Psychology and Aging
2006, Vol. 21, No. 3, 466–482

0882-7974/06/$12.00 DOI: 10.1037/0882-7974.21.3.466

Event Understanding and Memory in Healthy Aging and Dementia of the Alzheimer Type

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Segmenting ongoing activity into events is important for later memory of those activities. In the experiments reported in this article, older adults' segmentation of activity into events was less consistent with group norms than younger adults' segmentation, particularly for older adults diagnosed with mild dementia of the Alzheimer type. Among older adults, poor agreement with others' event segmentation was associated with deficits in recognition memory for pictures taken from the activity and memory for the temporal order of events. Impaired semantic knowledge about events also was associated with memory deficits. The data suggest that semantic knowledge about events guides encoding, facilitating later memory. To the extent that such knowledge or the ability to use it is impaired in aging and dementia, memory suffers.

Keywords: event planning, memory, aging, Alzheimer's disease, dementia

Access to the past reflects segmentation of the present. Although ongoing activity is continuous and complex, people appear to remember and conceive of it as consisting of discrete events (Zacks & Tversky, 2001). This fact has profound implications for the memory complaints that are a common feature of both healthy aging and senile dementia. Although memory complaints can include word-finding difficulties and failures of autobiographical memory, the most striking deficits are those in memory for the everyday events in one's recent past. This ability to recollect everyday experiences, termed *episodic memory* (Tulving, 1983), is critical to a number of everyday tasks, from cooking to navigating to following a television program. Older adults demonstrate decreased memory ability across a wide range of tasks (Prull, Gabrieli, & Bunge, 2000), but this memory impairment is most apparent when older adults recognize or recall recent events (Balota, Dolan, & Duchek, 2000). Such memory is further impaired in Alzheimer's disease (Greene, Baddeley, & Hodges, 1996). In both healthy aging and Alzheimer's disease, a primary cause of these memory deficits may be failure to encode information adaptively (Balota et al., 2000; Hodges, 2000).

Failing to remember what has just happened leaves one less able to keep track of what is happening right now. Accordingly, patients with dementia have difficulty remaining oriented with respect to space and time (Giannakopoulos et al., 2000; Meulen et al., 2004; Robert et al., 2003). Thus, one possibility is that in aging and dementia, selective deficits in the ability to parse ongoing activity into appropriate events impair the encoding of activity for later memory and reduce one's ability to remain oriented. In the following sections, we briefly review research on the relationship between event perception and memory and consider its application to memory in aging and dementia.

Events in Perception and Memory

There is substantial evidence that humans spontaneously segment ongoing activity into meaningful events and that this segmentation forms a basis for later memory (for a review, see Zacks & Tversky, 2001). Much of the relevant data come from a task in which participants are shown a movie of an everyday activity and asked to divide it into meaningful events by pressing a button to mark the boundaries between events (Newtson, 1973). For example, in a movie depicting a person making a bed, the point at which the actor finishes stripping the old sheets and begins laying on the new sheets would likely be perceived as an event boundary. Different observers show good agreement about the locations of these event boundaries (Hanson & Hirst, 1989; Newtson, 1976), but individuals do show stable individual differences in boundary locations (Speer, Swallow, & Zacks, 2003). Within observers, people appear to encode event segments on multiple time scales that are related by grouping fine-grained events into larger coarse-grained events. The reliability and structure of the data from the segmentation task suggest that event segmentation is an ongoing feature of normal perception, but more direct evidence comes from neurophysiological studies. These studies indicate that during passive viewing of movies, selected brain areas transiently increase in activity at those moments that viewers later identify as event

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Nicole K. Speer is now at the University of Colorado. Jean M. Vettel is now at Brown University.

This research was funded by National Institute on Aging Grants P50AG05681 (to John C. Morris at the Washington University Alzheimer's Disease Research Center) and R01AG013845-10 (to Larry L. Jacoby).

We thank Martha Storandt for invaluable technical and conceptual advice, Betsy Grant for assistance with the psychometric data, and Julian Ott and Aliza Machefsky for assistance with data collection. We also thank our five actors: Christine Hoyer, William Knapp, Carol McKenna, Jeremy Reynolds, and Andrew Vettel.

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boundaries (Speer et al., 2003; Zacks, Braver, et al., 2001; Zacks, Swallow, Vettel, & McAvoy, 2006).

Event segmentation can be based on physical changes, such as changes in actors' body positions (Newtson, Engquist, & Bois, 1977) or the movements of objects (Zacks, 2004). Segmentation also can be based on inferences about actors' goals or previous knowledge about the typical structure of activity (Baldwin, Baird, Saylor, & Clark, 2001). In particular, semantic knowledge about the organization of everyday events, sometimes described as *scripts* (Schank & Abelson, 1977) or *event schemas* (Rumelhart, 1977), may play a critical role in guiding the segmentation of ongoing activity (Zacks & Tversky, 2001).

Perceptual segmentation of events is associated with later memory for those events. After viewing a movie of an ongoing activity, people remember still pictures taken from event boundaries better than still pictures from the middles of events (Newtson & Engquist, 1976). Reinforcing the natural event boundaries in a movie by adding commercials (Boltz, 1992) or cuts (Schwan, Garsoffky, & Hesse, 2000) can increase memory for the events in the movie. Directing people's attention to the fine-grained structure of an activity improves recall memory performance, although its effects on recognition memory are a matter of debate (Hanson & Hirst, 1989, 1991; Lassiter & Slaw, 1991; Lassiter, Stone, & Rogers, 1988). In addition to these relationships to long-term memory, event segmentation has been shown to affect the ongoing availability of information in working memory. Cuing readers of narratives that an event boundary has occurred reduces the availability of information presented prior to that event boundary (Speer & Zacks, 2005). Together, these data suggest that event segmentation is an important component of the encoding processes that make memory for everyday events possible. In healthy perception, ongoing activity is segmented into meaningful events on the basis of physical cues and semantic knowledge about events and their parts. This segmentation selectively encodes event boundaries because they are points of maximal new information and facilitates building structured representations of events that bind information into a form that facilitates later retrieval.

Neuropsychological Deficits in Understanding Everyday Events

If one's semantic knowledge about events is impaired, it may become more difficult to deploy that semantic knowledge to guide segmentation and encoding. Grafman and colleagues have argued that structured representations of everyday events, called *structured event complexes*, are stored in the prefrontal cortex (Grafman, 1995; Grafman, Partiot, & Hollnagel, 1995; Sirigu, Zalla, Pillon, Grafman, Dubois, & Agid, 1995; Wood & Grafman, 2003). Patients with prefrontal lesions have selective difficulty remembering which fine-grained events make up a larger event and in which order those fine-grained events typically occur (Sirigu, Zalla, Pillon, Grafman, Agid, & Dubois, 1995). The prefrontal cortex is associated with action planning as well as action perception (Koechlin, Basso, Pietrini, Panzer, & Grafman, 1999), and patients with prefrontal lesions often have difficulty properly sequencing small actions to organize them into goal-directed activities (Humphreys & Forde, 1998; Humphreys, Forde, & Riddoch, 2001; Sirigu, Zalla, Pillon, Grafman, Dubois, & Agid, 1995; Zalla, Plassiart, Pillon, Grafman, & Sirigu, 2001). These findings converge in arguing that lesions to the prefrontal cortex impair people's ability to use semantic knowledge about events to guide ongoing behavior.

One recent study directly implicated the prefrontal cortex in the adaptive encoding of event structure (Zalla, Pradat-Diehl, & Sirigu, 2003). Patients with prefrontal lesions and neurologically healthy controls viewed movies of everyday activities and segmented them into events. Patients with prefrontal lesions were selectively impaired at identifying coarse-grained event boundaries. This result is consistent with the view that the patients with prefrontal lesions had a selective loss of the influence of semantic event knowledge on perceptual processing.

Investigating Event Memory in Aging and Dementia

If the prefrontal cortex is important for the adaptive encoding of events, event encoding should be selectively impaired in dementia of the Alzheimer type (DAT) and healthy aging. Pathology in older adults' prefrontal cortex is associated with cognitive deficits (Kanne, Balota, Storandt, McKeel, & Morris, 1998). Loss of volume in the prefrontal cortex is associated with healthy aging (Raz et al., 1997), and decline in prefrontal function has been implicated in the cognitive deficits associated with aging (West, 1996). One possibility is that patients with DAT (and possibly healthy older adults as well) have degraded semantic representations of events and, as a result, are less able to use semantic event knowledge to encode activity effectively for later memory. In particular, if impaired structured event complexes are an underlying source of cognitive deficits, memory for the temporal order of events should be impaired. One simple test of memory for temporal order is to ask participants which of a pair of items occurred more recently in a stimulus stream. Using this measure, recency memory for words and pictures has been found to decline with age (Fabiani & Friedman, 1997; Newman, Allen, & Kaszniak, 2001) and DAT (Sullivan & Sagar, 1989). However, recency judgments are an extremely simple test of knowledge about temporal order, which may be driven by heuristic evaluation of a memory strength trace rather than structured representations of temporal order. Another way to test memory for temporal order is to ask people to reproduce the ordering of a sequence in which a set of items occurred. Using this type of procedure has produced evidence that short-term memory for the temporal order of words declines with age (Dumas & Hartman, 2003; Kausler, Salthouse, & Saults, 1988) and that memory for the temporal order of remote events is impaired in DAT (Storandt, Kaskie, & Von Dras, 1998). However, no studies to date have examined temporal order in memory for recent everyday events.

