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Flexibility of event boundaries in autobiographical memory

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Events have clear and consistent boundaries that are defined during perception in a manner that influences memory performance. The natural process of event segmentation shapes event definitions during perception, and appears to play a critical role in defining distinct episodic memories at encoding. However, the role of retrieval processes in modifying event definitions is not clear. We explored how such processes changed event boundary definitions at recall. In Experiment 1 we showed that distance from encoding is related to boundary flexibility. Participants were more likely to move self-reported event boundaries to include information reported beyond those boundaries when recalling more distant events compared to more recent events. In Experiment 2 we showed that age also influenced boundary flexibility. Older Age adults were more likely to move event boundaries than College Age adults, and the relationship between distance from encoding and boundary flexibility seen in Experiment 1 was present only in College Age and Middle Age adults. These results suggest that factors at retrieval have a direct impact on event definitions in memory and that, although episodic memories may be initially defined at encoding, these definitions are not necessarily maintained in long-term memory.

Keywords: Autobiographical memory; Ageing; Event; Memory.

Defining an event and its boundaries is quite difficult. One way psychologists have addressed this issue is by observing how humans perceive ongoing events (Kurby & Zacks, 2008). By looking at the similarities between individuals' decisions when parsing a complex ongoing scene into discrete events, one is able to theorise how an event is actually defined. For example, Reynolds, Zacks, and Braver (2007) have suggested that event models are used by humans to understand ongoing activity. These models enable us to make predictions on what actions are likely to occur during the ongoing action sequence. As long as an event model is consistent with what is going on in the environment it will not be altered. When prediction errors start to increase, however, event models must be changed. Reynolds et al. (2007) have thus suggested that the perception of an event boundary emerges from this natural prediction process in which periods of stability (when action sequences are predictable and consistent with one's schemata) are viewed as events and periods of instability (when significant prediction errors occur) are viewed as event boundaries.

Physiological evidence suggests that the prediction process resulting in segmentation is an automatic process. Brain activation related to the perception of event boundaries is present whether

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or not a participant has been asked to actively parse a clip (Zacks et al., 2001). For instance, such activity has been observed in the superior temporal cortex and visual processing regions including the MT complex when simply viewing films and when actively parsing the films into events (see Kurby & Zacks, 2008, for review).

In fact, such event segmentation has an impact on long-term memory as well. Participants who segmented a scene in an abnormal manner tended to have impaired memory for that scene (Zacks, Speer, Vettel, & Jacoby, 2006). Further, when comparing non-boundary movie frames to boundary movie frames in a recognition task, boundary frames were recognised at a higher rate (Newtson & Engquist, 1976). This prompts the assumption that extra processing takes place at boundary markers which subsequently leads to better recall for that information (Swallow, Zacks, & Abrams, 2009; Zacks, Speer, Swallow, Braver, & Reynolds, 2007). However, it is less clear whether the perceived events then exist as distinct units and are organised in memory from boundary marker to boundary marker.

In addressing this particular question, Conway (2005) related event segmentation to autobiographical memory. He argued that human memory is goal driven and that the self and memory are inextricably linked. In his "Self-Memory System" (SMS) the boundaries of an event within autobiographical memory are determined by the beginning and termination of a focal goal. In support, he found that memories for recent events were divided based on actions that signalled changes in goal processing, such as meeting up with a friend, or catching a bus. In Conway's terms, "encoding processes are terminated ... by the implementation of new actions, marking the start of a new episodic memory" (Conway, 2005, p. 614). The implication is that, based on the implementation of new actions that mark the end of a previous action, events are encoded as discrete units in memory, with intact boundary information. At recall, then, one would expect these specific event boundaries to be somewhat inflexible and their placement to be dependent on processes that had already occurred at encoding.

In daily life it is rare that all episodic elements of an event are accessible at recall. Indeed, Conway's (2005) participants lost the vast majority of detail and all ability to order events that had taken place on the walk from their dorms to the experiment after just 1 week. Because the ability to order events has to depend on boundary information, it seems unlikely that the actual definitions of events in memory remained fully reliant on the initially perceived boundaries at encoding.

In contrast to encoding of event boundaries as a determinant of episodic memories, a host of work has shown that memory for events changes during recollection (e.g., Tulving, Donaldson, & Bower, 1972). For instance, misinformation can alter episodic memories at recall (e.g., Loftus, 1979a, 1979b), memory for pictures and stories can become more schematised with repeated recall (e.g., Bartlett, 1932), and memories are vulnerable to change at recall in a manner which impacts all future recollections of that specific episode (e.g., Hupbach, Gomez, Hardt, & Nadel, 2007). Indeed, reconstruction is a basic principle that guides human memory (Surprenant & Neath, 2009) and must also affect boundary recall, influencing the very definition of an event.

