

SCRAMBLED NARRATIVES AND CHANGES IN MEMORY COMPOSITION OVER TIME

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A THESIS SUBMITTED TO THE FACULTY OF GRADUATE STUDIES IN PARTIAL  
FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ARTS

GRADUATE PROGRAM IN PSYCHOLOGY

YORK UNIVERSITY

TORONTO, ONTARIO

July 2025

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## Abstract

Event memories consist of both episodic and schematic contributions. Typically, episodic details are more susceptible to forgetting than schematic details, resulting in memories becoming less episodic and more schematic over time. This thesis presents a novel paradigm to efficiently quantify changes in episodic and schematic contributions to retrieval over time. Participants ( $N = 201$ ) read a short story with the order of events randomly scrambled. After a delay (Immediate, 24-hour, 48-hour, 72-hour, 1-week), participants performed a temporal order memory test. Over longer delays, we found that participants' memory for the scrambled story became increasingly dissimilar to the scrambled order that was originally studied (i.e., less episodic). Instead, participants' memory increasingly resembled the never-presented coherent version of the story (i.e., more schematic). These results suggest that recall increasingly relies on prior knowledge, rendering incoherent memories more coherent with time.

## Acknowledgements

I would first like to thank my supervisors Drs. Buddhika Bellana and Andrée-Ann Cyr for your unwavering support prior to and throughout my master's studies. Your guidance and unique approaches to science have taught me many lessons both scholarly and personal. You took a chance on me as a graduate student and you have helped shape me into a better researcher and scientist, and together I think we have created some very cool science. I thank you both for your commitment and dedication to me as a mentee and to our project. Buddhika, I want to emphasize my gratitude to you as a mentor and friend. You, in particular, took a chance on me as an undergraduate student grappling with epilepsy, and have been an invaluable mentor for almost every single avenue of life that I've traversed over the last four years.

Second, I'd like to thank my MA committee member, Dr. Shayna Rosenbaum, for your support and guidance on this project and my MA defence committee members, Drs. Thanujeni Pathman and Raymond Mar.

Lastly, I would like to thank my family and friends. Without you all – who knows where I'd be. My partner, Sara, I thank you for your unconditional love, support, and encouragement and for lending your ears to the endless rambles about all the fascinating things I've learned throughout my studies. My parents, Alexandra and Richard Fisher, I thank you for your love, dedication and endless support to helping me navigate my path. My siblings, Kristen Brinksman, Hailey Fisher, Josh Brinksman and Derek Kropman, and all my nieces and nephews: Kai, Max, Cole, Teo, Wes, Naomi, Eden, and Elsie; you have all provided love and guidance as well as given me the absolute best excuse to get my mind off school when I need to. My friends, Riya Trikha and Christiane Marie Canillo for their love and support from the very beginning of my real academic journey.

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## **Chapter 1: Introduction**

Episodic memory is commonly regarded as the capacity to store and recall specific details of an experience, tied to a particular time and place. This ability to preserve past experiences, however, is time-limited. Episodic details are rapidly forgotten immediately after an experience before reaching a plateau (Diamond et al., 2020; Ebbinghaus, 1885; Sekeres et al., 2016; Tulving, 1972). This propensity to lose details may seem surprising for a system designed to maintain access to our past. However, episodic memory is not strictly preservative, but also highly constructive in nature. This constructive quality of episodic memory has been highlighted by research demonstrating that details of an episodic memory are not only rapidly lost (i.e., forgetting), but also modified or distorted (Bartlett, 1932; Loftus, 2005). Often, modifications to episodic details are not random but tend to correspond to an individual's general knowledge, i.e., semantic knowledge and schema (Bartlett, 1932; Bergman & Roediger, 1999). In this way, episodic memory may not be suited to retain the past as it was (i.e., preservative), but instead may be better suited to recreate the past as it was likely to have been. In this thesis, I explore the extent to which episodic memories accurately preserve past experiences as a function of time. To investigate this, I will present participants with an experience that does not correspond to typical general knowledge or schema (i.e., a temporally scrambled story) and then quantify the degree to which participant memory preserves an experience as it occurred vs. becomes modified to reflect what the past "should have been" (i.e., more consistent with semantic knowledge and schema).

