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Memory for Episodic Details of Naturalistic Events Remains Stable Over the Course of One Week

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Abstract

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We have many experiences every day, and we tend to parse them into individual events. While many studies have been conducted to understand the nature of event segmentation, less is known how event memories change over time. In the present study, participants watched a movie clip, and then were asked to immediately retell what they had seen. They performed the same free re-call task a week later. We found that the passage of time did not significantly affect the number of recalled events or the detailedness of event memories. We discuss potential explanations for our findings, including our small sample size and flaws in the experimental design.

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1. Introduction

On any given day, we have many experiences which can range from mundane (e.g. going to work)to highly significant (e.g. getting married). Our ability to recall these experiences is known as episodic memory (Tulving, 1972; 2002). The constituents of each episode include a time and place as well as characters, actions and causal relationships (Baldassano, Hasson, & Norman 2018). While episodes are assumed to be stored in memory as individual units or chunks, we do not initially experience them as discrete events but rather as a continuous stream of incoming information. Because of this discrepancy, we do not fully understand how we are able to recall episodes as distinct units.

According to event segmentation theory (EST), we parse continuous experiences into discrete events (Reynolds, Zacks, & Braver, 2007). The theory further posits that this segmentation process is guided by active mental models of the content and relational (temporal, spatial, causal) structure of an ongoing event. Event models are structured representations of events that are used to gain information about time, location, and other important features of a situation (Richmond & Zacks, 2017). However, event models are not simply based on the current situation. Rather, evidence suggests that event models also involve schematic knowledge of how the world is structured (Baldassano et. al., 2018). For example, if you arrive at a restaurant, your model of this event involves not only the current features of the event—specific time of day, number of people in the restaurant, etc.—but also your expectation about what typically happens during a restaurant visit, e.g., that soon after being seated, a server will bring you a menu. This expectation is not based on the current situation, but on knowledge acquired from previous experience at restaurants. According to a prominent view, event models are updated when the current sensory input violates our expectations, i.e., when a prediction error occurs (Reynolds et al., 2007; Zacks, Speer, Swallow, Braver, & Reynolds, 2007). This updating process generates an event boundary, the point at which one event ends and the next begins. Event boundaries are thought to trigger rapid retroactive encoding of the prior experience into a discretized episodic memory trace, allowing the event model to be later reinstated (e.g., Baldassano, Chen, Zadbood, Pillow, Hasson, & Norman 2017). There is, however, some debate as to how event boundaries are determined. Others have argued that contextual stability (e.g., temporal, spatial)—rather than prediction errors per se—dictate event boundaries (Clewett & Davachi, 2017; for a theory that integrates the latter account into the former, see Franklin, Norman, Ranganath, Zacks, & Gersman, 2020). The latter view assumes continuous, proactive binding of the elements of experience that is interrupted by boundaries. Both perspectives agree that event boundaries coincide with changes in salient features, temporal and spatial regularities, or causal relationships in the environment.

Explicit judgements about event boundaries in narratives, movies, or action sequences have been found to be highly consistent across human observers and coincide with shifts in the stability of fMRI and EEG activity patterns (Baldassano et al., 2017; Silva, Baldassano, & Fuentemilla, 2019). That is, each episodic event is associated with a unique neural signature, resulting in a stable pattern of neural activity throughout that same event despite variation in the ongoing sensory input.

Importantly, the representational structure that is created during perception has been shown to exert a profound impact on the recall of past events (Baldassano et al., 2017; Chen, Leong, Honey, Yong, Norman, & Hasson, 2017; Silva et al., 2019). Perceived event boundaries coincide with two (potentially related) phenomena that are predictive of later recall: (a) spikes in hippocampal activity and (b) rapid replay of the just-encoded event. Boundary-related activity bursts in hippocampal activity are larger for events that are later remembered relative to those that are forgotten, indicating that the hippocampus forms an episodic memory representation of the just-concluded event that can be later retrieved into the same cortical regions that encoded the event during perception. Indeed, event-specific brain activity patterns have been found to be reactivated during successful subsequent recall of an event–although undergoing systematic transformation (reorganization) from perception to recall (Baldassano et al., 2017; Ben-Yakov & Henson, 2018; Chen et al., 2017). Studies capitalizing on the high temporal resolution of scalp EEG recordings have revealed that event boundaries trigger a rapid reinstatement of the neural activity patterns elicited by the just-concluded event (Silva et al., 2019; Sols, DuBrow, Davachi, & Fuentemilla, 2017). This replay is thought to serve the strengthening of the just encoded memory trace and/or the integration of the discrete events into a temporally coherent memory sequence. Further evidence for the influence of event segmentation on episodic memory formation comes from studies showing that memory for individual items and their temporal order is enhanced if those items are experienced within the same event rather than across different events (i.e., divided by an event boundary; e.g., Ezzyat & Davachi, 2011; Radvansky & Copeland, 2006). Moreover, the better an individual's segmentation agrees with the average segmentation pattern of a given reference group, the better their memory for the corresponding events (e.g., Sargent et al., 2013).