We suggest that defining events during autobiographical retrieval is not entirely dependent on the initial segmentation that is automatically applied to the flow of information at encoding. That is, information that is encoded in memory is not already tagged with defined boundaries. Instead the original perception notwithstanding, the process of segmentation, and thus the defining of events in memory, happens at retrieval depending on the accessible details. Thus, for situations in which detail accessibility has waned, boundary placement should be somewhat arbitrary and vulnerable to change.

Two easily measured factors that impact detail accessibility are the age of the memory and the age of the recaller. Starting with Ebbinghaus (1885/1913), a multitude of studies have shown that episodic memory declines with time (e.g., Friedman & deWinstanley, 1998), and work by Piolino, Desgranges, Benali, and Eustache (2002) has shown that episodic recall declines with both age and retention interval, as well as that the rate of decline is significantly greater than that in semantic recall. Further, Levine, Svoboda, Hay, Winocur, and Moscovitch (2002) has demonstrated that older adults have more difficulty retrieving specific details of an event than younger adults. Within this context, we explored how boundaries in memory depend on factors during retrieval. Specifically, we used the Autobiographical Interview (Levine et al., 2002) to record memories and, during the parsing of those memories, classified their details into those internal and those external to each event. In Experiment 1 we investigated the flexibility of event boundaries in memory as a function of increasing time from encoding. In Experiment 2 we assessed the flexibility of event boundaries as a function of the age of the participant. In both experiments we also investigated the ways in which hierarchical definitions of events may change over time and how factors at retrieval may impact the way events in memory relate to one another.

EXPERIMENT 1

Method

Participants. A total of 16 participants between the ages of 18 and 22 were recruited from psychology classes at American University. Participants were offered extra credit at the discretion of their professor.

Materials, design, and procedure. In accordance with the Autobiographical Interview procedures (Levine et al., 2002), participants took part in three interview phases: a Free Recall phase, a General Probe phase, and a Specific Probe phase. Participants were asked to recall an event from eight time periods spanning their life: Early Childhood (0–5 years), Childhood (6–11 years), Teenage Years (12–18), One Year Ago, One Month Ago, One Week Ago, One Day Ago, and One Hour Ago. All participants completed the Free Recall and General Probe phases for each time period prior to going over each event a second time in the Specific Probe phase. During Free Recall participants described a memory without any guidance from the researcher. The General Probe phase was used to help the participants move to an episodic memory if they had not given one. Finally, the Specific Probe phase included questions about the duration of the reported event, certain qualitative characteristics on rating scales of 1–6 (where 1 was low and 6 was high), and questions about event boundaries. The order in which the specific probes were given was randomised for each participant.

During the Specific Probe phase the event boundary query comprised questions about what the participant considered the event boundaries to be (that is, what detail marks the beginning of the event and what detail marks the end of the event). Following these questions, boundary flexibility was probed by asking participants if they were able to recall details prior to the first boundary and after the end boundary (do you remember what happened before [the first boundary], do you remember what happened after [the last boundary]), and whether they would consider these new details to be part of the initially reported event (do you consider that to be part of the originally reported event). Finally a self-report of hierarchical structure was obtained by asking participants if the reported event was part of a larger, encompassing event, and whether the reported event contained smaller events of its own. All interviews were recorded via a Dell Inspiron 1420 laptop recorder, and interviews were later transcribed to allow for detail scoring.

Results and discussion

Boundary scoring. All scores reflect the answers of the participants during the Specific Probe phase. Flexibility, Extra-Event Information, and Hierarchy scores are thus self-report measures reflecting perceived boundary locations and inter-event relationships. Flexibility scores reflect how participants moved event boundaries and were scored on a 3-point scale. A score of 0 indicated that the participant did not include any details recalled prior to the first boundary or after the last boundary as part of the originally reported event. A score of 1 indicated that the participant included information in one direction and a score of 2 indicated that the participant included information in both directions. Half of the reported events showed a flexibility score greater than 0.

Extra-Event Information scores refer to whether information just beyond event boundaries could be recalled at all. That is, this score reflects whether or not boundary flexibility was possible and is also on a 3-point scale. A score of 0 indicated that no information on either side of the event could be recalled. A score of 1 indicated that information on only one side of the event could be recalled. A score of 2 indicated information on both sides of the event could be recalled. This factor was used primarily as a selection variable in that by looking at events based on the Extra-Event Information score, we were able exclude events in which it was impossible to move the boundary (a score of 0). Extra-Event Information was used primarily as a selection variable. For the flexibility analyses we filtered out all those events that had a score of 0 on Extra-Event Information. The vast majority of events (83%) showed an Extra-Event Information score greater than 0.

Finally, Hierarchy scores refer to how participants viewed events in relation to other events (cf. Conway, 2005) and were also scored on a 3-point scale. A score of 0 indicated there were no larger events that encompassed the reported event, nor were there smaller events that were contained within the reported event. A score of 1 indicated that there was either a larger event(s) or a smaller event(s) reported and a score or 2 indicated that both a larger and a smaller event(s) were present. All events showed a hierarchy score greater than 0.