### **On Memory Decay: Forgetting of Episodic and Schematic Details**

The passage of time typically results in forgetting; we lose the ability to recall information that we could recall at an earlier occasion (Tulving, 1974). Hermann Ebbinghaus (1885), a pioneer of memory research, was the first to empirically demonstrate patterns of

forgetting in recall. He collected data on his own ability to recall learned nonsense syllables and identified a common pattern in his forgetting. This pattern can be described as a steep loss of detail shortly after learning followed by a gradual plateau in the loss of detail as time passes – what is now often referred to as a ‘forgetting curve’ or the ‘power-law of forgetting’ (Ebbinghaus, 1885/1913; Kahana et al., 2022; Murre & Dros, 2015). More recently, it has been demonstrated that forgetting is not a uniform process – information may be forgotten via different mechanisms, such as interference or retrieval failure (Robertson, 2012; Tulving, 1974), and there are many factors that can influence the extent to which information is remembered or forgotten. One such factor is whether the to-be-remembered information is relevant to schema: details of an experience that conform to previous experiences (i.e., schema-congruent) are more likely to be recalled than details that do not match our expectations (i.e., schema-incongruent) ( Craik & Tulving, 1975; Schulman, 1974; Staresina et al., 2009; van Kesteren et al., 2010). Another factor that influences forgetting is detail-type. Episodic details of a memory tend to be more susceptible to forgetting over time than gist-like or schematic details (Radvansky et al., 2022; Sacripante et al., 2022; Sekeres et al., 2016; Thorndyke, 1977; Tulving, 1972). For example, Sacripante et al. (2022) found that over the course of one-month peripheral details (i.e., episodic details) of an auditory narrative were forgotten at a significantly faster rate compared to central, gist-like details (i.e., schematic details). Overall, the works I have outlined here demonstrate that the details from an experience are lost over time, but forgetting is not purely information loss. Instead, memory errors also manifest as inaccurate modifications or distortions to the details of the remembered experience (e.g., misremembering).

### **On Misremembering and Construction in Memory**

How our memory fails us is a complex picture to paint - failures of memory can take many forms. Schacter (1999) classified and defined several of the ways that human memory behaves suboptimally and describes these as 'sins' of memory. Some of these sins fall under the broader category of forgetting and are described as *errors of omission*. Errors of omission can be roughly thought of as missing details in ones' memory at the time of remembering – when you are unable to recall specific details from an experience. Another group of sins pertain to distortions or inaccuracies in memory and can be described as *errors of commission*. These can be roughly thought of as misremembering – recalling a piece of information or an experience, but details of the memory have been misattributed to a different time, place, or person; have been distorted and no longer reflect the truth; or were never experienced in the first place. Bartlett (1932) conducted early demonstrations of errors of commission by testing his students' ability to recall a story with Indigenous themes (*War of the Ghosts*). He found a pattern in the students' recall where Indigenous details of the story were replaced with more stereotypical American details (e.g., replacing the word 'canoe' with the word 'boat') – a phenomenon that he termed '*rationalization*'. Bergman and Roediger (1999) reproduced Bartlett's experiment and similarly found that when recalling a story 15-minutes after reading, over half of all the details recalled were distorted to some extent. Along similar lines, Bransford and Franks (1971) presented participants with sentences that contained overlapping information (e.g., '*the ants were in the kitchen*' and '*the ants ate the jelly*') and then tested their memory for these sentences in a recognition test where they had to respond if they had seen the sentence before and how confident they were. They found across several experiments that many new sentences were falsely recognized, many with equal to or stronger confidence ratings than studied sentences, and importantly, many of the falsely recognized new sentences contained abstractions and/or

