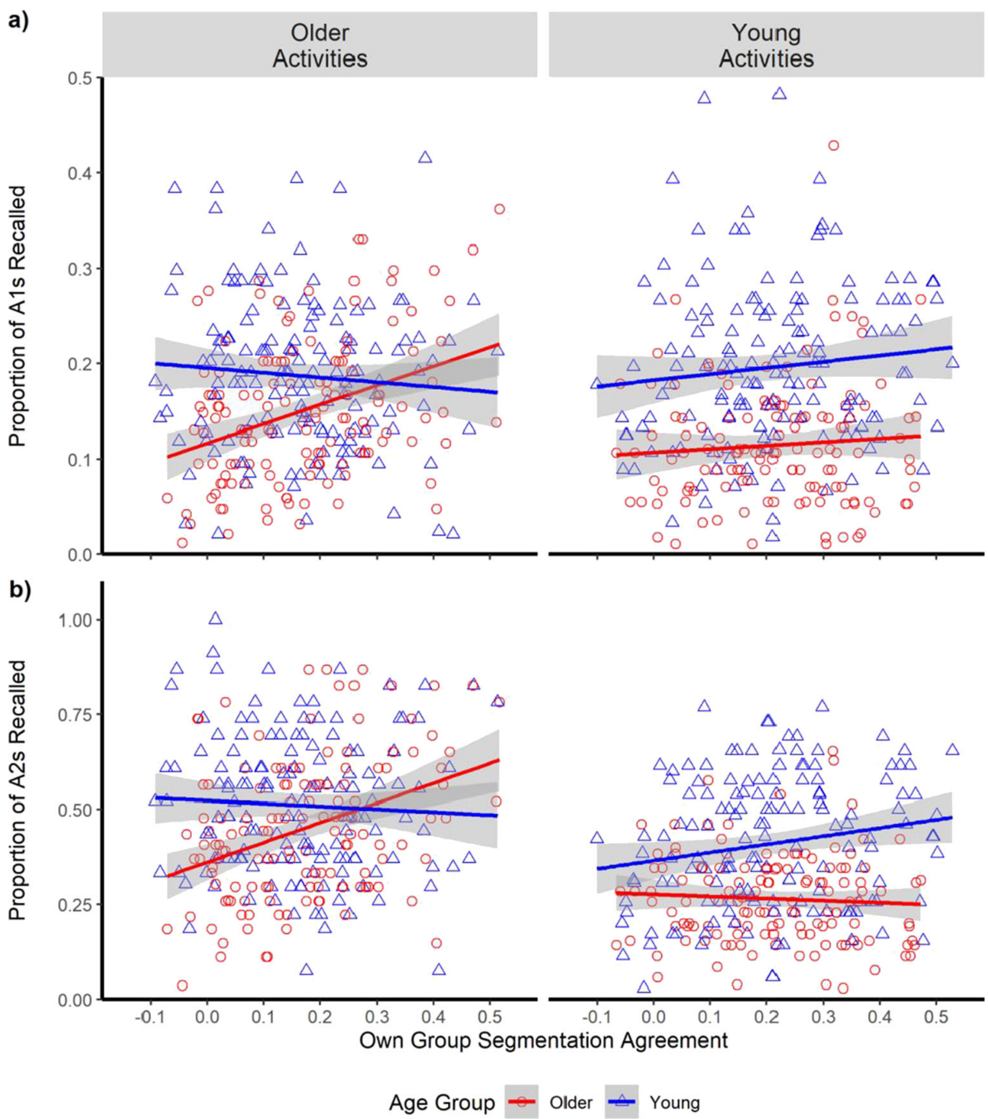

Fig. 6 Proportion of (**a**) A1 and (**b**) A2 units recalled as a function of segmentation agreement, age group, and activity type. Segmentation agreement predicted memory for the familiar activities. Age group is represented in different colors. Activity type is represented in the different panels. Lines represent the different age groups. The raw data values are represented by the points in the scatterplot. Lines in the plot correspond to the predicted values from the estimated regression equation. Ribbons correspond to 1 standard error

age, activity type, and segmentation agreement $B = 0.42$, $SE = 0.15$, $t(478.51) = 2.81$, $p = .005$.

Segmentation agreement again predicted free recall when participants were familiar with the activity, both when older adults viewed the older adult videos [Young Adult Videos: $B = -0.04$, $SE = 0.08$, 95% CI = (-0.11, 0.18); Older Adult Videos: $B = 0.35$, $SE = 0.08$, 95% CI = (0.19, 0.50)], and when young adults viewed the young adult videos [Young Adult Videos: $B = 0.08$, $SE = 0.07$, 95% CI = (0.05, 0.12); Older Adult Videos: $B =-0.02$, $SE = 0.07$, 95% CI = (-0.17, 0.12)]. This effect was again stronger amongst the older adults. Thus, segmentation agreement predicted memory only when the activity was familiar, and this familiarity advantage was larger for older adults.