Most studies of memory and aging have used laboratory tasks in which the material to be remembered is relatively simple. Studies using stripped-down materials and simple tasks may provide a biased picture of age differences in memory for several reasons (for a review, see Hess, 2005). Older adults may be less motivated to memorize arbitrary information and less engaged by material without social or emotional content. Older adults also may bring different information-processing resources and different strategies to bear when remembering naturalistic materials—an issue we return to in the General Discussion section. However, a few studies have used materials closer to naturalistic events, including narrative texts and brief movies. Although immediate memory for narrative text may not differ between younger adults and healthy older adults, with a short delay a significant age effect has been observed (Johnson, Storandt, & Balota, 2003). (Older adults with very mild to mild dementia remembered less than younger adults at both delays.) However, when testing narrative texts, such age differences may reflect memory for the surface linguistic structure. In one study designed to tease apart memory for surface structure from memory for the events described by a text, after a 1-week delay memory for the events was equivalent in older and younger adults (Radvansky, Zwaan, Curiel, & Copeland, 2001). Age-related declines in event memory cannot be attributed solely to linguistic surface structure, however, because memory for movies of everyday events (Koutstaal, Schacter, Johnson, Angell, & Gross, 1998) and memory for items in a news video (West, Crook, & Barron, 1992) both decline with age. Together, these studies suggest that memory for events that occurred within minutes to weeks is impaired in healthy aging and DAT.

If there is relatively little known about memory for everyday events in aging and DAT, then even less is known about event segmentation in aging and DAT. The two experiments reported in this article were designed to characterize event encoding and memory in healthy aging and DAT and to explore relationships between quality of event encoding and later memory. In each experiment, participants watched movies of everyday activities while segmenting them to mark boundaries between meaningful events. Afterwards, their memory for the events was tested.

Experiment 1

Experiment 1 aimed to answer three questions about event understanding and aging. First, are there age differences in event segmentation? Second, are there age differences in memory for the temporal order of events in everyday activity? Third, is one's ability to segment events related to later memory for those events? To answer these questions, we asked participants to view movies of everyday activities and segment them into everyday events. Their memory for the temporal order of events was then tested.

This experiment also addressed a secondary question about the relationship between event segmentation and memory: Does the intention to encode an activity for later memory change how one segments it, facilitating later memory for temporal order? One previous study reported that warning younger participants of an impending memory test had little effect on the grain at which they segmented and no effect on memory (Hanson & Hirst, 1989). However, the memory measures in that study consisted of a recall and recognition test for what happened in the movie. To address the relationships between intent to remember, event segmentation, and order memory, we warned half of the participants in each age group of the memory test before viewing the movies; the other half was not warned.

Method

Participants. Twenty-four younger adults (mean age = 20.3 years, range = 18–23 years) were recruited from the participant pool maintained by the Washington University Psychology Department. Twenty-four older adults (mean age = 78.0 years, range = 68–91 years) were recruited from the St. Louis, Missouri community by advertising. The younger participants were mostly college students and had a mean Shipley-Hartford (Shipley, 1940) Vocabulary score of 33.4 ($SD = 2.69$). The older participants were community-dwelling adults recruited without any special selection criteria and had a mean Vocabulary score of 35.3 ($SD = 2.35$). Participants received a $10 honorarium in return for participation. All participants had normal or corrected-to-normal vision. An additional 4 younger adults and 2 older adults were replaced because of computer malfunctions (4 participants) or failure to identify more than one event boundary in one of the movies (2 participants).

Materials and tasks. Participants viewed three movies in which an actor performed an everyday activity. These stimuli have been described previously (Zacks, Tversky, & Iyer, 2001). The movies depicted making a bed (female actor, 337 s duration), doing dishes (male actor, 255 s), and assembling a saxophone (female actor, 185 s). The movies were chosen to vary in familiarity, with the first two being rated as familiar (8.455 and 8.424 on a 9-point scale) and the third being unfamiliar (3.030; Zacks, Tversky, & Iyer, 2001). The initial 60 s of a fourth movie, depicting a female actor ironing a shirt, was used for practice. To capture as closely as possible the naturalistic experience of watching an ongoing activity, we shot the movies from a fixed head-height perspective without cuts or camera movement. The movies were presented using PsyScope (Cohen, MacWhinney, Flatt, & Provost, 1993) on Macintosh computers with 17-in. (43.18-cm) CRT monitors with the participants seated in a chair at a comfortable distance (approximately 65 cm). Movies were presented in the center of the screen and filled half the width and height of the monitor. Each movie started several seconds before the actor walked onscreen and ended several seconds after the actor left.

During movie viewing, participants performed a segmentation task (Newtson, 1973; Zacks, Tversky, & Iyer, 2001). Participants were asked to identify units that were natural and meaningful to them by pressing a button on a button box and were told there were no right or wrong answers in this task. Each participant practiced this segmentation task while viewing the ironing movie, after which the experimenter answered any questions.

To measure memory for the temporal order of events in the movies, we asked participants to complete an order memory test that required sorting still pictures taken from the movies into correct temporal order. For each movie, a set of 12 still pictures was chosen. Pictures were printed at 11.2 cm × 8.4 cm with a white border. For each test, the experimenter arranged the pictures in a pseudorandom order on a table in front of the participant in an array four cards wide and three cards high. The participant was asked to sort the pictures into the order in which they had occurred in the movie. They were told that accuracy was of primary importance but that the experimenter would record the time it took to perform the task. Completion time was recorded with a stopwatch.

The still pictures used in the memory task were chosen to maximize interpretability and distinctiveness. When possible, still pictures were chosen from points that previous participants had identified as event boundaries. Still picture sequences taken from event boundaries are more easily understood than still picture sequences taken from moments in between event boundaries (Newtson & Engquist, 1976). Pictures also were chosen to be perceptually distinctive. Because the environments and activities were relatively simple, in some cases a picture taken from early in a movie was visually very similar to a picture taken from later in the movie. In such cases, selecting either picture for the temporal order test would have reduced the sensitivity of the measure because errors could reflect failure to perceptually discriminate the moments rather than a failure of memory.

Procedure. After providing informed consent, participants were seated in front of the computer and made comfortable. They then were trained on the segmentation task using the ironing movie. Following

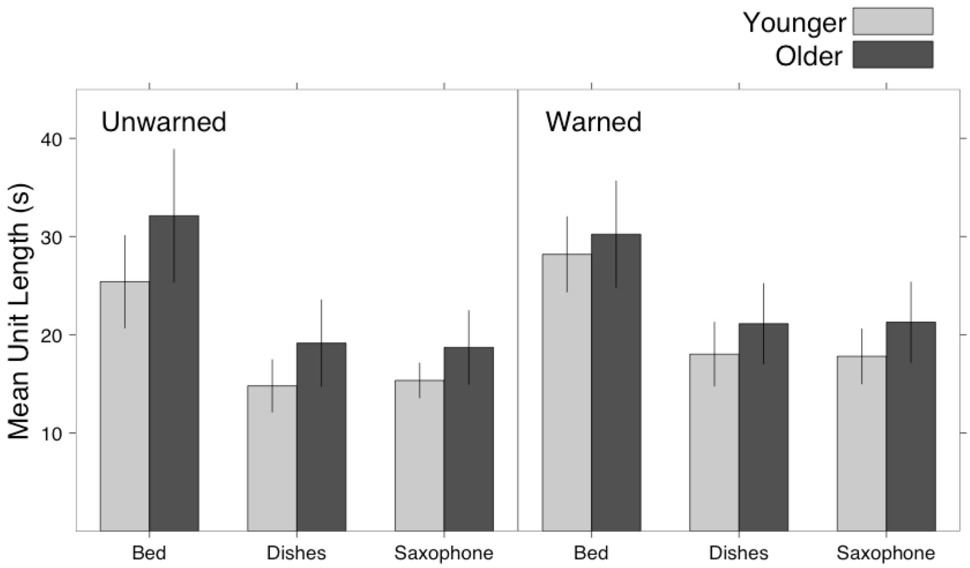

Figure 1. Event unit size as a function of movie, age, and experimental condition. Bars show the mean across participants, with *SEM* error bars. Data are from Experiment 1.

training, they received instructions for the main segmentation task. Participants in the warned group were told about the upcoming memory test as part of the instructions for the practice session and were reminded of this fact during the instructions for the main segmentation task; for participants in the unwarned group, the memory test was not mentioned. Each participant segmented all three movies, with order of presentation counterbalanced across participants. They then were given the order memory test for each movie. The order of memory testing was the same as the order of movie viewing. At the conclusion of the experiment, participants completed several other tasks: a computer-based version of the Shipley-Hartford Vocabulary test (Shipley, 1940), a brief visual acuity test using the Snellen eye chart, and another experiment that involved reading narrative texts (younger participants only).

Results and Discussion

Segmentation. Analyses of the segmentation data tested for two possible differences between older and younger adults: differences in the temporal grain at which they segmented and differences in where they identified segment boundaries. For each participant's viewing of each movie, the mean length of the event units identified was calculated by dividing the length of the movie by the number of events identified. Mean unit lengths were submitted to a mixed analysis of variance (ANOVA) with movie as a repeated measure and age and warning as between-participants independent variables. As can be seen in Figure 1, event units were longer for the bed-making movie than for the other movies, $F(2, 88) = 26.9$, $p < .001$. Older adults identified slightly longer event units than younger adults, but this difference was not statistically significant, $F(1, 44) = 1.07$, $p = .31$, nor was the main effect of warning nor any of the interactions (largest $F = 0.27$). Within each group, there was considerable variability in the mean length of event units; older participants ranged from 4.2 s to 67.2 s, and younger participants ranged from 3.4 s to 67.2 s.

To analyze participants' placement of event boundaries, we divided time within each movie into 1-s bins and for each viewing recorded whether a given participant identified an event boundary within each bin. As can be seen in Figure 2, some points in time were identified as boundaries by most of the participants and some points were not identified as boundaries by any participants. For all three movies, these large differences indicated that there are event boundary points on which most people agree (Newtson, 1976; Speer et al., 2003).