While there is considerable evidence to support the view that event segmentation plays a pivotal role for the formation of naturalistic event memories, fewer studies have investigated how these memories change over time (e.g., Conway, Cohen, & Stanhope, 1991; Furman, Dorfman, Hasson, Davachi, & Dudai, 2007; Sekeres, Bonasia, St-Laurent, Pishdadian, Winocur, Grady, & Moscovitch, 2016). In particular, our understanding of how consolidation and forgetting transform naturalistic event memories lags behind the knowledge of time-dependent changes in memories for discrete stimuli, such as single words or pictures. Previous work has shown that contextual details of complex memoranda such as narratives or autobiographical memories are lost at a faster rate than central elements (“gist”) of the original experience (e.g., Bahrick, 1984; Sekeres et al., 2016; Thorndyke, 1977). Furman, Dorfman, Hasson, Davachi, & Dudai (2007) conducted a study in which participants watched a 27 min movie clip and then performed a cued recall test a time ranging from 3 hours to 9 months after watching the film. The researchers found that while memory for the central events of the movie was retained even months after participants watched the movie, recall accuracy was higher when less time had passed between watching the movie and taking the test. Similar findings were reported in another study that used multiple brief film clips to probe the fate of event memories over time (Sekeres et al., 2016). Over the course of one week, memory for the peripheral details of events contained in the film clips declined rapidly, while memory for the central themes—the “gist” of the events—was largely retained.

The above findings are consistent with prevailing theories of memory consolidation. Consolidation is the process by which memories become stronger over time, as they are stored in long-term memory (Dewar et. al., 2014; Dudai, 2004). Researchers distinguish at least two kinds of consolidation. The first one is known as synaptic consolidation (Dudai, 2004). Synaptic consolidation occurs in the hippocampus within minutes to hours after learning (Dudai, 2004). The second type of consolidation is systems consolidation. This latter consolidation process is thought to operate on a much longer timescale of days to years and involves a reorganization of memory representations at the brain systems level. All episodic memories are assumed to initially depend on the hippocampus, which links together disparate representations from multiple cortical areas. During systems consolidation, hippocampal-cortical interactions result in memories to be increasingly supported by distributed cortical areas (Nadel, Samsonovitch, Ryan, & Moscovitch, 2000; Squire, Genzel, Wixted, & Morris 2015). At least three models on the nature of such hippocampal-cortical dialogue have been proposed. One model suggests that hippocampal "replay" of memories, i.e., their coordinated reactivation across hippocampus and cortex during sleep or wakeful rest results in strengthening of the corresponding cortical linkages (e.g., Alvarez & Squire, 1994). Other models posit that consolidation is accompanied by changes in the nature of the memories (McClelland et al., 1995; Winocur & Moscovitch 2011). Trace transformation theory (TTT, Moscovitch, Cabeza, Winocur, & Nadel, 2016) suggests that repeated reactivations of episodic memories result in transformation of the initial memory trace into new traces that retain and schematic features but fewer episodic and contextual details. Unlike the original detailed memories that remain dependent on the hippocampus, the transformed memories are represented outside of the hippocampus in distributed cortical networks. Similarly, the complementary learning systems (CLS; McClelland et al., 1995) theory proposes that hippocampal replay enables slow extraction of commonalities across overlapping experiences, thereby integrating newly acquired memories into preexisting schemas that are represented in the cortex. Notably, the latter two theories assume that consolidation involves some form of generalization such that not all details of the original episodic memory trace are maintained.

However, how consolidation-related processes change the nature of naturalistic event representations is less clear (Sekeres et al., 2018). In order to address this question, we recorded EEG while participants were watching a 33-minute movie clip followed immediately by a free recall test. They were asked to come in again a week later for another recall test. Rather than focusing on the EEG measures, this thesis asked how the passage of time would affect the ability to remember episodic details reflecting time, locations, perceptions, thoughts, and temporal integration (Levine, Svobota, Hay, Winocur & Moscovitch, 2002). Based on this evidence reviewed above, we predicted that the content of remembered events would be less rich after a week delay, meaning that fewer details would be remembered.

2. Methods

2.1 Participants

We collected data from a total of 35 participants but a technical defect rendered audio data from 22 participants unusable. The final sample thus consisted of 13 young adults (12 right-handed, 5 female, age range 18-26 years, mean age 21.84 years) who had never seen the movie or read the novel “Howl’s Moving Castle”. Participants were recruited from a subject pool of students who were enrolled in an introductory psychology course or were recruited from the Queens College campus community. They participated for course credit or were paid $15 per hour. All participants were proficient in English, with no history of psychiatric or neurological disorders, and had normal or corrected-to-normal vision. Informed consent was obtained from all participants in accordance with the Institutional Review Board (IRB) of Queens College.