inferences from the presented sentence stems (e.g., *'the ants in the kitchen ate the jelly'*). The semantic information from the sentences seemed to be influencing how participants recalled what they had read. The Deese-Roediger-McDermott is a popular paradigm that has repeatedly been used to demonstrate that people may falsely recognize words or introduce new words into recall that were never presented to them (Deese, 1959; Roediger & McDermott, 1995, Roediger et al., 1998). The above examples of errors of commission provide an important insight into episodic memory: memory is not a direct mental recording of an experience. If this were the case, forgetting should only consist of errors of omission.

Why do we commit errors of commission? The answer may lie in how we produce our memories - that our memories are not simple recordings of information that are saved in our mind. Falsely recognizing information that was never experienced but highly related to our experience suggests that general knowledge influences how we remember (Bransford & Franks, 1971; Deese, 1959; Roediger & McDermott, 1995). The existence of these types of errors of commission implies that memory is constructive. Recalling an experience seems to be a process where memory is constructed from information that is brought to mind as we search our memory for details that belong to this experience (e.g., accurate details, related general knowledge, and schema; Bartlett, 1932; Conway & Pleydell-Pearce, 2000; Neisser, 2014). Constructing a memory in this way can allow for both errors of omission and errors of commission. Errors of omission may occur when details that cannot be recalled or details that certainly do not belong to the relevant experience are omitted from recall. Errors of commission may occur when information that does not belong to the relevant experience is included because it is highly related or contextually similar. However, this still leaves an unanswered question of why we include information from general knowledge or schema into our recall. An account that comes

from the cognitive aging literature may provide a relevant perspective – that schemas provide compensatory support for forgotten details of an episodic memory (Castel, 2005; Hess, 1985; Ramey et al., 2024; Umanath & Marsh, 2014). Therefore, as accurate details of an experience are rapidly forgotten, they may be replaced or supplemented by highly relevant details abstracted from schema or general knowledge. Another related idea is that if schematic, gist-like details are less susceptible to loss than are episodic details (Radvansky et al., 2022; Sekeres et al., 2016; also see Rosenbaum et al., 2009) and memory is a constructive process, then over time schematic details may make up a greater proportion of all the available building blocks to form a memory.

### **Construction as a Route From Incoherent to Coherent**

To this point I have discussed rationalization as a compensatory mechanism for filling in specific details of a memory that are inaccessible or lost. However, there is evidence that rationalization can even occur at a larger scale, reorganizing temporal or causal structures of events. Kintsch and colleagues (1977) demonstrated that when participants were asked to recall and summarize a scrambled story immediately after reading, the summaries they produced were indistinguishable from summaries from participants who read the original unscrambled version of the same story. This result suggests that when people encode atypical or incoherent experiences, where temporal and causal connections are broken, we readily - perhaps even automatically - rationalize these experiences in memory to better coincide with our schematic knowledge of how events typically unfold (Graesser et al., 1994; Kintsch et al., 1977; Mandler, 1978). Whereas Kintsch et al. (1977) asked participants to summarize the scrambled stories they read, a task that may have encouraged or emphasized rationalization from participants in order to promote summary coherence, recent work by Antony and colleagues (2024) demonstrated rationalization in free recall. In their experiment, participants viewed *Memento*, a popular movie