Because event segmentation is an inherently subjective task, it is not possible to calculate an objective measure of segmentation accuracy. However, the fact that there is good normative agreement about the locations of event boundaries, however, means that one can approximate such a measure by asking how close an individual's segmentation pattern is to the pattern for the sample as a whole (including both older and younger participants). A given individual's agreement with the group can be characterized by calculating the point-biserial correlation between that individual's (binary) segmentation data and the segmentation probabilities for the group. We refer to this measure as *segmentation agreement*. Segmentation agreement scores were calculated for each individual and analyzed by converting the correlations to a normally distributed variable using Fisher's z transformation and submitting the z-transformed correlations to a between-participants ANOVA with age and warning as independent variables.[1] Segmentation agreement was significantly higher for younger adults (warned $M = .33$, $SD = .07$; unwarned $M = .31$, $SD = .08$) than for older adults

[1] To estimate the reliability of this measure, we computed z-transformed correlations for each movie separately and then used them to calculate Cronbach's alpha, which was .66. It should be noted that this is a conservative estimate because the individual movie correlations are based on relatively small numbers of observations whereas the actual segmentation measure was based on correlations across the full movie set.

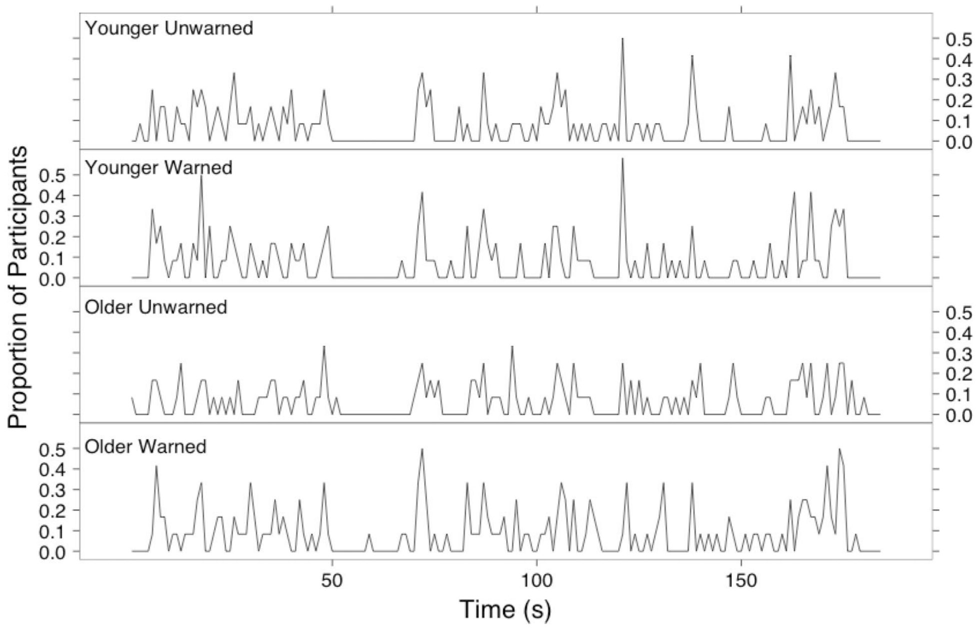

Figure 2. Individuals agree about the locations of event boundaries. Each pane plots the proportion of participants in one of the four groups in Experiment 1 who identified event boundaries during each second of one of the movies (assembling a saxophone).

(warned M = .30, SD = .10; unwarned M = .22, SD = .13), $F(1, 44) = 4.55$, $p = .04$. Participants who were warned of the upcoming memory test showed slightly better segmentation agreement, but this effect did not reach statistical significance, $F(1, 44) = 3.08$, $p = .09$. The interaction between age and warning did not approach statistical significance, $F(1, 44) = 0.91$, $p = .34$.[2]

Thus, although older and younger adults identified similar numbers of event boundaries, younger adults showed better agreement in where they placed those boundaries. To our knowledge, this is the first evidence for such an age difference in event perception. If some older adults are less able to encode the temporal structure of activity than younger adults, this might lead to poorer later memory for temporal order. The next set of analyses addressed this question.

Order memory. To test for age differences in memory for the temporal order of events in the movies, we calculated a measure of order error for each participant's three trials of the temporal order task. Order error scores were calculated by recording the position in which each person placed each picture, finding the absolute deviation of that position from the correct position, and averaging these deviations across each movie. Because this is an error measure, lower error scores indicate better performance; the best possible score is 0 (all pictures placed correctly), and the worst possible score is 6. Order errors were submitted to mixed ANOVAs with movie as a repeated measure and age and condition as between-participants variables. As can be seen in Figure 3, older adults had substantially larger order errors than younger adults, $F(1, 44) = 51.1$, $p < .001$. There were also small but statistically significant differences across movies, with the dishwashing movie producing the largest errors, leading to a main effect of movie, $F(2, 88) = 3.72$, $p < .001$. Neither the main effect of warning nor any of the interactions approached statistical significance (largest F = 1.43).

Participants varied considerably in the time they took to complete the order memory task. Older participants who had been warned of the upcoming memory test took the longest (M = 161 s, SD = 91 s). Older participants who had not been warned of the test were faster (M = 109 s, SD = 39 s), and younger participants were faster still (unwarned M = 80 s, SD = 24 s; warned M = 84 s, SD = 22 s). Completion times were analyzed using mixed ANOVAs with movie as a repeated measure and age and warning as between-participants variables. Both the main effect of age and the main effect of warning were statistically significant: age, $F(1, 44) = 14.7$, $p < .001$; warning, $F(1, 44) = 4.15$, $p = .05$. The effect of warning was larger for older than for younger participants, but this interaction was not statistically significant, $F(1, 44) = 2.97$, $p = .09$. There was a trend toward a difference in test completion time across movies, with the bed-making movie (M =

[2] In this analysis, each participant is compared with the whole sample, including other participants of different ages and experimental conditions. This means that group differences in agreement could result from systematic group differences in where event boundaries were located, as well as individual deviations from the group. To rule out this possibility, we conducted a parallel analysis in which each person was compared only with participants of their own age and experimental condition. This approach has the disadvantage of reduced sensitivity because the sample sizes used to assess normative segmentation are one fourth of those in the original analysis. This analysis produced a very similar pattern of results to that using the whole sample to estimate normative segmentation, but the main effect of age on agreement of segmentation was not significant, likely reflecting the reduction in sensitivity.

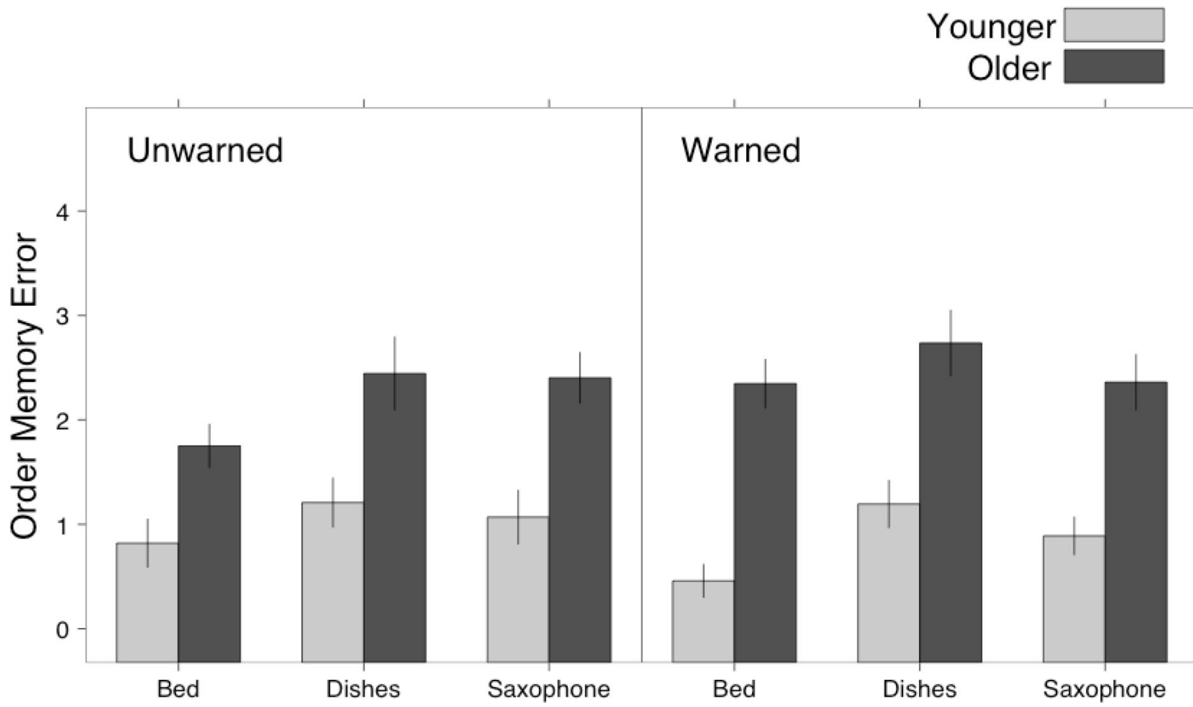

Figure 3. Younger adults had better memory for the order of events than older adults. The graph plots mean order memory error scores with *SEM* error bars for Experiment 1.

115 s) taking longer than the other two movies (*M*s = 102 s for dishwashing and 107 s for saxophone assembly), but this did not reach statistical significance, $F(2, 88) = 2.70$, $p = .07$. None of the other interactions approached statistical significance (largest $F =$ 1.93).