2.2 Stimuli

The movie stimulus was a 33-min segment of the animated fantasy film “Howl’s Moving Castle” (Studio Ghibli, 2004). The full movie is 1h 59 mins long and tells the story of an insecure young girl named Sophie who is turned into an old woman by a spiteful witch. Sophie encounters a wizard named Howl who she falls in love with. The bond makes both of them grow personally and eventually proves to be the key to breaking the witch’s spell. The movie clip was presented in 3 segments of ~10 mins each, divided by self-paced breaks. Timing of the two breaks are chosen to align with event boundaries in the movie (determined by independent adult raters, see below). This was done as a cautionary measure to reduce the risks of artifacts in the EEG data (e.g., due to movement).

2.3 Experimental Procedure

The procedure was adopted from a previous study by Chen and colleagues (2017). Participants watched the first 33 minutes of "Howl's Moving Castle" in English. They were given minimal instructions, but were told to watch the movie as though it was a movie they were interested in. They were also told that they would be asked to verbally describe the movie afterwards. Following the end of the movie, participants were asked to count aloud from 1 to 100[1]. Next, they were asked to freely recall the movie clip without cues, while their speech was being recorded (*immediate recall*). Participants were instructed to retell what they had just seen in as much detail as possible, to relate events in the order in which they occurred, and to try to speak for at least ten minutes. They were told that completeness and detail were more important than exact order, and that if at any point they realized they had forgotten something, to go back and recount it. Participants were then allowed to speak for as long as they wished, and verbally indicated when they had finished by saying something like "I'm done." While they were speaking, they were presented with a static black screen with a central white dot, but were not asked to fixate on the dot. There was no interaction with the experimenter until the participant was finished speaking. At the end of the free recall session, were instructed not to talk to anyone about the movie they saw, and were asked not to look up any information about the movie, or the book on which it was based. Participants returned approximately 7 days later to perform a second free recall session (*delayed recall*). The procedure was the same as for the first free recall session.

[1] The counting data is used to identify speech-related artifacts in the EEG recall data by means of independent component analysis.

Presentation® software (Neurobehavioral System, version 21.0) was used to display the movie stimulus and to synchronize stimulus onset with the EEG recoding. The movie's audio signal was delivered using in-ear headphones (ER1, Etymotic Research, Inc.). Participants' speech was recorded using a microphone and Presentation's built-in audio recording feature (AudioRecorder). The movie was presented on a 27-inch TFT monitor. Participants were seated about 90 cm (35 inches) away from the screen.

2.4 Event Coding and Verbal Recall Data Analysis

In order to determine event boundaries in the original movie clip, five independent raters, who did not take part in the study, were asked to watch the movie and then annotate—as precisely as possible—the time point at which the scene changed (cf. Silva et al., 2019). These are points at which there is a major change in topic, time, or location. We also asked raters to write down a short title for each event. An event boundary was deemed reliable and included in the analysis if at least 3 out of the 5 raters agreed on the temporal point at which it happened (within +- 3 seconds). Using these criteria, we obtained a list of 56 events for the 33-min movie segment. Event length ranged from 5 secs to 116 secs (M = 28 secs, SD = 19 secs).

The length of the audio recordings for the first recall session ranged from 3 to 19 minutes, with a mean recall time of 10 minutes. Recall length for the delayed recall session was very similar, ranging from 3 to 24 minutes, with a mean of 10 minutes. Audio recordings for both sessions were transcribed (see Appendix, for an example) and then analyzed in order to access overall recall performance (percentage of movie events recalled) and amount of details in the memory reports. Each of the 56 events from the list described above was classified as recalled if the participant remembered any part of it. For each participant, we calculated the percent of events recalled in each session. An event was classified as being out-of-order if it was recalled in an earlier or later position of the storyline compared to when it actually occurred in the movie. We also examined whether participants recalled any information that was not part of the movie (false memories). In the immediate recall condition, 9 out of 13 participants remembered at least one detail that wasn't in the movie with an average of 1.85 false memories (*SD* = 2.19). In the delayed recall condition, 10 out of 13 participants recalled at least one detail that was not present in the movie with an average of 2.62 false memories (*SD* = 3.07). In all cases, the false memory concerned minor details, usually a detail about a feature of an event e.g., the appearance of an object or a detail about a character e.g. the character's appearance or relationship to the protagonist. One participant had an unusually high number of false memories in both the immediate and delayed recall conditions (7 and 11 false memories respectively). To ensure that the high number of false memories did not bias our results, we performed all analyses excluding this participant, and found that the results did not change.