which recounts a crime by presenting the scenes out of chronological order. They were then asked to recall the movie *exactly as they saw it*. Even when participants were explicitly tasked with recalling the scenes in the scrambled order that had been presented, the order of scenes in participant recall were strongly reflective and seemingly guided by the underlying causal connections between events (Antony et al., 2024). In other words, when recalling an incoherent sequence of events, participants continued to use their overall understanding of how each event *should have been* associated with one another to organize recall, despite being instructed otherwise. In a similar experiment, Frisoni and colleagues (2024) investigated how participants recalled a movie where the six scenes were presented in a random order and participants were asked to recall the order of the six scenes. The results indicated that scenes that were presented later than they should have been in the original story tended to be recalled as happening earlier and vice versa for scenes that were presented earlier than they should have been. Similar to the findings from both Kintsch et al. (1977) and Antony et al. (2024) these results provide another example of memory for an experience undergoing rationalization wherein memory is shaped by the knowledge of how these movies should have unfolded - whether it is guided by contextual connections, causal connections, chronological relationships, etc. These works highlight the interaction of general knowledge and schema with our encoded experiences to produce memories that reflect how the past should have been instead of how the past was.

### **Gist and Construction Over Time**

An abundance of empirical work demonstrates that we forget details of an experience over time. I have also outlined other lines of work suggesting our episodic memories rely on schema and general knowledge. Do we, then, increasingly rely on our general knowledge and schema to reconstruct our memories with time? Early work on construction in recall over time

primarily relied on repeated retrieval paradigms. Bartlett (1932) reported that there was increased rationalization over time when his students were asked to recall the same story several times.

Similarly, Bergman & Roediger (1999) found that distorted details make up a greater proportion of all details recalled when participants repeatedly retrieve the same memory. While this research provides clues as to what happens to episodic memory over time, the influence of repeated retrieval in these cases cannot be disentangled from the influence of time alone. Neuroimaging research may provide some additional insight into the influence of time on rationalization.

Several theories suggest that episodically rich memories primarily rely on the hippocampus and medial temporal lobe structures - no matter the age of the memory - and rationalized or highly semantic memories instead rely on neocortical regions such as the anterior temporal, anterior cingulate and prefrontal cortices (Frankland & Bontempi, 2005; Moscovitch et al., 2016; Nadel & Moscovitch, 1997; Winocur & Moscovitch 2011; c.f., Squire & Alvarez, 1995). Recent neuroimaging studies have found that over time there are increases in neocortical contributions to recall (Bonasia et al., 2018; McCormick et al., 2020; Sekeres et al., 2018; Sommer, 2017). For example, Bonasia et al. (2018) found different patterns of functional connectivity between the medial temporal lobe and medial prefrontal cortex when recalling memories after seven days versus immediately, and that the seven-day old memories contained more errors of commission than those that were retrieved immediately. Sekeres et al., (2018) report that the hippocampus was similarly activated whether a memory was recalled immediately or after a seven-day delay, but the delayed recall was associated with increased activity in areas such as the frontal gyrus, medial prefrontal cortex, and the right anterior cingulate cortex. This neural differentiation across delays corresponded to behavioural changes where memories recalled after seven days had lower episodic content (peripheral details). These findings suggest that over time, even in the absence

of repeated retrieval, memories may undergo rationalization and increasingly rely on brain regions that are associated with more schematic forms of memory.

### **Present Study**

The time course of forgetting episodic memories has been relatively well established, there is less work on the time course of rationalization. While repeated retrieval paradigms and neuroimaging establish that there is a relationship between time and rationalization in memory, research on rationalization over time is often limited in granularity (e.g., comparing immediate recall to recall from a single delayed time point). The current study seeks to investigate patterns of forgetting and rationalization in episodic memory over time at a scale of minutes to one-week and establish a more detailed understanding of the relationship between these processes and time.

To approach this investigation, I devised an efficient but sensitive measure of episodic and schematic qualities of a memory and established a novel paradigm that applies both within-subject and between-subject measures to capture forgetting (i.e., reductions in episodic quality) and rationalization (i.e., increases in schematic quality) within individuals as well as across individuals over time. An important feature of this investigation is the utilization of a short story as a naturalistic memorandum. Reading stories involves active engagement in a narrative experience and is a better reflection of the episodic nature of our lived experience than would be a generic series of words or pictures (Lee et al., 2020; Schank & Allison, 1995). Additionally, we leverage our schemas during story comprehension (Alaoui-Soce, 2025; Graesser et al., 1994; Mandler, 1984). That is, we hold cognitive structures that organize general knowledge about stories and how they typically unfold, which we rely upon when engaging with stories. Therefore, by manipulating the order in which the story events occurred I was able to establish a version of the story that was inconsistent with general story schema. Then, by asking participants