These analyses showed that, as expected, order memory was worse in older adults than in younger adults. Older adults produced larger order errors and took longer to complete the test than did younger adults. Participants who had been warned of the memory test spent more time completing it, suggesting that the warning affected participants' motivation; however, this increased time did not lead to reductions in order memory errors. This fact suggests that the age differences in performance on the order memory test might reflect operations at encoding rather than operations at retrieval.

Relationship between segmentation and order memory. To characterize the relationship between event encoding and order memory, we conducted a series of analyses looking at individual differences in memory performance within each group. One possibility is that participants who are better able to encode an activity produce more normative segmentation and later remember the events better, leading to a negative correlation between segmentation agreement and order memory errors. Each individual's overall order memory performance was calculated by taking the mean order error across the three movies, and these memory performance scores were plotted against each participant's segmentation agreement score in Figure 4. As can be seen in the figure, older adults who performed better on the order memory test tended to have higher agreement scores. Younger adults showed a similar pattern but with less variability in both order memory and agreement. This led to a significant correlation between agreement and order memory for the older participants, $r(22) = -.46$, $p = .02$, but not for the younger participants, $r(22) = -.24$, $p = .25$. Hierarchical linear regression provided no evidence that the effect of segmentation agreement on order memory varied with age: Age Group × Agreement interaction, $F(1, 44) = 0.278$, $p = .60$. Thus, segmenting the movie in a normative fashion was associated with better recall for the order of events, at least for older adults.

It is also possible that the temporal grain at which one segments activity is related to later memory. Segmenting a movie into fine-grained units may facilitate better coding of the temporal ordering of events, leading to better order memory. This would produce a positive correlation between unit size and order memory errors. Another possibility is that participants who segment into coarser units might have a better sense of the larger structure of the activity, leading to a negative correlation. To test these possibilities, we computed the correlation between unit size and order memory for each group. This correlation was not significant for either younger participants, $r(22) = .04$, $p = .88$, or older participants, $r(22) = .31$, $p = .14$.

In short, for older adults, those who segmented the activity into commonly agreed on events had better later memory for the temporal order of the activity. Younger adults showed a similar pattern, but it was not statistically significant. This likely reflects the fact that younger adults were less variable in both their event segmentation performance and order memory performance. The pattern for older adults suggests that common processes operating

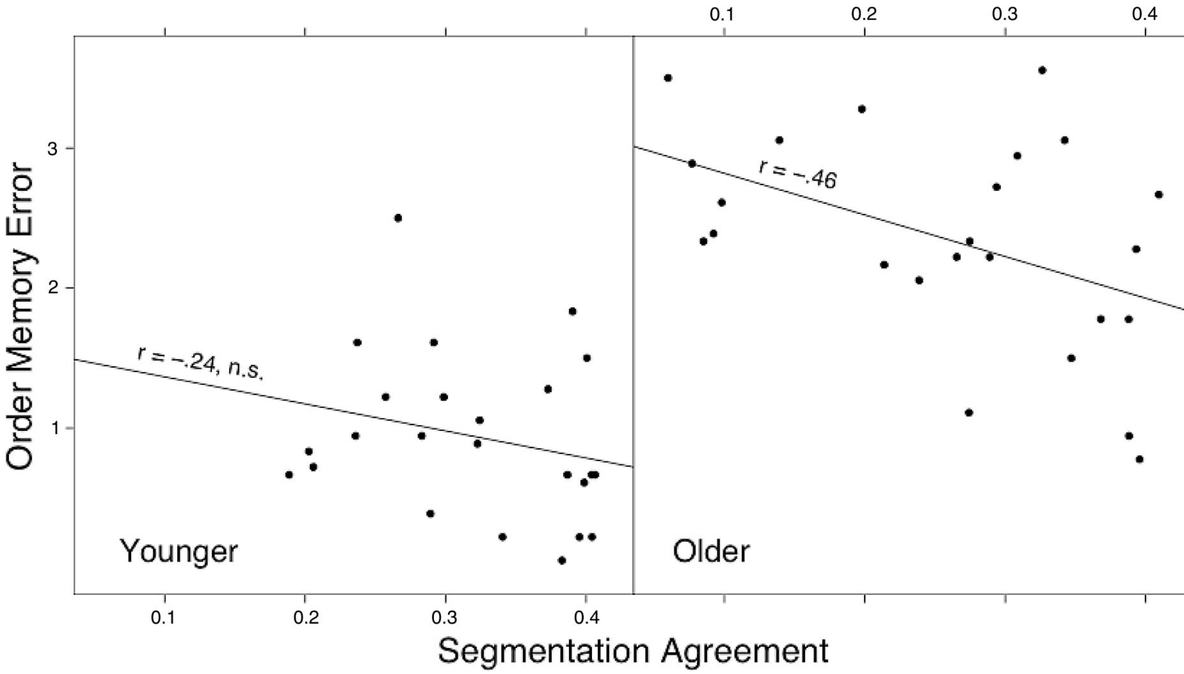

Figure 4. In older adults, segmenting in a normative manner was associated with lower errors in memory for temporal order. Data are from Experiment 1.

during the encoding of events affect one's ability to segment activity and one's ability to remember it later. That is, impairments in memory for everyday activity in aging may reflect, in part, deviations from the norm in the way these older adults segment activities at encoding. However, it is also possible that both the overall age differences in segmentation agreement and order memory and the correlation between those measures resulted from general cognitive decline. Such decline could reflect processes associated with normative aging or undiagnosed early stage dementia. Participants who were less able to remember the task instructions or pay attention to the movies would be expected show low segmentation agreement and poor later memory. This issue was addressed in Experiment 2.

Experiment 2

Experiment 1 suggested that event segmentation may be impaired in aging and that this impairment may be related to memory for events but left a number of important questions unanswered. Experiment 2 addressed four of these questions. First, how does event segmentation change in DAT? On many measures, dementing diseases lead to patterns of deficit that could be described as an extension of the typical aging process (e.g., Storandt & Beaudreau, 2004), but in some cognitive domains, DAT appears to lead to deficits that are qualitatively different from those in healthy aging (e.g., Johnson et al., 2003). To address this question, Experiment 2 tested older adults with and without a diagnosis of DAT as well as younger adults.

Second, how do other forms of memory relate to the impairment of order memory observed in Experiment 1? Memory for what happened has been studied much more heavily than memory for when; do the two aspects of episodic memory show similar patterns of impairment? To address this question, we asked participants to complete recognition memory tests in addition to order memory tests.

Third, can event memory be improved by telling people how to segment activity? As noted in the introduction, previous research indicates that instructing participants to segment at a fine temporal grain can improve recall memory and perhaps recognition memory (Hanson & Hirst, 1989, 1991; Lassiter & Slaw, 1991; Lassiter et al., 1988). Does this extend to memory for temporal order? To address this question, we had participants segment movies at both a coarse and a fine temporal grain.

Finally, can the deficits in event segmentation and memory observed in Experiment 1 be explained solely on the basis of general cognitive decline with age or dementia, or is there a specific aspect of cognitive performance that is picked out by measures of event understanding and memory? The ability to perform sequentially structured actions is strongly correlated with psychometric performance in older adults and adults with dementia (Baum, Edwards, Yonan, & Storandt, 1996). A general decline in some basic aspect of brain function, such as neural transmission efficiency, may be responsible for both global changes in cognitive performance and the event-processing deficits observed here. This question is important for theories of cognitive aging: If event understanding is selectively impaired in healthy aging or DAT, then this would argue for directly investigating the status of semantic representations of events, which may be subserved by the prefrontal cortex (Wood & Grafman, 2003) in these conditions. This question is also of practical importance: To the extent that deficits in event understanding are selective, they can be targeted for interventions. To address this question, we characterized older adults using a comprehensive psychometric battery and compared psychometric performance with measures of event segmentation and memory and with a measure of semantic knowledge about events.

Method

Participants. Older adults were recruited from Washington University's Alzheimer's Disease Research Center (ADRC) and were compensated for their participation ($30 for 3 hr). The cognitive and demographic characteristics of this population have been previously characterized (Rubin et al., 1998); the present sample was well educated (mean years of education = 15.0, *SD* = 2.94 years) and predominantly White (42 of 48, with the remaining 6 being African American). The ADRC maintains longitudinal information about participants that includes an annual assessment of their cognitive ability (a battery of cognitive–behavioral measures and in-person interviews with both the participant and family). A research-trained clinician reviews the annual assessment and classifies each participant with a clinical dementia rating (CDR). A CDR of 0 reflects a clinical judgment that the participant does not have dementia. A CDR of 0.5 indicates very mild dementia, consistent with early stage Alzheimer's disease. We tested 24 participants classified with a CDR of 0 (10 men; mean age = 73 years, range = 63–81 years) and 24 participants with a CDR of 0.5 (14 men; mean age = 76 years, range = 65–85 years). An additional participant in the CDR 0.5 group was tested but was unable to complete the tasks. The experimenter was unaware of participants' CDR score during the experimental session. Twenty-four younger participants were recruited from Washington University (6 men; mean age = 19 years, range = 18–23 years) and received 1.5 hr of course credit in return for their participation.

Psychometric tests. As part of ongoing research at the ADRC, the older participants completed a comprehensive psychometric battery within the previous year. This battery has been described in detail elsewhere (Storandt & Hill, 1989). The analyses presented here focused on three factors identified in previous research as characterizing distinct aspects of cognitive functioning (Kanne et al., 1998). The Memory factor includes the Information subtest of the Wechsler Adult Intelligence Scale—III (WAIS–III; Wechsler, 1997), the Boston Naming Test (Kaplan, Goodglass, & Weintraub, 1983), and the Logical Memory and Associative Learning subscales of the Wechsler Memory Scale—Revised (WMS–R; Wechsler, 1987). The Visuospatial factor includes Benton's Visual Retention Test, Form D (Benton, 1963) and the Block Design and Digit Symbol subtests of the WAIS–III. The Executive Function factor includes the Mental Control and Digit Span Forward subscales of the WMS–R, the Trail Making Test, Part A (War Department, 1944), and a word-fluency measure (Thurstone & Thurstone, 1949). The three factors reliably characterize cognitive functioning and its decline in older adults (Kanne et al., 1998).