Memory coding. Memories were transcribed and coded for internal and external details as described in Levine et al. (2002). Each memory was transcribed whole and broken into phrases that communicate an idea. These details were then scored as either internal to the event (a particular detail having to do with the self-defined event, such as "Jimmy and Martha were talking to me") or external (a detail pertaining to something not specific to the event or semantic in nature, such as "I had lived in that town for 5 years"). All details were then tallied to calculate an External and an Internal Detail score.

There were also five factors that were scored on 6-point rating scales. The mean Visualisation score was 4.57 ($SD = 1.27$); the mean Importance Now (at recall) score was 3.02 (*1.66*); the mean Importance Then (at the time of encoding) score was 4.18 (*1.49*); the mean Emotional Change score was 3.30 (*1.65*); and the mean Rehearsal score was 2.29 (*1.36*). These were all self-report measures of the subjective characteristics of the memory. Finally, duration was recorded in minutes based on a self-report of how many minutes of the event the participants believed they could recall. They were asked: "How long was the event in minutes, and how much of that do you have detailed recollection for in minutes?" Duration reflected the number of minutes of the event for which they had detailed recollection.

Factors impacting boundary flexibility

To examine how our measures of interest related to event boundary flexibility, we applied a Generalised Estimating Equations (GEE; Liang & Zeger, 1986) model with Time Period entered as the repeated index. First, as previously described, we used Extra-Event Information as a selection variable to filter out those events in which boundary flexibility was impossible (a score of 0 on Extra-Event Information). Then a GEE model was applied with Flexibility Scores as the ordinal response variable and Distance from Encoding, Importance Now (at retrieval), Importance Then (at encoding), Emotionality, Internal Detail, and External Detail entered as predictors. We also entered all interactions with Distance from Encoding given that this was our main variable of interest. We did not include visualisation, duration, or rehearsal as covariates in our model because they were correlated with Distance from Encoding ($p < .005$). Backwards elimination was used to eliminate non-significant terms from the model. There was a main effect of Distance from Encoding (Wald $\chi^2 = 16.27$, $p < .001$), Importance Now (Wald $\chi^2 = 11.88$, $p = .001$), Importance Then (Wald $\chi^2 = 18.68$, $p < .01$), and a significant interaction between Distance from Encoding and Importance Now (Wald $\chi^2 = 11.556$, $p = .001$). Thus the level of importance and the distance from encoding both play an important role in boundary flexibility, and as shown in Figure 1 distance appears to be an especially strong predictor for more important events.

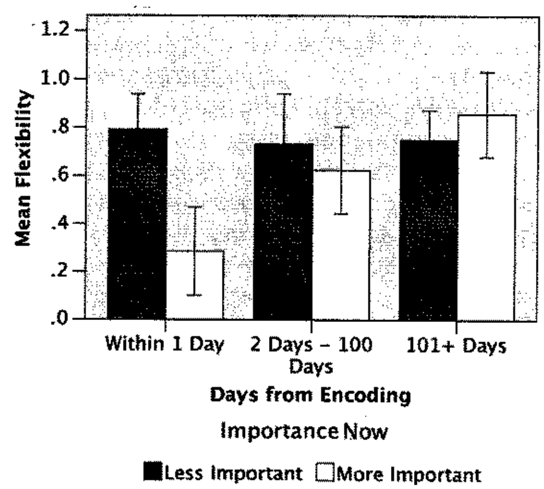

Figure 1. Increases in boundary flexibility as a function of importance and distance from encoding. For events that were rated as more important at encoding, boundaries were more flexible as distance from encoding increased. Boundaries for less-important events did not show changes in flexibility as distance from encoding increased. The grouping of Distance from Encoding was performed for illustration purposes only. Error bars represent standard error of the mean.

Next we investigated how all measures related to the possibility of boundary flexibility. In this case Extra-Event Information scores were set as the ordinal response variable, and the same measures above inserted as predictors. There was a main effect of Distance from Encoding (Wald $\chi^2 = 43.49$, $p < .001$) and no significant interactions. Participants were less likely to recall information beyond event boundaries for more distant events (Figure 2).

Finally we investigated how our measures related to the presence of a hierarchical structure. For this analysis Hierarchy was entered as the ordinal response variable into the GEE model with the same predictors as above. There was a main effect of Distance from Encoding (Wald $\chi^2 = 10.47$, $p = .001$), External Detail (Wald $\chi^2 = 5.37$, $p = .02$), and Emotionality (Wald $\chi^2 = 5.54$, $p = .02$). More emotional events and events with more external detail were more likely to be reported in a hierarchical structure while events from the more distant past were less likely to be reported in a hierarchical structure.