Discussion

The current study investigated the effects of semantic knowledge on event segmentation and episodic memory for everyday activities in older and young adults. We predicted that familiarity with an activity would lead to more effective event segmentation in older adults, and that this knowledge-related benefit in segmentation would lead to better episodic memory for the activity. Consistent with prior studies, we observed age-related differences in both segmentation and episodic memory performance (Kurby & Zacks, 2011), but only when older adults lacked semantic knowledge for an everyday activity. Most importantly, older adults segmented similar to young adults, and they remembered information just as effectively as young adults when they were able to access relevant semantic knowledge.

These results are consistent with previous findings that semantic knowledge improves the efficiency of encoding processes, such as reading efficiency (Miller, Cohen, & Wingfield, 2006) and the identification of goal-directed actions (Levine et al., 2017). But they are in opposition to claims that event segmentation is primarily driven by bottom-up perceptual changes (e.g., Cutting et al., 2012; Hard et al., 2006; Huff & Papenmeier, 2017). Semantic knowledge appears to provide a framework that helps people understand and construct episodic memory representations for ongoing events (Renoult et al., 2019). Our findings extend this line of research in determining a particular encoding mechanism – event segmentation – that benefits from semantic knowledge (see also Newberry & Bailey, 2019; Smith et al., 2020). Additionally, we have identified that older adults are able to leverage this knowledge-related benefit to eliminate age-related differences in encoding of new instances of familiar activities.

The observation that age-related differences in event segmentation were eliminated when older adults had prior knowledge is consistent with claims from theories of event comprehension that propose that prerequisite knowledge guides event perception (Zacks et al., 2007). For instance, Event Segmentation Theory claims that knowledge informs the event model, which guides future predictions. Individuals may make more efficient predictions when they have prior knowledge, which should make them more sensitive to the actors' goals. The quality of their perceptual predictions should be impaired when they are unfamiliar with the activity, resulting in the inability to successfully discriminate important event boundaries when goals change. Consistent with this notion, in an exploratory analysis, we found that older adults were less likely to identify event boundaries when goals changed if the activity was unfamiliar, but they segmented the activity in a similar manner to the young adults when the activity was familiar. It remains an open question, however, what features influenced event segmentation behavior in older adults when they were unfamiliar. Note that older adults did not show a deficit in their segmentation agreement when they were unfamiliar. Instead, we found that they agreed more with one another than with the boundaries identified by young adults. Given that young adults' segmentation behavior aligned more with the endings of goals than older adults, it is plausible that older adults relied more heavily on perceptual rather than conceptual changes when making their segmentation responses than did young adults. In other words, participants may segment when conceptual features, such as goals, change when they can readily infer the actions of the actor, but they may rely on changes in perceptual features when the activity is unfamiliar.

Knowledge could also facilitate segmentation ability by helping individuals maintain global coherence (Gernsbacher, 1997). According to the Structure Building Framework, incoming information is mapped onto one's mental model when the incoming information is coherent and new mental representations are created when the incoming information lacks coherence. Knowledge may aid the interpretation of incoming information, which facilitates how observers build mental representations. Likewise, knowledge should also help individuals determine when the incoming information lacks coherence, which should lead to better agreement on where boundaries are located. Future research should evaluate these alternative possibilities.

Further, we found that older adults segment less often than younger adults regardless of the activity. Given that experts perceive fewer (and larger) events (Blasing, 2015), it is possible that older adults have developed a general expertise for everyday events (Umanath & Marsh, 2014). However, we know from previous work on normative scripts (Rosen et al., 2003) and from our own familiarity ratings that there are age-related differences in script knowledge and self-reported experience with these activities, rather than a general expertise for all of them. Instead of a general expertise effect, the dual-task nature of the segmentation task may be more cognitively demanding for older adults than for young adults, which in turn leads to age-related differences in segmentation count. This is consistent with work suggesting that older adults segment ongoing information less often than young adults (Kurby & Zacks, 2011; but see Magliano et al., 2012). In fact, other studies using covert measures of event processing have shown that older adults may accurately perceive boundaries. For example, older and young adults similarly slow down when reading sentences containing an event boundary (Bailey & Zacks, 2015; Radvansky, Zwaan, Curiel, & Copeland, 2001); however, Smith, Newberry, and Bailey (2020) recently found that this increased processing time only occurs when older adults are familiar with the activity portrayed. Future work should consider using covert measures of event segmentation to further evaluate the age- and knowledge-related effects on boundary perception without the increased demand of the overt segmentation task.