In addition to the factor scores, one other measure from the psychometric battery was used. This was a free-recall measure calculated by summing the total number of items correctly answered on three free-recall trials during a task combining free and cued recall (Hannay & Levin, 1985). The free-recall measure was added to the battery after calculation of the factor scores and so was treated separately. A final psychometric test that is not part of the standard ADRC battery was administered during the experimental session. The Picture Arrangement subtest of the WAIS–III requires participants to sort line drawings of everyday activities into the temporal order in which they typically occur in that activity. Its form and administration are similar to the order memory task described previously. However, whereas the order memory task tests episodic memory for a particular experienced event, the Picture Arrangement test measures semantic knowledge about how a particular class of event typically proceeds. Test–retest reliability for the Picture Arrangement test (averaged across age groups) is .74 (Wechsler, 1997).

Materials and tasks. As in Experiment 1, participants viewed movies in which an actor performed an everyday activity. Four new movies were filmed digitally. They depicted setting up a tent (female actor, 379 s duration), planting flowers in a window box (female actor, 355 s), washing a car (female actor, 432 s), and washing clothes (male actor, 300 s). A fifth movie depicting construction of a house from toy blocks (male actor, 156 s) was used for training. All movies were shot from a fixed head-height perspective without cuts or camera movement. The movies were presented using PsyScope (Cohen et al., 1993) on Macintosh computers with 17-in. (43.18-cm) CRT monitors with the participants seated in a chair at a comfortable distance (approximately 65 cm). The movies were presented in the center of the screen and filled 42% of the width and 35% of the height of the monitor. Each movie started several seconds before the actor walked onscreen and ended several seconds after the actor left.

Participants performed segmentation and order memory tasks that were virtually identical to those used in Experiment 1. The single difference in the segmentation task was that the instructions specified that participants should identify either the largest or smallest units that were meaningful to them (*coarse* or *fine* segmentation, respectively), whereas in Experiment 1, the grain of segmentation was left to the participants.

For the order memory task, 12 pictures were selected for each movie from the 25 pictures used in the recognition memory test using the same criteria as for Experiment 1. Pictures were printed on 15.2-cm × 10.2-cm paper and laminated.

Participants also performed a recognition memory test in which pairs of pictures were presented; one was an old picture taken from the movie the participant had seen, and the other was a new picture taken from a visually similar movie that the participant had not seen. For each movie that participants viewed, two similar movies were filmed with the same actor in the same location, and the foil pictures were selected from those movies.[3] For each movie, 25 old pictures and 25 new pictures were selected. On each trial, one of the old pictures and one of the new pictures were selected at random and were presented side by side on the screen, with the location of the old picture varied randomly. Participants were instructed to identify the still picture that had appeared in the movie they had just seen by pressing one of two buttons. Responses and response latencies were recorded by the computer.

Procedure. After providing informed consent, participants were seated in front of the computer and given the instructions for the segmentation task, specifying either fine or coarse segmentation. To practice the task, they then segmented the house-building movie. During this practice session, we used a shaping procedure to reduce individual variability in segmentation grain and to ensure that a sufficient number of boundaries were produced to allow for analysis of segmentation locations (Zacks, 2004). During the first viewing, the computer recorded the number of event boundaries identified. This was compared with target minimum numbers of boundaries based on previous data from similar stimuli (Zacks, Tversky, & Iyer, 2001). The target criterion for coarse segmentation was at least three boundaries during the 156-s movie; for fine segmentation, the target was at

[3] For the movie of setting up a tent, one of the new movies showed the actor setting up the same tent but facing in a different direction; the other showed the actor setting up a different tent. For the flower-planting movie, one of the new movies showed the actor planting flowers in a different flower box; the other showed the actor planting flowers in a flowerbed. For the car-washing movie, one of the new movies showed the actor waxing the car; the other showed the actor washing a different car. Finally, for the laundry movie, one of the new movies showed the actor folding clothes rather than washing them, and the other showed the actor washing towels rather than clothes.

Table 1
Segmentation and Memory Performance by Group and Segmentation Grain in Experiment 2

Grain and group	Unit length (s)	Segmentation agreement	Order memory error	Order memory time (s)	Recognition accuracy	Recognition time (s)
Coarse						
Younger	39.6 (20.8)$_{0.5}$	.39 (.11)$_{0.5}$	0.39 (0.51)$_{0,\ 0.5}$	136.8 (47.4)$_{0,\ 0.5}$	.89 (.09)$_{0,\ 0.5}$	4.31 (1.41)$_{0,\ 0.5}$
CDR 0	43.5 (21.8)	.34 (.17)	1.33 (0.89)$_{Y}$	252.0 (93.4)$_{Y,\ 0.5}$	.77 (.12)$_{Y,\ 0.5}$	7.36 (3.36)$_{Y}$
CDR 0.5	53.0 (23.5)$_{Y}$	.26 (.12)$_{Y}$	1.87 (1.08)$_{Y}$	354.7 (151.4)$_{Y,\ 0}$	.70 (.13)$_{Y,\ 0}$	8.91 (3.88)$_{Y}$
Fine						
Younger	10.7 (7.1)$_{0,\ 0.5}$	.43 (.11)$_{0,\ 0.5}$	0.69 (0.59)$_{0,\ 0.5}$	124.5 (34.1)$_{0,\ 0.5}$	.89 (.07)$_{0,\ 0.5}$	4.43 (1.33)$_{0,\ 0.5}$
CDR 0	20.7 (14.8)$_{Y}$	.32 (.16)$_{Y}$	1.50 (1.07)$_{Y,\ 0.5}$	272.5 (106.4)$_{Y}$	.79 (.14)$_{Y,\ 0.5}$	6.84 (3.42)$_{Y}$
CDR 0.5	29.7 (37.4)$_{Y}$	.24 (.14)$_{Y}$	2.30 (1.24)$_{Y,\ 0}$	357.4 (183.5)$_{Y}$	.65 (.11)$_{Y,\ 0}$	7.83 (4.01)$_{Y}$

Note. Values are means (and standard deviations). Subscripts indicate which groups differed significantly (by *t* tests) from each cell for a given grain. For example, in the top cell for unit length, the subscript "0.5" indicates that coarse-grained unit lengths were significantly shorter for younger adults (subscript "Y") than for CDR 0.5 older adults. CDR = clinical dementia rating.

least six boundaries. If participants' unit lengths were outside the range, then they were told that "a lot of times, people identify more units than you did," and were asked to repeat the practice and to try to adjust their grain of segmentation. This process was repeated at most one additional time. During the practice phase, all participants were told that the segmentation task would be followed by tests of their memory for the events. Following the practice session, participants segmented one of the four movies. They then completed the recognition memory and order memory tests for that movie. The sequence of segmentation, recognition memory, and order memory was repeated for a second movie. Participants were then trained on whichever segmentation grain they had not been trained on initially and completed the same sequence with the two remaining movies. During the second training session, participants were required to identify more (if doing fine segmentation) or fewer (if doing coarse segmentation) boundaries than they had identified during the initial practice session. Assignment of movies to coarse or fine segmentation, order of segmentation grain, and order of presentation of the movies were counterbalanced across participants. After completing the segmentation task and memory tests for all four movies, participants completed the Picture Arrangement subtest of the WAIS–III.

Results and Discussion

Segmentation. To test for group differences in event segmentation, we analyzed the lengths of the units participants produced and the locations of unit boundaries, as in Experiment 1. In a small number of cases, participants (all older adults) failed to make any button presses during a movie. Because participants received training indicating that they should identify more than one event boundary, these instances were treated as failures to comply. These failures to comply appeared to result primarily from a lapse of attention to the task. One participant from the CDR 0 group failed to identify event boundaries during three of the four movies; 7 participants from the CDR 0.5 group failed to identify boundaries during one to three of the movies. Mean unit lengths were averaged across the two viewings at each grain (or one viewing for cases in which no boundaries were recorded during one of the two viewings). In cases in which no event boundaries were recorded for either of the two viewings at a given grain, data were treated as missing for that condition for that participant. Mean event unit lengths for each grain were submitted to a mixed ANOVA with grain as a repeated measure and group as a between-participants variable.

Unit lengths for coarse and fine segmentation for each group are shown in the first column of Table 1. Participants identified longer units when asked to do so in the coarse condition and shorter units in the fine condition, $F(1, 65) = 55.6$, $p < .001$. Unit length increased from the younger group to the CDR 0 group to the CDR 0.5 group, leading to a significant main effect of group, $F(2, 63) = 4.79$, $p = .01$. The Grain × Group interaction was not statistically significant, $F(2, 65) = 0.34$, $p = .72$. Thus, the unit length analyses lead to two straightforward conclusions. First, participants were able to follow the instructions to modulate their grain of segmentation. Second, older adults produced longer units than younger adults—particularly those with a diagnosis of very mild DAT.

Segmentation agreement was calculated and analyzed as for Experiment 1, with one small computational difference: Because different participants saw the same movie at different grains, it was not possible to cumulate across movies before computing correlations. Therefore, agreement scores were computed on a per-movie basis, comparing each participant's event boundaries with those of all participants in the sample who viewed the movie at the same grain as the participant.[4] Per-movie scores were averaged across movies for subsequent analyses. As can be seen in Table 1, agreement was highest for the younger adults and lowest for the older adults with a diagnosis of dementia, leading to a main effect of group, $F(2, 65) = 9.89$, $p < .001$. Neither the main effect of grain nor the Grain × Group interaction was statistically significant: grain, $F(1, 65) = 0.05$, $p = .82$; Grain × Group interaction, $F(2, 65) = 1.68$, $p = .20$.[5] This result replicates and extends the pattern observed in Experiment 1 and provides further support for the hypothesis that processes related to event encoding are impaired in aging and DAT.