In this experiment we have demonstrated that boundary flexibility is related to the amount of time that has passed since initial encoding, and thus event definitions in memory depend on factors at retrieval, as well. In addition we have demonstrated that events from childhood are likely to be recalled with fewer hierarchical relationships to other events, and with less Extra-Event Information. It appears that very distant events are qualitatively different from more recent events; especially in the way those events are related to surrounding events and surrounding episodic details.

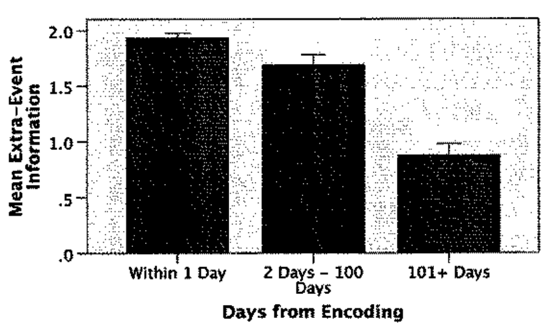

Figure 2. Decreases in extra-event information as a function of distance from encoding. For more distant events, participants were less able to recall extra-event information. The grouping of Distance from Encoding was performed for illustration purposes only. Error bars represent standard error of the mean.

EXPERIMENT 2

Results in Experiment 1 suggested that there was a relationship between the passage of time and boundary flexibility. In this experiment, given the fact that Older Age adults recall fewer internal details than College Age adults, we expected Older Age adults to have more flexible event boundaries than College Age adults when controlling for distance from encoding. Further, we tested whether the differences in hierarchical structure and extra-event information in early childhood in Experiment 1 were due primarily to distance from encoding or age at encoding. If distance from encoding was the critical factor, it should be even more exaggerated in Older Age and Middle Age adults when compared to College Age adults, and we thus expected Older Age adults to show less hierarchical structure and less extra-event information than College and Middle Age adults.

Method

Participants. A total of 36 participants were recruited from the American University community and included 12 Older Age adults (70 years or older; 7 Male, 6 Female, Mean Age: 75.92, Standard Deviation: 4.25), 12 Middle Age adults (40–55 years; 4 M, 8 F, Mean Age: 46.83, *SD*: 4.21), and 12 College Age adults (18–25 years; 1 M, 10 F; Mean Age: 20.92, *SD*: 1.83). All College Age students were undergraduates at American University and all Middle Age and Older Adults were highly educated, the majority of whom were alumni, current faculty, or faculty emeritus at American University. Older and Middle Age adults were compensated at a rate of $10/hour, and College Age Adults received extra credit for their participation as in Experiment 1 or monetary compensation at the same rate as the Older and Middle Age Adults.

Materials, design, and procedure. As in Experiment 1, participants were asked for episodic memories in the modified version of the Autobiographical Memory Interview (Levine et al., 2002). However, the Time Period cues used in each group were slightly different so as to span the entire lifespan. College Age adults received the same time period cues as Experiment 1. Middle Age adults received those cues, and in addition were asked for two memories from Early

Adulthood (19–30 years old). Older Age Adults were asked for the cues from Experiment 1 and in addition were asked for one event from Early Adulthood (19–30 years old) and one event from Middle Adulthood (30–55 years old). Older Age adults and Middle Age adults were asked to give only one event from Childhood (0–11 years old).

All phases in this experiment were the same as Experiment 1 except that another group of questions was added to the Specific Probe phase. In addition to questions about event flexibility beyond event boundaries, participants were asked whether there was a natural beginning point after the initial reported boundary as well as a natural end point prior to the initial reported boundary. This allowed us to measure boundary contraction in addition to the boundary expansion that had been measured in Experiment 1.

Results and discussion

All scoring was performed as in Experiment 1. In addition there was one other score relating to boundary flexibility besides the Flexibility score in Experiment 1 (now called the Expansion Flexibility score). This was the Contraction Flexibility score, also on a 3-point scale, which reflected whether or not participants were able to shrink the event by redefining the beginning or the end. If they were able contract both boundaries, and thus define the event without the original boundaries, the Contraction Flexibility score for that event was 2. If they were able to contract in only one direction the score was 1. If they did not believe there was another meaningful beginning or end point within the event boundaries, the Contraction Flexibility score was 0.

The effect of age and time on boundary flexibility. Again the GEE model was used to investigate the relationship between Age, Distance from Encoding, and Expansion Flexibility Scores. We restricted the analysis to include only those events in which boundary flexibility was possible (Extra-Event Information score of 1 or 2). Time Period was entered as the repeated index with only those time periods that were used as cues in all three age groups (Childhood, Teenage Years, One Year Ago, One Month Ago, One Week Ago, One Day Ago, One Hour Ago).

First, Contraction Flexibility scores were entered as the ordinal response variable, Age Group was entered as between-participants predictor, and Distance from Encoding was entered as a within-participants predictor. There was a main effect of Distance from Encoding (Wald $\chi^2 = 8.36$, $p = .004$), but no effect of age and no interaction. Regardless of age group, participants were less likely to contract event boundaries for more distant events compared to more recent events.