In order to determine how the passage of time effected the amount of event details participants recalled, we scored each sentence of the recall transcripts using five dimensions as defined by Levine et. al., (2002; see Table 1). Every sentence in a given participant's transcript was given a score from 0 to 3 in order to rate the richness of the informational bits. A score of 3 was given if the description was rich, highly specific, evocative and/or vivid, and appeared to emerge from a feeling of re-experiencing. A score of 2 was given if the description was detailed, but fell short in the degree of richness and so could not be given a score of 3. A score of 1 was given if the description was limited to general, non-specific information but was still episodic. A score of 0 was given if no information was provided for the specified dimension, if the information was semantic rather than episodic, or if erroneous information was recalled. We use the term *semantic* to refer to information that reflected the participant's general knowledge and did not require recollection of the movie contents as such. The scores for each dimension were summed, resulting in five scores per participant. Table 2 shows sample scores for three participants describing the same event.

Table 1. Description of the dimensions used to analyze event contents.

Dimension	**Description**
Time	Year, season, month, day of week, time of day
Place	Localization of an event, including, city, street, building, room, part of room
Perceptual	Auditory, olfactory, tactile, taste, visual and visual details, body position
Thought/Emotion	Emotional state, thoughts, implications
Temporal Integration	Integration into a larger timescale as evidenced by inclusion of temporal contextual Information

Table 2. Sample Scores for Three Sentences Describing an Event.

Recalled contents	Time	Place	Perceptual	Thought Emotion	Temporal Integration
She runs into these two guards and then they try to talk to her.	0	0	0	0	0
She looks at the guards and the guards try to have their way with her.	0	0	2	0	0
And as she's walking, she goes down an alleyway where she's confronted by two guards, which try to advance on her making her feel uncomfortable and threatened.	0	3	1	3	0

2.5 Statistical Analysis

In order to analyze whether the percent of events recalled by participants was significantly different between the immediate and delayed recall conditions, we performed the Wilcoxon signed-rank test with testing session as the independent variable and percent of events recalled as the dependent variable. In order to determine whether the richness of events changed significantly from immediate to delayed recall, we performed Wilcoxon signed-rank tests with testing session as the independent variable and the summed scores for the given dimension as the dependent variable. Type-I error rate was set to $\alpha = .05$. Bonferroni correction was used to control for Type-I error accumulation due to multiple testing by dividing the nominal error rate by the number of tests performed. Effect sizes, r, were calculated from the normal approximation of the distribution of the test statistic as $r = \frac{z}{\sqrt{N}}$.

3. Results

During the immediate recall condition, participants were able to remember an average of 51.2% of the events (*SD* = 16%). In the delayed recall condition, participants were able to recall an average of 48.9% of the events (*SD* = 17%). There was no significant difference in the percent of events recalled by participants between the immediate (*Mdn* = 55.4%) and delayed (*Mdn* = 53.6%) recall conditions, $V = 54.5$, $p = 0.53$, $r = -.17$. This result suggests that time between testing sessions did not have an effect on the percent of events recalled by participants.

Table 3. Summed Scores and Test Statistics for Remembered Event Details from Immediate vs. Delayed Recall.

Dimension	**Immediate Recall *Md (IQR)***	**Delayed Recall *Md (IQR)***	***p*-value**	***r***
Time	3 (2)	3 (3)	0.69	-0.11
Place	23 (31)	24 (30)	0.21	-0.35
Perceptual	50 (91)	65 (74)	0.97	-0.007
Thought/Emotion	16 (46)	15 (43)	0.78	-0.08
Temporal Integration	19 (24)	19 (31)	0.41	-0.23

Note: Md = Median, IQR = Interquartile Range.

Table 3 shows the summed detail scores for each of the five event dimensions (time, place, perceptual, thought/emotions, temporal integration). The median summed score for each dimension in each condition is also reported. For none of the dimensions, Wilcoxon signed-rank tests revealed a significant difference between the immediate and delayed recall. These results suggest that time between sessions did not have an effect on the richness of events recalled by participants.

4. Discussion

The present study sought to understand how the passage of time affects memory for details of naturalistic events. We found that over the course of one week neither the overall number of recalled events from an audiovisual movie nor the detailedness of memories changed.

The former finding is broadly consistent with an earlier study that used similar stimulus material but probed event memory with a cued recall task (Furman et al., 2007). In particular, the aforementioned study did not find memory performance differences between groups of participants that were tested 3 hours vs. 1 week after viewing the movie, whereas recall accuracy steadily declined from 1 week to 3 weeks to several months post initial encoding. Thus, the present study might have revealed changes in event recall performance over time if memory had been tested after longer delays. There is, however, there is a crucial difference in the way memory was assessed in our study (free recall) and in that by Furman and colleagues (cued recall). Providing recall cues has been shown to substantially enhance naturalistic memory performance in previous work (Robin and Moscovitch, 2014; Sekeres et al., 2016; Winocur et al., 1981). Indeed, Sekeres and colleagues (2016) observed a significant decline in memory performance over a time course of 7 days for both central elements of naturalistic film clips and peripheral details. Although the authors did not segment the movies into events as defined in the present study, their findings suggest a rather broad decline in memory over time that is likely to affect retrieval success for whole events.