[4] Reliability was estimated as for Experiment 1 on the basis of the 65 participants with complete data sets; $\alpha = .80$. This is conservative because which movies were segmented at coarse and fine grain varied across participants.

[5] As for Experiment 1, we conducted a parallel analysis in which each participant's segmentation was compared with their own group rather than to the whole sample. The results were equivalent to those reported here.

Order and recognition memory. Order memory errors were calculated as for Experiment 1, averaged across the two movies for each segmentation grain, and submitted to mixed ANOVAs with grain as a repeated measure and group as a between-participants variable. As can be seen in Table 1, order memory errors were lowest for the younger adult group and highest for the CDR 0.5 group, $F(2, 69) = 28.6$, $p < .001$. Order errors were slightly but significantly larger following fine-grained segmentation than following coarse-grained segmentation, $F(1, 69) = 4.62$, $p = .04$. The Group × Grain interaction was not significant, $F(2, 69) = 0.28$, $p = .75$.

Time taken on the order memory test was analyzed using the same methods as for analyzing order memory errors. (Timing information for one viewing was unavailable because of a timer malfunction.) As can be seen in Table 1, younger participants completed the memory test most quickly and older participants in the CDR 0.5 group most slowly, $F(2, 69) = 31.5$, $p < .001$. Neither the main effect of grain nor the Group × Grain interaction was statistically significant (largest $F = 0.45$).

The recognition memory data in this experiment allowed us to determine whether memory for what happened in movies of everyday events declined with aging (or dementia or both), as did memory for temporal order in Experiment 1 and Experiment 2. Recognition memory accuracy was scored by computing the proportion correctly answered for each participant, separately for the coarse- and fine-segmentation conditions. These scores were submitted to a mixed ANOVA with segmentation grain as a repeated measure and group as a between-participants variable. As can be seen in Table 1, younger adults correctly identified the greatest proportion of old pictures and older adults in the CDR 0.5 group correctly identified the fewest, $F(2, 69) = 34.1$, $p < .001$. There was no evidence that grain of segmentation during viewing affected later recognition accuracy, $F(1, 69) = 0.28$, $p = .60$. The Group × Grain interaction was not significant, $F(2, 69) = 1.42$, $p = .25$.

Recognition memory response time was analyzed by computing the mean response time per picture pair for each participant, separately for the coarse- and fine-segmentation conditions. Mean response times were submitted to ANOVAs of the same form as those for recognition accuracy and are listed in Table 1. Response times were fastest for the younger adults and slowest for the CDR 0.5 group, $F(2, 69) = 12.0$, $p < .001$. There was a nonsignificant trend, such that responses were faster for pictures from movies that were segmented at a fine grain, $F(1, 69) = 3.43$, $p = .07$. The Group × Grain interaction was not significant, $F(2, 69) = 1.69$, $p = .19$.[6]

Thus, both memory for temporal order and memory for what happened showed marked declines with aging and further declines with very mild dementia. The order memory results replicate and extend those of Experiment 1, and the recognition memory results converge with previous research on memory and aging. For both types of memory, participants diagnosed with very mild DAT performed less well than healthy older adults.

The results did not provide strong evidence that segmenting at a fine grain improved recognition memory. As noted in the introduction, previous studies concur that fine-grained segmentation leads to better recall memory than coarse-grained segmentation, but the data on whether fine-grained segmentation leads to better recognition memory are mixed (Hanson & Hirst, 1989, 1991; Lassiter & Slaw, 1991; Lassiter et al., 1988). The present data appear most consistent with the suggestion of Hanson and Hirst (1989) that fine-grained segmentation leads to a richer encoding of the relationships between events in an activity. This is argued to facilitate free recall by providing an appropriate retrieval structure but to have less impact on recognition memory tasks, which provide rich retrieval cues. Surprisingly, fine-grained segmentation led to slightly worse order memory performance than coarse-grained segmentation. One possibility is that segmenting at a fine grain directed participants' attention to the temporal relations between fine-grained units, leading to weaker encoding of coarse-grained temporal relations.

During debriefing, a number of participants reported that during the order memory test they made use of knowledge about how the activity depicted was usually performed to make judgments about the likely temporal order of events. To obtain an estimate of the contribution of semantic event knowledge to performance on the order memory test, we tested a new group of participants who had not seen the movies. Participants were asked to arrange the pictures in the correct temporal order on the basis of what they knew about how the activities were typically performed. We tested 26 younger adults (20 women; mean age = 19.5 years, range = 18–27 years) drawn from the same participant pool as the experimental sample and 24 older adults (18 men; mean age = 76 years, range = 67–94 years) drawn from the pool used for Experiment 1—roughly comparable with the CDR 0 group in the current experiment. The younger group had a mean error score of 2.22 ($SD = 0.78$); the older group had a mean error score of 2.70 ($SD = 0.41$). These values are much higher than the corresponding values in Table 1, smallest $t = 6.76$, $p < .001$, indicating that performance on the test depends in part on episodic memory for the movies. However, performance was considerably better than the worst possible score (6), and the younger group performed significantly better than the older group, $t(48) = 2.68$, $p = .01$, suggesting that semantic event knowledge does play a substantial role in performance on the order memory test. In short, this comparison indicated that performance on the order memory test depended both on episode-specific information about the movie just seen and on general semantic knowledge about how similar activities typically unfold and that older adults were less able than younger adults to take advantage general semantic knowledge.

Predictors of memory performance. The fact that order memory and recognition memory show similar group differences suggests that these differences may reflect a common deficit in the encoding of ongoing activities. However, a great many cognitive

[6] For these analyses, it is not clear how to appropriately handle participants who failed to identify any event boundaries during the segmentation task. It could be argued that they should be omitted from analysis because it is not clear they attended to the movies. However, in no instance was it obvious that this was the case, and in comparing participants with dementia to others, it might be considered appropriate to include such lapses of attention in performance metrics. For both the accuracy and response time analyses reported here, all data were retained. Parallel analyses were conducted excluding data from participants who failed to identify at least one event boundary at each segmentation grain. Those results were equivalent to the reported ones.

measures show age-related impairments, so it is possible that these group differences simply reflect general changes in cognitive ability with age and dementia. To address whether changes in event memory reflect changes in processes specific to event encoding, we conducted a series of analyses using participants' segmentation agreement scores, the results of the Picture Arrangement test, and the results of the psychometric battery.

For each participant, an overall agreement score was formed by computing the mean correlation between that individual's segmentation and the segmentation of the group as a whole at each segmentation grain and then taking the mean of those two agreement scores. (For the 4 participants who failed to identify any event boundaries at one of the two grains, their score for that grain was set to the lowest score for their diagnostic group.) The relationship between segmentation agreement and order memory was similar to that in Experiment 1 (see Figure 5). For younger participants, there was no significant relation between segmentation agreement and order memory, $r(22) = .08$, $p = .71$. For older adults without a diagnosis of dementia, participants with higher segmentation agreement performed better on the order memory test, $r(22) = -.41$, $p = .05$. The CDR 0.5 group showed a similar trend, but it was not statistically significant, $r(22) = -.32$, $p = .13$. As in Experiment 1, hierarchical linear regression provided no evidence that the effect of segmentation agreement on order memory was moderated by group: Group × Agreement interaction, $F(2, 62) = 0.96$, $p = .39$.

As can be seen in Figure 6, recognition memory performance showed a pattern similar to that for order memory. For younger participants, there was no significant relation between segmentation agreement and recognition memory, $r(22) = -.28$, $p = .19$. For both older adult groups, there was a strong relation, such that participants with more normative segmentation had better recognition memory: CDR 0, $r(22) = .57$, $p = .003$; CDR 0.5, $r(22) = .41$, $p = .05$. Unlike for order memory, hierarchical linear regression indicated that the affect of segmentation agreement on recognition memory varied by group: Group × Agreement interaction, $F(2, 62)= 4.22$, $p = .02$.

We examined the relations between semantic knowledge about everyday activities and episodic memory for the events depicted in the movies by computing correlations between Picture Arrangement subtest scores and the memory measures. As can be seen in the rightmost columns of Table 2, Picture Arrangement was significantly correlated with both order memory and recognition memory for the CDR 0 group; the CDR 0.5 group showed a similar pattern, though it was not significant for recognition memory. The younger adults showed no significant relationship between performance on the Picture Arrangement test and either of the memory measures.

Finally, we examined the relationship between psychometric measures of cognitive ability and event memory. These analyses focused on the older adult groups, for whom the comprehensive psychometric test battery was available. The psychometric performance of the three groups is summarized in Table 2. The CDR 0 group outperformed the CDR 0.5 group on all measures. Younger participants had scores only for the Picture Arrangement test. They performed best on this measure, and the CDR 0.5 group performed worst. The rightmost two columns of Table 2 show the correlations between the psychometric measures and performance on the two memory tests. Both the CDR 0 and CDR 0.5 groups showed strong relations between the psychometric measures and memory performance. To quantify the strength of this relationship, we computed linear regressions predicting memory performance from the psychometric tests (excepting the Picture Arrangement test). For the CDR 0 group, psychometric performance accounted for 49% of the variance in order memory and 54% of the variance in recognition memory.