Then Expansion Flexibility scores were entered as the ordinal response variable, Age Group was entered as a between-participants predictor, and Distance from Encoding was entered as a within-participants predictor. There was a main effect of Age Group (Wald $\chi^2 = 10.68$, $p = .005$), and a significant interaction between Distance from Encoding and Age Group (Wald $\chi^2 = 11.97$, $p = .003$). As can be seen in Figure 3, in the case of Age Group, Older Age adults reported more flexible event boundaries than the other groups, with College Age adults reporting the least flexible event boundaries. Also, as seen in Figure 4, while both Middle Age and College Age adults showed increased flexibility with distance, Older Age adults' event boundaries did not become increasingly flexible with distance from encoding. Only when Older Age adults were removed from the analysis, was there a main effect of Distance from Encoding on boundary flexibility ($p = .001$).

Dissociating the effect of time and age at encoding. In order to disentangle the effect of passage of time from that of age of encoding on the presence of extra-event information and on the isolation of the earliest events recalled, we

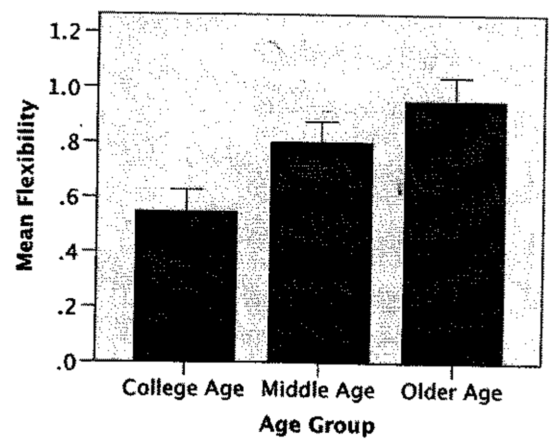

Figure 3. Boundary flexibility as a function of age. For events in which it was possible to move event boundaries (Extra-Event Information > 0), Older Age adults showed more flexible event boundaries ($p = .005$). Error bars represent the standard error of the means.

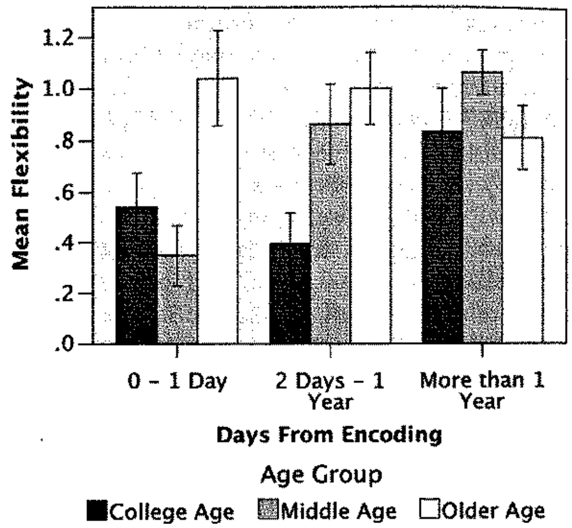

Figure 4. Boundary flexibility as a function of distance from encoding and age. For those events for which participants recalled extra-event information, College Age and Middle Age adults show increases in event flexibility with distance from encoding, while Older Age adults do not show this pattern. Grouping of Distance from Encoding represents approximate tertile for each age group and is for illustration only. Error bars represent the standard error of the means.

looked at events from Childhood and the Teenage years separately. If distance from encoding was the most critical factor in the observed differences for the most distant memories, then an age effect should be present. If the difference was primarily due to age at encoding, then the differences should be consistent from one age group to the next.

It appears that distance from encoding played a critical role in the observed differences, as there was an effect of Age on the amount of Extra-Event Information reported, KW(2, 73) = 10.71, p = .005, as well as on the tendency to report events in the context of a hierarchical structure KW(2, 73) = 10.89, p = .004. Thus Older Age adults reported significantly less Extra-Event Information than College Age and Middle Age adults, and they also reported fewer hierarchical relationships. These findings suggest that age at encoding was not driving these differences in the young cohort from Experiment 1. Instead, as time passes, it becomes increasingly difficult to remember information around an event and to relate an event to other events in memory.

Effect of time and age on Extra-Event Information and hierarchy. As in Experiment 1 we set Extra-Event Information as the ordinal response variable and inserted Distance from Encoding, Age Group, and an interaction term in the model. There was a main effect of Distance from Encoding (Wald $\chi^2 = 56.44$, $p < .001$). There was also a significant interaction between Age Group and Distance from Encoding (Wald $\chi^2 = 16.78$, $p < .001$), with College Age adults showing the steepest decline in extra-event information across Distance from Encoding and Older Age adults showing the most gradual decline. These differences make intuitive sense given the difference in range for Distance from Encoding between groups. In all cases, less Extra-Event Information was recalled for more distant events.