Which factors might account for the divergent findings? One possible cause is that Sekeres and colleagues (2016) used a total of 40 short, unrelated film clips as stimulus material, whereas participants in our study watched a single, coherent movie segment. Previous research has consistently shown superior recall performance for information that is presented as a narrative, including novels, movies, and plays (Cohen, 1996; Lichtenstein and Brewer, 1989; Rubin 1977). As such, memory for the longer movie clip could have benefitted from its inherent thematic structure that can be linked to preexisting event schemas and socially relevant knowledge (cf. Furman et al., 2007).

Another plausible reason for the high delayed memory performance in the present study is that participants actively retrieved the movie contents immediately after encoding. The so-called “testing effect”—better retention due to repeated retrieval or restudying of the to-be-remembered material—is a robust phenomenon that has been observed across multiple memory domains (e.g., Wheeler et al., 2003; Carpenter and Pashler, 2007; Carpenter et al., 2006). In order to prevent the testing effect from biasing findings of time-dependent changes in memory, studies typically either test only subsets of the initially encoded stimulus material at different delays or use a between-subjects design with each group’s recall performance measured at a single delay only. We decided against these options for two main reasons. First and foremost, the present study aims to use event-specific multivariate EEG activation patterns to track changes in neural event representations from immediate to delayed recall. This comparison is harder to implement when using different sets of events in the two recall sessions. A potential workaround could be to combine representational similarity analysis (RSA, Kriegestorte & Lievit, 2013) with natural language processing tools, such as sentence embedding[2], to determine whether events with higher semantic overlap come to be represented more similarly over time.

Second the data reported here are part of a larger developmental project that compares naturalistic event memory in children and young adults. Testing participants repeatedly with subsets of the original stimulus material would require at least two movie segments and thus increase the duration of the experiment to an extent that is unsuitable for younger participants. Alternatively, using a between-subjects design would dramatically increase the required sample size and reduce power.

Still, the current findings highlight the shortcomings of the chosen approach and call for reconsideration of the study design. Thus, future experiments could use an alternative design in which two movies are used as experimental stimuli. Participants would watch both movies, and then perform an immediate free recall test for only one of them. Later, they would perform a second recall test for the other movie. The order of recall would be counterbalanced across participants. This type of design would allow researchers to understand how time effects event memory without the immediate recall session serving as a way of rehearsing the events.

Finally, we cannot exclude the possibility that participants did seek information about the movie after completing the first session, despite being asked not to do so. In order to avoid this potential confound, future studies could use of a movie stimulus that is not available outside the lab—although this solution is not trivial to implement.

[2] Sentence embedding denotes a collection of machine learning algorithms aimed at quantifying semantic similarities between sentences or paragraphs based on their distributional properties in large corpora of language data using numerical values (vectors; e.g., Cer et al., 2018).

Perhaps more puzzling was our finding that the passage of time did not have an effect on the ability to recall episodic details pertaining to time, place, perceptual features, thoughts, and emotions. The present result contrasts with a considerable body of previous evidence that peripheral details are susceptible to rapid forgetting (e.g., Bahrick, 1984; Sekeres et al., 2016; Thorndyke, 1977). Again, the testing effect provides a plausible explanation. Immediate retrieval of the movie contents could have preserved not only memory for the central elements, i.e., events, but also the fine details. One piece of evidence that may support this explanation is that participants oftin recalled many of the same details in the delayed recall condition as in the immediate recall condition including the major events in the narrative, as well as details that were not directly related to the events of the story e.g. character's' physical appearances. Indeed, participants who recalled a detail that was not present in the movie—a false memory—in the immediate recall condition recalled the same detail in the delayed recall condition. Additionally, event recall was far from perfect during immediate recall (just above 50% of the original movie events) but then remained virtually stable over the course of a week, indicating that initial retrieval immunized the memory trace against further degradation or transformation. Although the precise mechanisms underlying this mnemonic benefit remain somewhat hazy (Carpenter, 2009; Pyc and Rawson, 2007), the current findings is consistent with theories of memory consolidation that emphasize the co-existence of both detailed and gist-like memory traces (Winocur and Moscovitch, 2011). Such a conclusion, however, warrants caution given that the recall delay in this study was relatively short (7 days), while systems consolidation in humans is typically thought to operate on timescales of multiple weeks to several years.