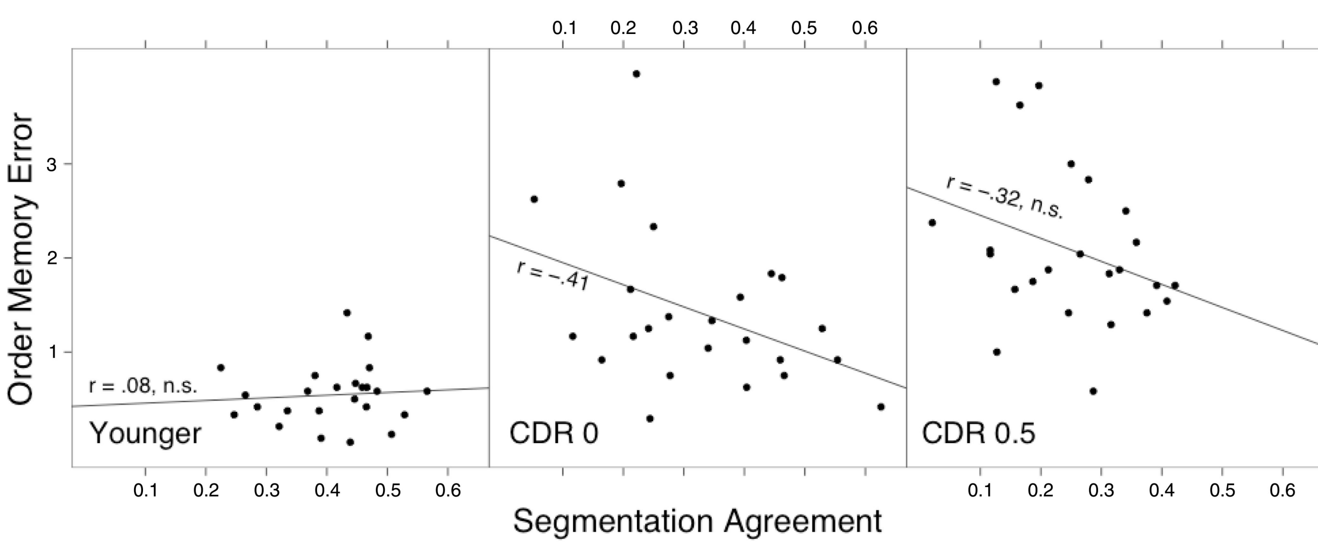

Figure 5. In older adults without a diagnosis of dementia, segmenting in a normative manner was associated with lower errors in memory for temporal order. Data are from Experiment 2. Correlations are based on *z*-transformed agreement scores. CDR = clinical dementia rating; CDR 0 = no diagnosis of dementia; CDR 0.5 = diagnosis of very mild dementia.

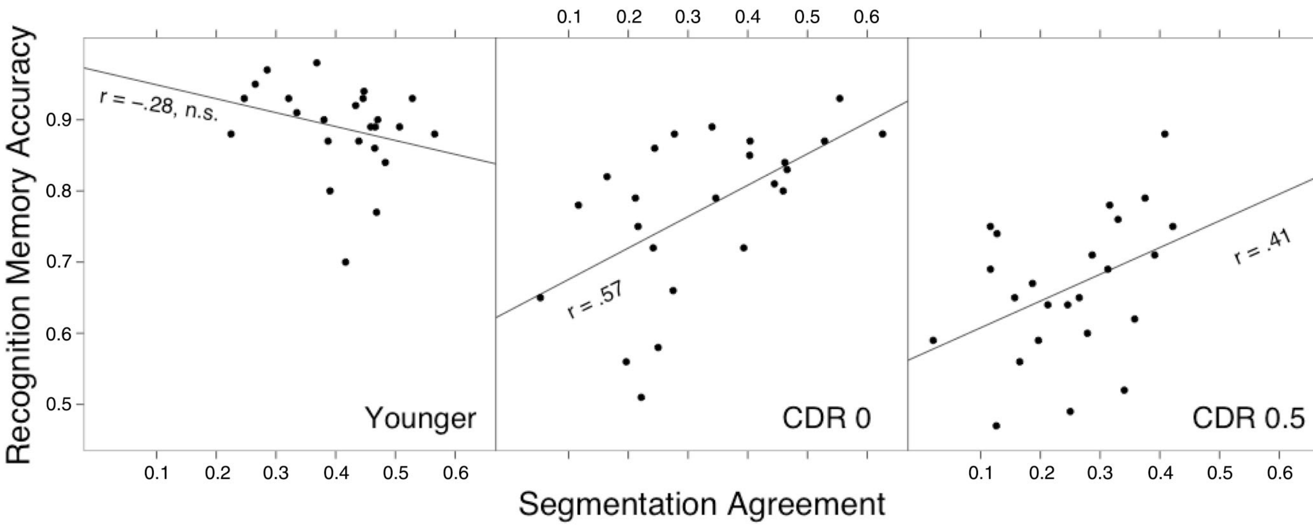

Figure 6. In older adults, segmenting in a normative manner was associated with higher recognition memory accuracy. Data are from Experiment 2. Correlations are based on *z*-transformed agreement scores. CDR = clinical dementia rating; CDR 0 = no diagnosis of dementia; CDR 0.5 = diagnosis of very mild dementia.

For the CDR 0.5 group, psychometric performance accounted for 48% of the variance in order memory and 39% of the variance in recognition memory.

In short, for older adults, segmentation agreement and Picture Arrangement performance were related to later memory. For younger adults, no such relationships were observed; this may reflect the limited range of scores for younger adults (i.e., a ceiling effect). The pattern for older adults raises the question of whether the relations observed between event segmentation and memory or between semantic memory for events and event memory reflect general effects of overall cognitive state. In other words, to what extent do the measures of event segmentation and semantic event knowledge simply capture variability in general cognitive functioning, which is predictive of event segmentation?

To address this question, we conducted a series of hierarchical regression analyses, which are summarized in Table 3. For both order memory and recognition memory, we first fit linear models predicting each individual's performance from their diagnostic category, their psychometric factor scores, and their free-recall score. We then fit models that added either individuals' segmentation agreement or their score on the Picture Arrangement test. As can be seen in Table 3, diagnostic category and the general psychometric measures accounted for a substantial amount of the variance in both order memory and recognition memory. Beyond these measures, Picture Arrangement scores accounted for a significant amount of additional variance in order memory, and segmentation agreement accounted for a significant amount of additional variance in recognition memory. (Picture Arrangement scores also accounted for incremental variance in recognition memory that approached but did not reach statistical significance.) Thus, the relationships between event memory, event segmentation, and event knowledge do not appear to be due solely to variation in overall level of cognitive function.

Table 2
Psychometric Performance of the Three Groups in Experiment 2

Group and measure	*M*	*SD*	Correlation with order memory	Correlation with recognition memory
Younger				
Picture Arrangement	16.42	3.03	−.06	−.05
CDR 0				
Memory	1.51	0.93	−.63**	.62*
Visuospatial	0.44	0.36	−.65**	.70**
Executive Function	0.69	0.79	−.43*	.44*
Free Recall	27.25	6.82	−.51*	.60*
Picture Arrangement	11.75	5.18	−.57*	.65**
CDR 0.5				
Memory	0.54	0.92	−.49*	.46*
Visuospatial	0.23	0.36	−.57*	.55*
Executive Function	0.34	0.75	−.22	.32
Free Recall	18.27	9.50	−.37†	.26
Picture Arrangement	7.13	4.39	−.62*	.40†

Note. For each measure, the groups were compared with *t* tests. For the Picture Arrangement test, all three groups differed significantly. For the measures from the psychometric battery, the two older adult groups (CDR 0 and CDR 0.5) differed significantly for all factors except the Executive Function factor, $t(46) = 1.55$, $p = .13$. CDR = clinical dementia rating.
† $p = .06$. * $p < .05$. ** $p < .001$.

General Discussion

To a psychologist, memory comes in many forms and is used in myriad circumstances, but to most people, memory is what allows one to know what happened before so that one can decide what to do now. In particular, it often is extremely valuable to keep track of which events have recently transpired and in what order. The two experiments reported here reveal three important things about

Table 3
Measures of Event Segmentation and Semantic Knowledge About Event Ordering Predict Memory for Events Above and Beyond Global Psychometric Performance

Model	Equation	R^2	$F(1, 41)$	p
1	Order Memory = M + V + E + Free recall + CDR	.55		
1a	Order Memory = M + V + E + Free recall + CDR + Segmentation agreement	.56	0.86	.36
1b	Order Memory = M + V + E + Free recall + CDR + Picture Arrangement	.60	7.05	.01
2	Recognition Memory = M + V + E + Free recall + CDR	.59		
2a	Recognition Memory = M + V + E + Free recall + CDR + Segmentation agreement	.64	5.34	.03
2b	Recognition Memory = M + V + E + Free recall + CDR + Picture Arrangement	.62	3.67	.06

Note. Results of hierarchial regressions predicting order memory and recognition memory from psychometric test scores and measures of event understanding. M = Memory; V = Visuospatial; E = Executive; CDR = clinical dementia rating.

the perception of and memory for everyday events. First, one's ability to segment ongoing activity into meaningful events appears to decline with age and to decline further with very mild dementia. Second, two aspects of everyday event memory also decline with age and dementia: memory for what events happened and memory for the order in which those events occurred. Third, event segmentation and semantic knowledge about events are unique predictors of which older individuals will have worse memory for events. In fact, inspection of Figures 5 and 6 suggests that those healthy older adults whose segmentation agreement scores were in the range of the younger adults also had order memory and recognition memory scores in the range of the younger adults and that those adults with very mild dementia whose segmentation scores were in the range of the healthy older adults had memory scores similar to those of the older adults without dementia.