In the case of Hierarchical structure, Distance from Encoding, Emotionality, and Age Group were entered as predictors along with all interaction terms. There was a main effect of Distance from Encoding (Wald $\chi^2 = 17.69$, $p < .001$), with more distant events showing a less-hierarchical structure, and Emotionality (Wald $\chi^2 = 10.47$, $p = .001$), with more emotional events showing a greater hierarchical structure. There was also a significant interaction between Age Group and Distance from Encoding (Wald $\chi^2 = 7.38$, $p = .025$), with College Age adults showing a steeper decline in hierarchical structure across distance from encoding than the other two groups.

Given the difference in gender distribution, all GEE analyses were rerun including gender in the model as a covariate. In all cases there was no main effect of gender and all significant main effects and interactions remained statistically significant after the addition of this participant variable into the model.

We have replicated the findings from Experiment 1 relating to distance from encoding and also demonstrated an effect of age on boundary flexibility. These data further support the notion that factors at retrieval influence how events are defined and redefined in memory. In addition we have demonstrated that the passage of time, rather than the age at encoding, seems to drive the qualitative differences between events from early childhood and events from the recent past.

GENERAL DISCUSSION

Experiment 1 showed that event definitions in memory change with the passage of time and depend on factors at retrieval. When recalling more distant events, participants were less likely to recall Extra-Event Information, but were more likely to redefine an event to include those details that could be remembered. It thus appears that boundary flexibility is related to the passage of time. Experiment 1 also showed that events from childhood were likely to be recalled with fewer hierarchical relationships to other events, and with less Extra-Event Information. From Experiment 1 data it was unclear whether this was due primarily to the distance from encoding, or due to the young age of the participants at the time those events were encoded.

Experiment 2 attempted to identify a relationship between age and boundary flexibility while also disentangling distance from encoding from age at encoding. We replicated the findings from Experiment 1. Especially in the case of College Age and Middle Age adults, event boundaries were increasingly flexible with distance from encoding. It appears that boundary placement in memory can change with time, suggesting that differences at retrieval play a role in defining and redefining events in memory. As one moves farther from encoding, it becomes increasingly likely that the original boundary details will be forgotten and event definitions begin to change. Experiment 2 also showed that, as hypothesised, Older Age adults report more flexible event boundaries than College or Middle Age adults and that differences in extra-event information and hierarchy scores for events from childhood are due primarily to the great distance from encoding during recall, rather than the young age at which they were encoded.

Distance from encoding and event flexibility

In both experiments events in autobiographical memory displayed more flexible event boundaries as distance from encoding increased. For more distant events participants were less likely to recall information beyond event boundaries, but were more likely to redefine events to include extra-event information when it was recalled. From these results it is possible that boundary placement at recall is less reliant on factors at encoding and more akin to the processes involved in time estimation in memory. When estimating time across varying time scales, Friedman and Wilkins (1985) found that participants were most accurate on fine time scales rather than coarse time scales, suggesting that instead of having time as an inherent attribute of a memory, participants inferred it based on the reconstructive process. In the same way, boundaries in memory may not be an inherent attribute of the memory trace, but rather may be imposed at recall based on the reconstructive process. Interestingly, in prior workings of his Self Memory System (SMS) Conway avoided predefined episodic events as memory units (Conway & Pleydell-Pearce, 2000, p. 272). However, in the more recent versions of the SMS model predefined episodic memories with clear boundaries based on the predominant goal lie at the foundation of the episodic hierarchy (Conway, 2005, 2009). Our data suggest that while processes at encoding play a crucial role in initial event definitions, memories may not be in a predefined form at recall.

Effect of age and distance from encoding on event flexibility

Because Older Age adults reported less event-specific detail when recalling autobiographical memories (Levine et al., 2002), we hypothesised that there would be age differences in the flexibility of event boundaries, similar to those observed in Experiment 1. Indeed, our data showed a significant effect of age on event flexibility. In general, Older Age adults were more likely than College Age adults and Middle Age adults to move event boundaries at recall and thus include extra-event information. Interestingly, Zacks et al. (2006) reported differences in the initial segmentation of activity in Older Age adults when compared to College Age adults. The current data suggest that the same abilities that impact event segmentation at encoding may also impact event definitions at retrieval. Perhaps, in both cases, an increased reliance on gist-based processes leads to less-rigid event boundaries and less-specific event definitions.

Although Older Age adults showed more flexible event boundaries in general, they did not show increasingly flexible boundaries with distance from encoding. Whereas College Age adults and Middle Age adults showed increased flexibility with time, Older Age adults had high levels of flexibility for recent events and levels remained high for events throughout their lifespan. Indeed, the pattern shown by Older Age adults was very similar to the pattern in College Age adults for relatively unimportant events. One explanation for these findings is that both scenarios rely more heavily on gist-based reconstructive processes. In the case of Older Age adults the decreased amount of event-specific detail at retrieval leads to gist-based reconstruction. In the same way the less-important events in College Age adults need only be recalled at the gist level and thus show a similar flexibility pattern to that of Older Age adults.