Since systems consolidation is thought to be accompanied by changes in the structure of neural memory representations (Dudai 2004; Squires et. al., 2015), the EEG data collected in this study might provide valuable further insights. Time-dependent transformation of memory representations between immediate and delayed recall should be reflected in systematic changes of event-specific brain patterns (cf. Baldassano et. al., 2017, Silva et. al., 2019). Such changes are typically measured using representational similarity analysis approaches, in which spatio-temporal activity patterns, i.e., matrices of raw voltages across electrodes and timepoints, are correlated (a) within vs. across event boundaries and (b) between viewing vs. recall of a given event. Neural measures might be more sensitive to potential subtle effects of short-term memory reorganization during the consolidation period than the reported behavioral measures.

A few general methodological weaknesses of the current study further limit the generalizability of our findings and thus are discussed in the following. First, our final sample size was very small. Although adequate sample size is important for having sufficient statistical power to detect an effect (Cohen, 1992), the very small effect size estimates for the reported analyses suggest that lack of power was not the primary issue in this investigation. The only exception was spatial details (place), with a small to medium effect size estimate ($r = -0.35$). Still, the experiment needs to be repeated with a larger sample, potentially using a modified design as detailed above. Other potential issues arise from the scale that was used to characterize the richness of event details recalled by participants (Levine et al., 2002). The scale was devised to study autobiographical memory and therefore might not be quite adequate for the narrative quality of the movie stimulus used in the present study. Some of the dimensions used in the scale—particularly time —could be difficult to relate when retelling a narrative that is not about oneself because it can be difficult to gain information about these dimensions from a movie. For example, in an autobiographical memory, one might say something like, “I remember it was a Saturday morning in autumn”… However, there seemed to be very little indication of these details in the movie we chose. There are two possible solutions to this problem. One is to be more rigorous in selecting the experimental stimulus, choosing movies where there are very clear indications of time. This could include a visual cue—such as the leaves changing colors, indicating that it's autumn—or auditory cues—such as a character in the film explicitly stating that it's Saturday. However, this could limit the types of films used to study event richness. A more comprehensive solution may be to modify the scale used by Levine et. al., (2002), so it is more appropriate for studying naturalistic memory. For example, the definitions of dimensions such as time could be modified, or simply not included. Alternatively, different scoring methods, such as implemented in the Rivermead Behavioral Memory Test (Wilson, Cockburn, & Baddeley, 1991) could be used. Furthermore, subjectivity of the ratings themselves could be problematic. Future studies should include multiple raters for each participant to assess interrater-reliability. Another problem with the scale is that it does not differentiate between central and peripheral details. Previous studies have found that central details and "gist-like" memories are not forgotten at the same rate (Sekeres et al., 2016). It is possible that the central details of the narrative would remain stable over time, while the peripheral details would be forgotten. Future studies should differentiate between central and peripheral details in order to determine if both types would remain stable. In order to accomplish this, central and peripheral details would need to be defined. A central detail could be defined as any detail that is critical to understanding the events of a given narrative (Sekeres et al., 2016; Thorndyke 1977), while a peripheral detail could be defined as any detail that is part of the narrative, but not critical for understanding an event. Using these definitions, individual transcripts of participants could be analyzed to determine how many of each detail type they remembered in both the immediate and delayed recall conditions.

5. Conclusion

The present study sought to understand how the passage of time effects memory for episodic details of naturalistic events. We found that the passage of time did not significantly affect any of the variables studied. Future studies should use a larger sample and a modified method to score details from participants' recall data, as well as an alternative design using two movies as stimuli to avoid testing effects.

6. Appendix

Sample Transcript Movie Recall

Okay, so the movie started with the castle moving through the fog, the giant castle with a bunch of different moving parts. And then the scene changed over to a village or town or seemed like a city actually. We were then introduced to Sophie who works at a hatter shop. So basically you meet Sophie in a hatter's shop. She seems to be a little disappointed in her life. We then meet Howl because Sophie was going to go visit her sister at the bakery. And while she was on her way to the bakery, these two soldiers walked up to her and they were trying to flirt with her. But then Howl came and used a spell to make them walk away, and leave her alone, and then he took her and they started flying through the air as they were evading these different blob creatures. Afterwards, he dropped her off at—he dropped Sophie off at her sister's bakery. And her and her sister were talking. Her sister was telling her she doesn't have to work at the Hatters shop anymore. She should do what she wants what she wants with her life. That's all. So, what happened after that? After that, Sophie went back to the Hatter shop, it was late at night, and then the witch came in and cast a spell on her turning her old. Sophie started to freak out. She was pacing back and forth. And she was just kind of hoping that this whole thing was a, was a bad dream, but she woke up the next day and she was the same person, and her mother then walks up the stairs and she wants to go see her daughter, but Sophie tells her don't come in, I have a cold. Sophie then gets dressed up and takes some food and then decides to go to the wastelands to go find Howler because she knows he's the only way that she could get back to normal. On the way there she meets a scarecrow with a turnip head. She told the scarecrow that she didn't like turnips since she was a kid. What else? Then Howl's castle appeared. She went in and then she met, she met Calcifer the fire demon. And they made a pact together that they would help each other to break each other's spells. Then Sophie woke up the next morning and there was a child who walked down the stairs who was able to turn into…who uses a spell to shapeshift himself into an older man. And the government started to knock on their door and there's many different doors that they handle. There's a knob that allows them to switch between these doors. There's a door that goes to the main, the Royal city. Then there's a door that goes to the wastelands which was part of Howl's castle. And then there was a door for the Grand Wizard. And basically, the government was at their door telling them because Howl poses as different wizards so the government wants him to fight the war that was just declared. So after that, Sophie was like playing with the door,