In interpreting our claim that event segmentation appears to decline with age and dementia, it is important to keep in mind that the measure of segmentation quality used here was that of intersubjective agreement. For many events, there exists no ground truth "correct" segmentation on which to base an objective accuracy measure. So, strictly speaking, the present data establish merely that segmentation becomes more idiosyncratic with age and dementia. Activities with well-defined segments and rigid ordering, such as religious rites or sporting events, may provide more opportunity to identify segmentation patterns that can be characterized as objectively correct or incorrect. Our hunch is that if this procedure is replicated with events that have normative segmental structure, older adults and adults with dementia will be less able to accurately identify this normative structure; in other words, we believe the idiosyncrasy observed here reflects a true decline rather than simply a difference of opinion. That hypothesis is based in part on the present finding that segmentation agreement was related systematically to memory; that is, it had good criterion validity as a measure of event understanding.

Unique Contributions of Event Structure to Memory

Semantic knowledge about the temporal order of events, as measured by the Picture Arrangement test, could be uniquely related to performance on the order memory test by at least two mechanisms. One possibility is that these relationships arise because both tasks depend on semantic relationships of activities that encode information about the temporal relations amongst events, often described as schemata, scripts, or structured event complexes (Grafman et al., 1995; Rumelhart, 1980; Schank & Abelson, 1977). In the case of the Picture Arrangement test, semantic representations are presumably activated in a top-down fashion when participants identify the activity whose pictures are being sorted. In the case of the order memory task, both bottom-up and top-down processing are likely involved during memory retrieval. Bottom-up processing of the stimulus pictures leads to activation of stored episodic traces. This, in turn, likely leads to activation of semantic knowledge about the activity that was depicted. Judgments about temporal order can be influenced both by bottom-up activation of timing information and top-down inferences based on semantic knowledge about the order in which events typically occur. Evidence consistent with this interpretation comes from studies of scene memory: Older adults with and without dementia have been found to use schemata when remembering which items were present in a complex scene (Rusted, Gaskell, Watts, & Sheppard, 2000). However, it must be noted that the Picture Arrangement test and the order memory test also share a number of surface features that are not specific to event understanding; for example, both involve sorting pictures with cards. An alternative possibility is that some incidental cognitive demands related to encoding the pictures, retaining them in working memory, or moving them into the correct order lead to correlations between Picture Arrangement and order memory performance above and beyond overall level cognitive functioning.

The unique relations between segmentation agreement and recognition memory are consistent with previous experimental manipulations of cues to event segmentation. In those studies, encouraging participants to segment activity into perceptually and conceptually natural events led to better memory for what had happened (Boltz, 1992)—at least at the moments of the event boundaries (Schwan et al., 2000)—and to better estimates of the durations of events (Boltz, 1995). If people spontaneously encode continuous activity as a series of discrete events and use this discrete representation to guide later retrieval, then parsing the activity at the right moments is likely to be critical for later memory. By analogy, imagine a system that stores representations of human conversations for later retrieval. Good retrieval is likely to be very difficult if the units that are stored do not correspond to words, sentences, and larger discourse units.[7]

Implications for Theories of Cognition and Aging

These findings have implications for theories of event understanding. They establish that event segmentation plays a selective role in the encoding of activity for later memory. The fact that in older adults higher segmentation agreement scores were predictive of better later recognition memory for what happened suggests that to remember an activity later it is important to encode it by segmenting the activity into appropriate events (Hanson & Hirst, 1989; Zacks, Speer, Swallow, & Braver, in press; Zacks & Tversky, 2001). Thus, one way that semantic knowledge about events may contribute to later memory is by allowing people to encode activity in appropriately integrated representations that facilitate later recollection. However, memory test performance reflects not only recollection for previous events but also biases based on expectations or habit (Jacoby, Debner, & Hay, 2001). Semantic event knowledge may establish biases based on how a particular activity typically unfolds. For example, if one's semantic representation of "going to the dentist" specifies having one's teeth cleaned by a hygienist before meeting with the dentist, then one might be prone to misremembering the temporal order of events during a visit in which the meeting with the dentist occurred first. Such biases are often adaptive (because things usually go the way things usually go), but when an activity unfolds in an atypical fashion, biases can lead to errors.

The finding that event segmentation is uniquely related to memory also is important for theories of cognitive aging. The memory tasks used here come quite close to measuring the sorts of memory that older adults complain of losing. Memory for what happened recently, and in what order, is important for tasks of daily living, for following television programs, and for maintaining conversations. One possibility is that age-related declines in this sort of memory could arise solely from reductions in general cognitive resource availability or from general slowing. However, the present results suggest that specific computational mechanisms for processing knowledge about events make unique contributions to account for memory across the life span. Semantic knowledge about events may allow for better episodic memory for events throughout the life span in much the same way the semantic knowledge possessed by experts allows for better episodic memory for words throughout the life span (Hambrick & Engle, 2002; Morrow, Leirer, & Altieri, 1992). In accounting for the role of knowledge and expertise in moderating the effects of aging and dementia on cognition, semantic knowledge about events may be a critical variable. This possibility argues for looking more closely at memory for everyday events in aging and dementia. It also argues for further direct investigations of semantic knowledge about events; the present studies included one brief psychometric test (the Picture Arrangement test) and one measure that likely depends on both semantic knowledge about events and attentional control processes for good performance (the segmentation agreement measure). Studies of discourse processing indicate that older adults rely on semantic knowledge about events at least as much if not more than younger adults when reading and remembering stories (Wingfield & Stine-Morrow, 2000) and devote more cognitive resources to encoding the situation described by the text, compared with the surface structure, than do younger adults (Radvansky et al., 2001; Radvansky, Copeland, Berish, & Dijkstra, 2003; Stine-Morrow, Morrow, & Leno, 2002; Stine-Morrow, Gagne, Morrow, & DeWall, 2004). Adopting a situation-oriented comprehension strategy, driven by memory for similar previous events, may be an adaptive response to declines in perceptual or attentional resources (Radvansky et al., 2003). However, to be effective it requires that comprehenders have good access to previous knowledge about events (indexed by Picture Arrangement performance) and also have the ability to identify appropriate units and structures in the present input for retrieving that knowledge (indexed by segmentation agreement). The present data indicate that individual differences in both of these attributes within older adults are related to comprehension and memory. We speculate that event knowledge would show even larger relations to recall memory for events than recognition or order memory because recall tests provide less rich cues during retrieval.

These results argue for further investigation of the relationship between event understanding and frontal status in aging and DAT. One possibility is that semantic event representations in the prefrontal cortex (Wood & Grafman, 2003) degrade during healthy aging and degrade further as a result of Alzheimer's disease pathology. This degradation would explain the present results by positing a reduced influence of those representations on ongoing processing during encoding and a reduced effectiveness of top-down influence from semantic event representations during memory retrieval. In particular, the finding that semantic knowledge about event order declined with age and dementia argues for this interpretation. At first blush, this account may appear to be at odds with arguments that frontal lobe damage in Alzheimer's disease produces an attentional control deficit, which is the primary cognitive impairment in early stages of the disease (Balota & Faust, 2001). However, this may not be the case. A recent analysis of cognitive control in working memory argues for an episodic buffer (Baddeley, 2000) that integrates information across modalities to maintain a representation of "what is happening now." This working memory representation is implemented by binding together modality-specific working memory representations and activated portions of long-term memory, including semantic representations of events. If this account is correct, then the updating of the episodic buffer is likely to be a central component of attentional control (see Zacks et al., in press), which depends on the proper operation of frontal event representations.

[7] A second reason that segmenting an activity idiosyncratically might impair recognition memory in this task is that the still pictures we selected for the recognition test were often taken from event boundaries. Previous research suggests that recognition memory for still pictures taken from event boundaries is superior to recognition memory for pictures from nonboundaries. Failing to perceive the same boundaries as were used to select the picture might lead a viewer to fail to encode those particular moments in time adaptively. To explore this possibility, we analyzed recognition accuracy as a function of pictures' proximity to participants' own event boundaries or to normative event boundaries (those identified by a preponderance of the participants). Neither of these analyses provided evidence that recognition memory in this case varied as a function of proximity to an event boundary.

Implications for Evaluation and Training

The fact that measures of event segmentation and semantic event knowledge uniquely predicted memory performance suggests that such measures may be useful in diagnosing memory disorders. In Experiment 2, measures of event segmentation and semantic event knowledge accounted for modest amounts of variance in memory performance, once diagnostic category and overall level of cognitive ability were accounted for. However, such small increments in prediction can be valuable for diagnosis if they pick out a subgroup of participants with a specific cognitive impairment. In future research, it would be valuable to test whether measures of event understanding account for unique variance in other measures of memory, including memory complaints and objective measures of everyday memory failures. It is quite possible that event-understanding measures provide an especially sensitive measure of the encoding processes that are important for everyday memory.

The fact that event knowledge appears to contribute uniquely to comprehension and memory raises the possibility that it could be a target for cognitive training. If, for some people, impaired event segmentation is a primary cognitive deficit leading to poor event memory, then training on event perception may facilitate better memory performance. In the present study, two interventions were tested: warning participants of an impending memory test (Experiment 1) and asking participants to segment at a fine temporal grain (Experiment 2). Neither of these interventions improved memory performance substantially. (The data suggest that encouraging participants to segment at a coarse grain may help order memory slightly; to verify this, it would be important to compare coarse-grained segmentation with segmentation at a neutral grain and with viewing without segmentation.) However, it would be worthwhile to explore other interventions designed to facilitate adaptive encoding of event structure to determine whether they may help remediate some kinds of age-related memory loss. One possibility is that memory would be helped by asking people to think about how a particular activity they are watching compares with their knowledge about how that activity typically unfolds. Such instructions might help compensate for weakened semantic event representations. Another possibility is that simply thinking about the temporal structure of activity, as is required when performing the segmentation task, would improve later memory. This last possibility also implies a suggestion for psychologists: Thinking about the temporal structure of activity can productively inform theories of memory, aging, and dementia.

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Received September 16, 2005
Revision received February 7, 2006
Accepted March 27, 2006 ■