to read this event-scrambled story and subsequently retrieve it from memory, I could assess the extent to which their memory reflected their experience (i.e., how similar is their recall to the event-scrambled story) and the extent to which their recall reflected a rationalized version of their experience (i.e., how similar is their recall to the never-read original schema-consistent form of the story).

My paradigm consisted of two main parts: a study phase, and a test phase. In the study phase participants performed a self-paced reading task where they were asked to read the event-scrambled story at their own pace, unaware that their memory for the story would be tested. In the test phase participants were presented with descriptions of all story events and were asked to sort them into the order in which they were presented. A between-subject manipulation of the delay between the study and the test phase was used to examine the effects of time. Five different groups performed the test phase, each at a different delay (i.e., immediately, 24-hour, 48-hour, 72-hour, and 1-week). This between-subject manipulation allowed us to investigate changes in forgetting and rationalization across time, free from any influence from repeated-retrieval. The measure episodic and schematic qualities of participant recall simply relied on two Spearman rank order correlations: the correlation between the order of events in participant recall and the order of events in the event-scrambled story represented how accurately a participant could recall their experience (i.e., episodic), and the correlation between the order of events in participant recall and the order of events in the original story represented how story-like a participant's recall was (i.e., schematic).

With this experimental paradigm I was able to capture within-subject patterns of episodic and schematic qualities in recall as well as between-subject measures of how forgetting and rationalization change over time. In accordance with an abundance of literature on forgetting, I

hypothesized that episodic qualities of recall would decrease as a function of delay (i.e., forgetting) and this function would reflect the typical forgetting-curve. Additionally, we predicted that schematic qualities in recall would increase as a function of time, in line with the notion that the passage of time is associated with increased activation in brain areas responsible for schematic forms of memory (Bonasia et al., 2018; Sekeres et al., 2018) and that recall of narrative content may be guided by causal connections or other schematic knowledge (Antony et al., 2024; Frisoni et al., 2024). Broadly, I predicted that memory for the incoherent event-scrambled story would become increasingly coherent over time.

## **Chapter 2: Methods**

### **Participants**

A total of 278 online participants were recruited for this experiment. Participants were recruited via Prolific ([www.prolific.com](http://www.prolific.com)), an online participant-recruitment platform. The pre-recruitment eligibility criteria for our study were that (i) the participant must reside in Canada or the United States of America, (ii) English must be the participant's first language, and (iii) the participant must not have been diagnosed with MCI or dementia.

Participants were assigned to one of six conditions based on the nature of their instructions for a memory test (i.e., Episodic, Schematic) or the delay between study and test (i.e., Immediate, 24-hour, 48-hour, 72-hour, 1-week). The specific conditions that were tested are as follows: Episodic (Immediate); Schematic (Immediate); Episodic (24-hour), Episodic (48-hour), Episodic (72-hour), Episodic (1-week). For detailed explanation of these conditions in the context of the broader experimental paradigm, see Procedure. Data for the Episodic (Immediate) and Schematic (Immediate) were collected first and sample sizes per condition were initially set to  $n = 40$  based on previous work on episodic memory (Cooper et al., 2019; Diamond et al.,

2020; Frisoni et al., 2021). After collecting data for these two conditions, we conducted a post-hoc power analysis using the *pwr* package in R (Champely et al., 2020) to determine sample size for the remaining four delay conditions. The power analysis conducted on the Episodic (Immediate) condition indicated that a sample size of 40 resulted in 96% power to detect an effect ( $n = 40$ ; Cohen's  $d = 2.92$ , power = 0.96,  $p = 0.05$ ). Given the high power and the likelihood of memory performance declining over time, we decided to continue with a sample size of forty for all remaining delay conditions. This resulted in a total target sample size of 240 participants ( $n = 40$  per condition).