The higher levels of flexibility for recent events, and lower levels for distant events (relative to those of College Age adults, or relative to more important events) is also consistent with the stereotyping that takes place with repeated reconstruction (Bartlett, 1932). For very recent events gist-based reconstruction would decrease the likelihood of recalling the perceptual boundaries. Over long periods of time, however, a memory would develop until eventually clear schema-induced boundaries would surround the stabilised event and define it consistently in all future recall. In support of this point, when comparing the flexibility of event boundaries from childhood, Older Age adults showed significantly more rigid boundaries than College Age and Middle Age adults, KW(2) $=6.66$, $p=.036$.

Effect of distance from encoding on extra-event information and hierarchy

In both experiments there was a clear relationship between Extra-Event Information and Distance from Encoding. Participants were less likely to recall information beyond event boundaries for more distant events. Further, Hierarchy scores showed a similar relationship to Distance from Encoding. For the most distant events participants were less likely to report a hierarchical structure. As previously noted, the differences in hierarchical structure and extra-event information may be due to the rather late development of autobiographical memory (Nelson & Fivush, 2004; Picard, Reffuveille, Eustache, & Piolino, 2009; Piolino, Desgranges, & Eustache, 2009). Children may not have the ability to encode sequential events into their autobiographical memory system in relation to one another, and for that reason each event may become isolated in memory. Conway (2009) suggests that in early childhood, episodic elements do not contain "frames" which would be the theoretical equivalent of the larger encompassing events in the current study. Perhaps, given the lack of full development of a "self" in children, the autobiographical hierarchy is not yet present at an early age, and thus events are not stored in any sort of context (Nelson & Fivush, 2004). Yet, when holding age of encoding constant and examining the data across age groups, we found that Older Age adults reported significantly less extra-event information and less-hierarchical relationships between events, suggesting that the differences in early childhood memories are due primarily to the effect of distance from encoding rather than age at encoding.

Similar to the differences in flexibility observed in Older Age adults, differences in extra-event information and hierarchy scores may be explained in terms of the increased stereotyping that occurs with time and age. Regardless of age group, the impact of time on stereotyping is present in the events reported from early childhood, but in the oldest cohort an additional reliance on reconstructive processes may result in increasingly schematised representations. As time passes, less detail can be recalled and thus fewer surrounding details and events can be recalled, and events shrink to a size where there are no longer sub-events. Although age at encoding may contribute to some differences in extra-event information and hierarchy scores, it appears that distance from encoding is a major contributing factor.

Theoretical implications

Several theoretical models may reconcile the present data with data from past research on event memory. One group of such models relies on the notion that autobiographical memory is made up of discrete representations and these representations are defined during encoding. Such an idea is well represented by Conway's (2009) most recent hierarchical conception of autobiographical memory, with discrete episodes at the bottom of the hierarchy. Another group of models relies on an alternative notion that autobiographical memory is made up of seemingly continuous representations that do not have a time-bound structure. Such an idea could be represented by a previous model of Conway and Pleydell-Pearce (2000), which includes event specific knowledge at the bottom of the hierarchy rather than time-bound episodes. In addition, of course, a combination of these two frameworks is possible where autobiographical memory is made up of some blend of temporally bound episodes and continuous representations.

In accounting for the current data a framework of autobiographical memory that includes only discrete representations may rely on reconsolidation theory (e.g., Hupbach et al., 2007) as an explanation. Each time a discrete episode is recalled it becomes open to alteration and begins to be changed based on the other facts and events accessed during retrieval. This allows the possibility that originally encoded boundaries could be altered when a memory is recalled from a different perspective or within the context of other events. Indeed, a shift in perspective at retrieval can alter the type of information that is retrieved, and even lead to the retrieval of previously inaccessible episodic details (e.g., Anderson & Pichert, 1977). Thus, even when emphasising encoding in the definition of discrete episodes in memory, retrieval processes and retrieval contexts must be considered for a complete description of event memory. Although boundaries are encoded, they may be altered in the process of retrieval as a function of the details recalled and the context in which the event memory is retrieved.