she was seeing all the different places that you could go to. But then the child gets angry and then they decided to have breakfast, and Sophie manipulates Calcifer into making breakfast by blackmailing him, and as she's making breakfast Howl walks in and it's the same wizard as before that she had, that she had flown with. Then Howler takes, Howl makes breakfast for all of them. And Marco who was the little boy says he hasn't eaten this great in a while.
And then after that…that was really good. All right, done.

7. References

Alvarez, P. & Squire, L. R. (1994). Memory consolidation and the medial temporal lobe: A simple network model. *Proceedings of the National Academy of Sciences of te United States of America, 91*, 7041-7045.

Bahrick, H.P. (1984). Semantic memory content in permastore: fifty years of memory for Spanish learned in school. *Journal of Experimental Psychology: General, 113*, 1–29.

Baldassano, C., Chen, J., Zadbood, A., Pillow, J. W., Hasson, U., & Norman, K. A. (2017). Discovering event structure in continuous narrative perception and memory. *Neuron*, *95*, 709-721.

Baldassano, C., Hasson, U., & Norman, K. A. (2018). Representation of real-world event schemas during narrative perception. *Journal of Neuroscience*, *38*, 9689-9699.

Ben-Yakov, A. & Henson, R. N. (2018). The Hippocampal Film Editor: Sensitivity and Specificity to Event Boundaries in Continuous Experience. *Journal of Neuroscience, 38*, 10057-10068.

Carpenter, S. K. (2009). Cue strength as a moderator of the testing effect: the benefits of elaborative retrieval. *Journal of Experimental: Learning, Memory, & Cognition, 35*, 1563–1569.

Carpenter, S. K. & Pashler, H. (2007). Testing beyond words: using tests to enhance visuospatial map learning. *Psychonomic Bulletin & Review, 14*, 474–478.

Carpenter SK, Pashler H, Vul E. 2006. What types of learning are enhanced by a cued recall test? *Psychonomic Bulletin & Review, 13*, 826–830.

Cer, D., Yang, Y., Kong, S., Hua, N., Limtiaco, N., St John, R., Constant, N., Guajardo-Cespedes, M., Yuan, S., & Tar, C. (2018). Universal sentence encoder. *arXiv preprint arXiv:1803.11175*.

Chen, J., Leong, Y. C., Honey, C. J., Yong, C. H., Norman, K. A., & Hasson, U. (2017). Shared memories reveal shared structure in neural activity across individuals. *Nature Neuroscience*, *20*, 115-125.

Clewett, D., & Davachi, L. (2017). The ebb and flow of experience determines the temporal structure of memory. *Current Opinion in Behavioral Sciences*, *17*, 186-193.

Cohen, J. (1992). Statistical power analysis. *Current Directions in Psychological Science*, *1*, 98-101.

Cohen, G. (1996). *Memory in the real world*. (2nd ed.). Hove, UK: Psychology Press.

Conway, M. A., Cohen, G., & Stanhope, N. (1991). On the very long-term retention of knowledge acquired through formal education: twelve years of cognitive psychology. *Journal of Experimental Psychology: General*, 120, 395–409.

Dewar, M., Alber, J., Cowan, N., & Della Sala, S. (2014). Boosting long-term memory via wakeful rest: intentional rehearsal is not necessary, consolidation is sufficient. *PloS one*, *9*, e109542.

Dudai, Y. (2004). The neurobiology of consolidations, or, how stable is the engram?. *Annual Review Psychology*, *55*, 51-86.

Franklin, N. T., Norman, K. A., Ranganath, C., Zacks, J. M., & Gershman, S. J. (2020). Structured event memory: a neuro-symbolic model of event cognition. *Psychological Review*, *127*, 327–361.

Ezzyat, Y., & Davachi, L. (2011). What constitutes an episode in episodic memory? *Psychological science*, *22*, 243-252.