Four participants were excluded for either failing two of three attention checks or for correctly answering less than 25% of story comprehension questions (i.e., what would be expected by chance on a 4-alternative multiple choice). Two participants were excluded for returning for the memory test on the incorrect day (e.g., a participant assigned to the 48-hour delay completed the memory test after a 72-hour delay). Twenty-three participants were excluded for indicating that they completed the memory task using a strategy that was different from how they were instructed to perform the task. Three participants were excluded for having read the story before. After exclusions there were a total of 246 participants that were included in our analyses ( $N_{\text{female}} = 138$ ,  $N_{\text{male}} = 97$ ,  $N_{\text{non-binary}} = 8$ , one participant self-described as “two-spirit”, and five participants selected “prefer not to say”). Median age range in the final sample was 30-34 years of age (Q1 = 25-29, Q3 = 40-44, min = 18-19, max = 70-74). Median level of completed education was a bachelor's degree (Q1 = “some college but no degree”, Q3 = “bachelor's degree”, min = “Some high school or less”, max = “doctoral degree”). In terms of ethnic composition, 165 participants identified as “White”, twenty identified as “Black”, sixteen identified as “South Asian”, thirteen identified as “East Asian”, thirteen identified as “Another

race category”, six identified as “Latin American”, four identified as “Southeast Asian”, four identified as “Indigenous (First Nations, Inuk/Inuit, Métis)”, two identified as “Middle Eastern”, and three selected “prefer not to answer”. Log likelihood ratio tests of independence without correction (*G*-test) were performed with the *Gtest()* function in the *DescTools* package (version 0.99.57; Signorell, 2024) to assess if demographic distributions were comparable across groups and all tests confirmed that distributions were comparable (Gender:  $G = 24.77, p = .210$ ; Age:  $G = 65.89, p = .149$ ; Education:  $G = 33.33, p = .308$ ; for a breakdown see Table B1, Table B2, and Table B3 in Appendix A).

All participants were compensated £6.00 per hour for their participation. Additionally, participants in the delay conditions were provided with a bonus payment of 20% (about £1.22 GBP) of the total experiment payment for returning and completing Part 2 of the study. All participants provided informed consent prior to participating in the study, and all aspects of the experiment were approved and abided by policies of the Human Research Ethics Board of York University.

## **Materials**

### ***Story Stimulus***

Across all experiments, participants’ memory for an incoherent, event-scrambled short story was tested. The short story that we selected was *The Paper Menagerie* by Ken Liu (Liu, 2011). *The Paper Menagerie*, in its originally published form, is an engaging and emotional story, 4911 words in length and approximately a 15-minute read. It describes a tale of a mixed-race boy growing up in America and his evolving relationship with his Chinese mother and heritage. It is also highly legible, with a score of five on the Flesch-Kincaid Grade level scale - indicating that the story is written at about a grade 5 reading level. Furthermore, it consists of a

variety of clearly demarcated events, often separated by shifts in spatial location and time, which coincided well with our goal of selecting a story that would lend itself to event-scrambling. Concretely, event-scrambling was achieved in two steps: first (i) dividing the story into its constituent events and then (ii) shuffling the order of events. To identify the constituent events, a group of independent raters ( $n = 12$ ) read the original published version of *The Paper Menagerie* while identifying transitions between individual sentences where they believed one event ended and another began (i.e., an event boundary). Events were defined by selecting sentences where  $>60\%$  of raters agreed on placing an event boundary, resulting in 26 story events. The order of these 26 events was then randomly shuffled 100,000 times, and we selected a version that was uncorrelated with the order of events in the original published version ( $r(24) = -0.002$ ). Brief descriptions of each event were manually written by the first author of this paper (WF) and were presented to participants before reading each event and again during the memory test (see Procedure). All participants across all experiments were presented the same scrambled version of the story.