A framework of autobiographical memory that includes only continuous representations may rely on the Basic-Systems Model (Rubin, 2006) in order to explain the current results. The Basic-Systems Model suggests that, instead of all information being assembled and integrated into a single representation at encoding and then stored as a unit, modality-specific details are stored in modality-specific regions of the brain (Rubin, 2006, p. 293). In support of this claim Rubin presents evidence of deficits in sensory aspects of episodic memories when there is focal damage to the sensory systems, even for memories encoded prior to the damage. Further, episodic memory construction and reconstruction rely on an interaction between the proposed "basic systems". Such an interaction could explain the boundary flexibility results of the current study as well as the boundary maintenance results of Ezzyat and Davachi (2011). Specifically, one could argue that when constructing a memory at encoding and reconstructing during retrieval, the same narrative system within the Basic-Systems model could be used. This narrative system would presumably encapsulate the event segmentation model of Zacks et al. (2001). In this way a similar event segmentation system, including the event schemata and event models, would be active during encoding as well as during retrieval. Thus, when the reconstructed information reflects the originally perceived information, boundaries are perceived in the same location. However, as reconstruction becomes more stereotyped (e.g., Bartlett, 1932), and event schemata in the narrative system are updated and modified (cf., Zacks et al., 2007), the retrieved information becomes less and less reflective of the originally perceived information, and boundaries become more arbitrary. Thus, with time and age, boundary locations become more flexible as they become less reliant on the actual episodic details.

Because of the inherent difficulties in dissociating encoding from retrieval in general (cf. Watkins, 1978), teasing apart the utility of discrete and continuous representation frameworks with respect to boundary flexibility would indeed be a daunting task. One starting point, however, might be to focus on the narrative schemata during retrieval to identify boundary locations, the influence of which would be unique to the continuous representation framework. If such schemata could be manipulated between encoding and "first" retrieval (prior to any reconsolidation), the two frameworks would have opposing predictions. The discrete representation framework would predict that the event memory would include the originally perceived boundaries whereas the continuous representation framework would predict that the event memory would be recalled with boundaries that reflect the altered narrative schema. The current data do not favour either framework, and perhaps the best framework would include some combination of the two.

Limitations

Our primary measure of boundary flexibility reflects the likelihood that a participant, when prodded, would alter an event definition by redefining the location of an event boundary. The premise of such a measure is that the likelihood of redefining an event boundary should be directly related to the certainty of the originally reported boundary location. We predicted that boundary locations would become increasingly arbitrary as episodic detail was lost, and in such scenarios participants would become more open to redefining the events when reconsidering boundary locations. For this reason, what we call boundary "flexibility" could also be thought of as boundary indeterminacy. Our measure is intended to tap into what the participant believes to be the beginning and end points and to indicate the stability of such a point when prodded to reconsider its location. However, this initial attempt at measuring the flexibility or determinacy of event boundaries must be interpreted within the context of the inherent limitations of our method.

One such limitation in our boundary measure is a general limitation inherent in cue-based autobiographical memory techniques: a reliance on self-report measures. Indeed, such measures may be influenced by personality (Rubin & Siegler, 2004), and self-reported details may be influenced by factors at retrieval such as misinformation (e.g., Loftus, 1979a). However, in support of using such measures, self-reports during autobiographical recall appear to reflect the neural processing that takes place during retrieval, and the changes in neural function that take place over the course of normal ageing and dementia. For example, ratings of emotionality are correlated with activation in emotional-relevant brain structures including the amygdala and somatosensory cortex, and ratings of reliving are related to activation in brain regions involved in visual imagery including the extrastriate cortex (Daselaar et al., 2008). In addition, when counting and categorising self-reported details during retrieval, age-related differences emerge that reflect differences on objective measures of memory (Levine et al., 2002), and self-reported measures of autonoetic experience reflect deficits in line with objectively observed memory impairments in semantic dementia and Alzheimer's disease (e.g., Piolino et al., 2003).

Our self-reported measures of boundary location and flexibility likely reflect a similar mix of true characteristics of a memory representation in addition to personality biases and demand characteristics inherent to the interview process. Further, despite the same inherent limitations in the perceptual boundary literature, research has indeed produced meaningful results showing that boundary definitions appear to be consistent from one person to the next and influenced by perceptual characteristics of a given scene (Newtson, Engquist, & Bois, 1977). There is no reason to believe that the self-reported nature of event definitions during memory scenarios would be any less reliable than the self-reported event definitions reported in perceptual scenarios, although of course more work is needed to verify this claim. It is clear from the current data that time and age impact the likelihood of redefining events to include detail initially reported to be outside of that event. However, the findings in the current work must be interpreted in the context of the interview itself and the inherent limitations of self-report measures.

Conclusions

We have explored changes in event boundaries and thus event definitions at retrieval in relation to time, age, and subjective qualities of a memory. It appears that although episodic memories may be initially defined at encoding in line with Event Segmentation Theory (Reynolds et al., 2007), these definitions are not necessarily maintained in long-term memory. This finding is especially interesting given the recent suggestion that event definitions are maintained in episodic memory (Ezzyat & Davachi, 2011). Encoding plays a crucial part in how episodic memories are defined, but encoding alone cannot explain the current findings. We have shown that two predictors of event boundary flexibility are distance from encoding and age. As one gets older all event boundaries appear to be increasingly flexible, and similarly although regardless of age, memories from the distant past appear to be increasingly flexible.

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