There is some disagreement in the literature as to whether there are age-related differences in event segmentation between older and young adults. For example, studies using self-paced text or picture stories generally conclude that there are no age-related differences in processing of the event model (Magliano et al., 2012; Radvansky & Dijkstra, 2007). Consistent with these results, we did not find an age-related deficit in event segmentation agreement (see Fig. 3). Instead, we found that older and young adults identify different event boundaries when older adults lack semantic knowledge of the activity, but they identify similar event boundaries when older adults had relevant semantic knowledge. The reason why some experiments have found an age-related deficit in segmentation agreement (Kurby & Zacks, 2011; Kurby & Zacks, 2019; Zacks et al., 2006) but others have not (Magliano et al., 2012) is unknown; however, our results could suggest that previously observed deficits in event-segmentation agreement could have been due to differences in where older and young adults perceived the location of event boundaries. If older and young adults identify different event boundaries, then using the entire group as the norm could add noise to the normative boundary locations. Consistent with this proposal, we found the typical age-related deficit in segmentation agreement when we used the event boundary locations identified from all of the participants as the norm (see Online Supplementary Materials.) The age-related deficit observed in previous studies could have arisen from differences in how participants segmented rather than a deficiency in encoding.

We also found that older adults showed less of a deficit in free recall of everyday activities when they could access relevant knowledge. These findings are consistent with previous findings that semantic knowledge improves episodic memory for familiar activities (Chase & Simon, 1973) and that older adults can leverage their intact semantic knowledge to negate age-related deficits in episodic memory (Castel, 2005; Smith et al., 2020; Smith, Loschky, & Bailey, under review). Our results extend these findings to show that this occurs with complex video stimuli that more closely mimic real-world events than previously used simple, static stimuli. This pattern of memory results is consistent with previous findings that suggest that semantic knowledge benefits recall and not recognition (Sulin & Dooling, 1974; but see Newberry et al., 2021). It is possible that we did not show knowledge-related benefits on recognition memory because recall declines with normal healthy cognitive aging, but recognition memory does not (Danckert & Craik, 2013; Jennings & Jacoby, 1997). Processes involved in free recall are much more effortful, and older adults may be less able to deploy such processing. As such, they may be more likely to rely on prior knowledge when they are unable or when they have difficulty in recollecting information, but not when they must identify whether the information being presented is familiar.

We also evaluated whether segmentation ability moderated the relationship between age, knowledge, and memory. It is possible that segmentation agreement may only predict memory performance when the activity is unfamiliar (Smith et al., 2020; Newberry, Feller, & Bailey, 2021). That is, viewers may rely on how the information is encoded when the activity is unfamiliar, and they may rely on their prior knowledge when the activity is familiar. Alternatively, it is possible that semantic knowledge only benefits episodic memory when people can leverage it to normatively segment an ongoing activity. The latter explanation is consistent with the effects plotted in Fig. 6. Specifically, segmentation agreement was a stronger predictor of episodic memory for older adults when they viewed familiar activities compared to unfamiliar activities. But interestingly, not all older adults benefitted from having prior knowledge. That is, some showed poor segmentation and memory regardless of the to-be-remembered activity. This result suggests that rather than a general effect of knowledge on segmentation and memory, there may be a specific benefit of knowledge on memory for those who can use it to segment effectively. Further research should delineate these effects to further understand the individual differences that allow some older adults to more effectively leverage their semantic knowledge. Our results support the knowledge hypothesis, but they are notably in contrast (and in fact the opposite) to what we have observed previously (Newberry et al., 2021; Smith et al., 2020).

The current work has some limitations. First, the event segmentation task requires that participants remember what is happening in the video and also remember to press a button when they perceive a boundary. The dual-task nature of this task may be particularly difficult for older adults who may struggle with goal maintenance in the face of secondary tasks (McGatlin et al., 2018). Despite the drawback of this dual-task measure, we still found that older adults benefitted from knowledge when completing this task. Second, differences in segmentation ability and memory may be due to age-related differences in attention and visual perception, as these are also affected by age (Mahoney et al., 2010; Monge & Madden, 2016). Since we do not have task-related attention and perception measures we cannot say unequivocally that performance on our cognitive measures were not primarily due to deficits in these areas.

Despite these limitations, our findings suggest that semantic knowledge changes how events are segmented, possibly by making people more sensitive to goal structures, and it improves episodic memory for real-world, complex events. Further, our findings suggest that older adults are able to use this knowledge-related benefit to attenuate the commonly observed age-related deficits in event segmentation (Kurby & Zacks, 2011; Sargent et al., 2013; Zacks et al., 2006) and memory (Kurby & Zacks, 2011). These results advance our understanding of the interactive relationship between semantic and episodic memory by demonstrating that semantic knowledge improves both encoding processes and episodic memory retrieval. These effects suggest that older adults may benefit from interventions that leverage intact semantic knowledge to attenuate age-related deficits in event segmentation and episodic long-term memory. Future research should further delineate the respective contributions of semantic knowledge and episodic memory on memory performance for specific episodes of familiar events.

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