### ***Narrative Transportation***

To measure the subjective experience of immersion while reading the story, all participants completed a modified version of the Narrative Transportation Questionnaire (Green & Brock, 2000), a 14-item self-report measure designed to assess how transported into the world of the story participants felt while reading. Sample items included statements like “While I was reading the text, I could easily picture the events in it taking place,” and “The text affected me emotionally,” rated on a 7-point scale from *Not at all (1)* to *Very much (7)*.

### ***Individual Differences in Everyday Memory***

To assess individual differences in autobiographical memory, participants completed the Brief Survey of Autobiographical Memory (B-SAM; Palombo et al., 2013), a 10-item questionnaire that assesses self-reported episodic autobiographical, semantic, and spatial memory, and future prospection. B-SAM scoring was calculated according to appropriate weights and specifications made available by the authors. (Palombo et al., 2013)

### ***Individual Differences in Sleep Quality***

As we tested memory across delays that included nights of sleep, participants completed a modified version of the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989). The PSQI is a 24-item questionnaire that assesses sleep quality and disturbances in the days prior to both parts of the experiment (i.e., study and test phase).

### **Procedure**

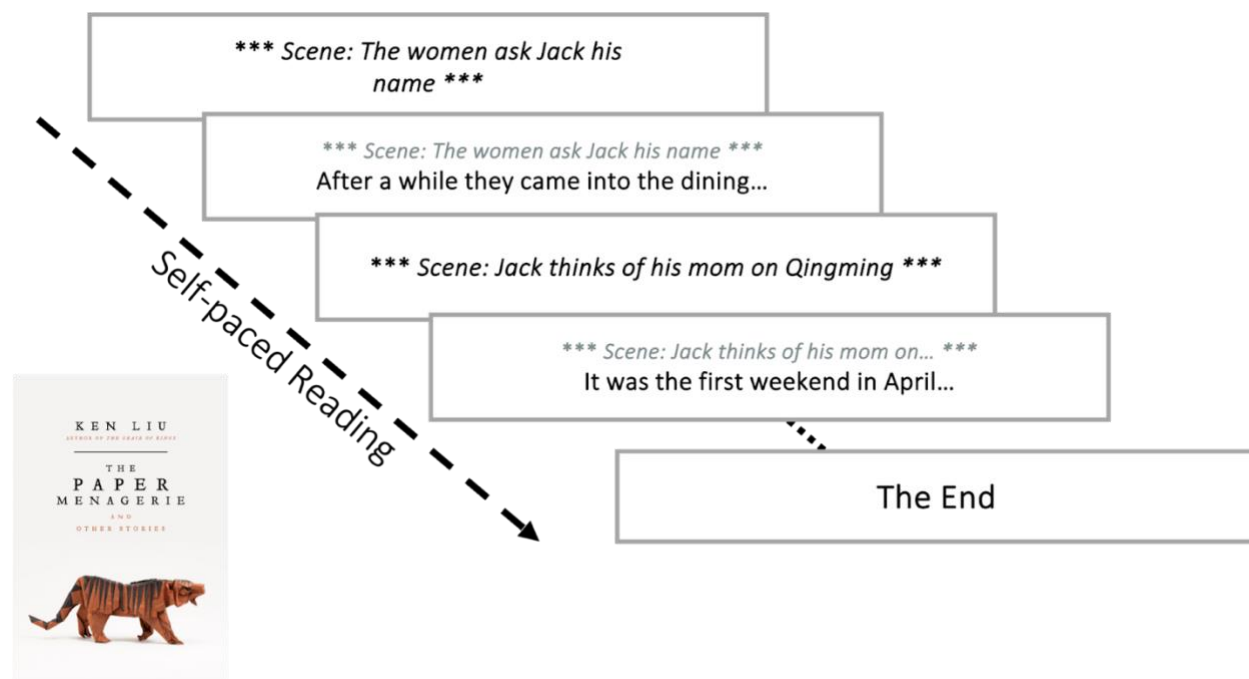
All aspects of the experiment were conducted online via Qualtrics (Qualtrics, Provo, UT), an online survey platform.