Furman, O., Dorfman, N., Hasson, U., Davachi, L., & Dudai, Y. (2007). They saw a movie: long-term memory for an extended audiovisual narrative. *Learning & memory*, *14*, 457-467.

Kriegestorte, N. & Kievit, R. A. (2013). Representational geometry: integrating cognition, computation, and the brain. *Trends in Cognitive Sciences, 17*, 401-412.

Levine, B., Svoboda, E., Hay, J. F., Winocur, G., & Moscovitch, M. (2002). Aging and autobiographical memory: dissociating episodic from semantic retrieval. *Psychology and Aging*, *17*, 677.

Lichtenstein, E. H. & Brewer, W. F. (1980). Memory for goal-directed events. *Cognitive Psychology, 2,* 412–445.

McClelland, J. L., McNaughton, B. L., & O'Reilly, R. C. (1995). Why there are complementary learning systems in the hippocampus and neocortex: insights from the successes and failures of connectionist models of learning and memory. *Psychological Review, 102,* 419–457.

Moscovitch, M., Cabeza, R., Winocur, G., & Nadel, L. (2016). Episodic memory and beyond: The Hippocampus and neocortex in transformation. *Annual Review of Psychology, 67,* 105–134.

Nadel, L., Samsonovich, A., Ryan, L., & Moscovitch, M. (2000). Multiple trace theory of human memory: computational, neuroimaging, and neuropsychological results. *Hippocampus, 10*, 352-368.

Pyc, M. A. & Rawson, K, A. (2007). Examining the efficiency of schedules of distributed retrieval practice. *Memory and Cognition, 35*, 1917–1927.

Radvansky, G. A., & Copeland, D. E. (2006). Walking through doorways causes forgetting: Situation models and experienced space. *Memory and Cognition, 34*, 1150–1156.

Reynolds, J. R., Zacks, J. M., & Braver, T. S. (2007). A computational model of event segmentation from perceptual prediction. *Cognitive science*, *31*, 613-643.

Richmond, L. L., & Zacks, J. M. (2017). Constructing experience: Event models from perception to action. *Trends in cognitive sciences*, *21*, 962-980.

Robin, J. & Moscovitch, M. (2014). The effects of spatial contextual familiarity on remembered scenes, episodic memories, and imagined future events. *Journal of Experimental: Learning, Memory, &* Cognition, 40, 459–475.

Rubin, D.C. (1977). Very long-term memory for prose and verse. *Journal of Verbal Learning and Verbal Behavior, 16*, 611–621.

Sargent, J. Q., Zacks, J. M., Hambrick, D. Z., Zacks, R. T., Kurby, C. A., Bailey, H. R., … Beck, T. M. (2013). Event segmentation ability uniquely predicts event memory. *Cognition, 129*, 241–255.

Sekeres, M. J., Bonasia, K., St-Laurent, M., Pishdadian, S., Winocur, G., Grady, C., & Moscovitch, M. (2016). Recovering and preventing loss of detailed memory: differential rates of forgetting for detail types in episodic memory. *Learning & Memory*, *23*, 72-82.

Silva, M., Baldassano, C., & Fuentemilla, L. (2019). Rapid memory reactivation at movie event boundaries promotes episodic encoding. *Journal of Neuroscience*, *39*, 8538-8548.

Sols, I., DuBrow, S., Davachi, L., & Fuentemilla, L. (2017). Event Boundaries Trigger Rapid Memory Reinstatement of the Prior Events to Promote their Representation in Long-Term Memory. *Current Biology, 27*, 3499 –3504.

Squire, L. R., Genzel, L., Wixted, J. T., & Morris, R. G. (2015). Memory consolidation. *Cold Spring Harbor perspectives in biology*, *7*, a021766.

Thorndyke, P. W. (1977). Cognitive structures in comprehension and memory of narrative discourse. *Cognitive Psychology, 9*, 77–110.

Tulving., E. (1972). Episodic and semantic memory. In E. Tulving & W. Donaldson (Eds.), *Organization of memory* (pp. 381–403). New York: Academic.

Tulving, E. (2002). Episodic memory: From mind to brain. *Annual Review of Psychology, 53*, 1–25.

Wheeler, M. A., Ewers, M., & Buonanno, J. F. (2003). Different rates of forgetting following study versus test trials. *Memory, 11*, 571–580.

Wilson, B. A., Cockburn, J., & Baddeley, A. D. (1991). *The Rivermead Behavioural Memory Test*. Suffolk, United Kingdom: Thames Valley Test.

Winocur, G., & Moscovitch, M. (2011). Memory transformation and systems consolidation. *Journal of the International Neuropsychological Society: JINS, 17*, 766.

Zacks, J. M., Speer, N. K., Swallow, K. M., Braver, T. S., & Reynolds, J. R. (2007). Event perception: a mind-brain perspective. *Psychological bulletin*, *133*, 273.