Overall, the experiment consisted of two parts: a study phase and a test phase. During the study phase, participants performed a self-paced reading task where they read the event-scrambled version of *The Paper Menagerie* (Figure 1). Participants were first presented with a brief description of an event. These event descriptions ranged in length from 1-4 sentences long and were manually written by the first author (WF) to summarize the content of a given event. After reading the event description, participants were presented with the full text of the associated event. Note that event descriptions were essential for our temporal order memory test, described below. Events typically consisted of multiple sentences (average number of words = 189.88; average number of sentences = 16.6). After reading the event, participants were presented with the next event description. They continued in this fashion at their own pace until

they read all twenty-six events. After the self-paced reading task, participants completed the modified Narrative Transportation Questionnaire.

## Figure 1

### *Self-paced reading task*



The test phase of the experiment centered around a temporal order memory test. Participants were presented the 26 event descriptions from the story listed in a box on the left side of the screen (Figure 2). Their task was to drag and drop the events into an empty box on the right side of the screen. For all *Episodic instruction* conditions, participants were asked to rearrange the event “to reflect the order in which you remember them occurring” (hereafter referred to as the *Episodic test*). For the *Schematic instruction* condition, participants performed an identical test, but were instructed to rearrange the events “to reflect the order that you believe the story would have originally been told (hereafter referred to as the *Schematic test*). Note that performance of the Episodic test can only be accomplished if participants encoded the original sequence of events in memory. The Schematic test, instead, relies only on general knowledge

and schema for how events and stories tend to unfold. The memory test had no time limit, participants were only given the opportunity to move on once all events had been placed into the box. Participants in the Episodic (48-hour); Episodic (72-hour) and Episodic (1-week) delay conditions performed the Episodic test followed by the Schematic test. This was done to gain additional insight into how performance on these tests interact within the same individuals (for details, see Appendix A).

To ensure participants understood how to perform the temporal order memory test, they performed a brief practice task prior to the actual test. The practice test consisted of presenting participants with a four-sentence story, with sentences presented out-of-order. After reading, participants were then presented four different orders of the sentences and were asked to identify the option that best corresponded to their assigned instructions (i.e., Episodic or Schematic). To ensure comprehension, participants were only allowed to continue after selecting the correct answer.

To examine the influence of time on memory performance, we manipulated the delay between the study and test phases across-participants: immediate (i.e., no delay), 24-hour, 48-hour, 72-hour and 1-week. Note: participants assigned to any of the delays were asked to provide their informed consent before completing the test phase, given it was administered on a separate day.

Following the temporal order memory test, participants performed a battery of post-test questionnaires that consisted of: a 20-item multiple choice comprehension test about *The Paper Menagerie*; the Brief Survey of Autobiographical Memory (B-SAM; Palombo et al., 2013); a 20-item survey feedback questionnaire, assessing a variety of aspects of their experience reading the

story; a 9-item demographic questionnaire; a modified version of the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989).

## Figure 2

*Graphic of temporal order memory test format*

**Items**

Jack is at the hospital, busy thinking about his career instead of his mom

Jack's mom made an origami shark but it fell apart, so she created a new shark out of tinfoil

Jack is bullied at school

Jack brings up a name that he was called at school and gets frustrated at his mom for not speaking English, then Jack's mom explains why she wants to speak in Chinese

Jack goes downtown to ask Chinese tourists to read the letter for him

Laohu pounced on a bird and it tore his ear

Drag and order scenes below:

*Note.* This is a summary depiction; participants were presented all 26 event descriptions.

Participants were instructed to place the beginning of the recalled story at the top of the box.

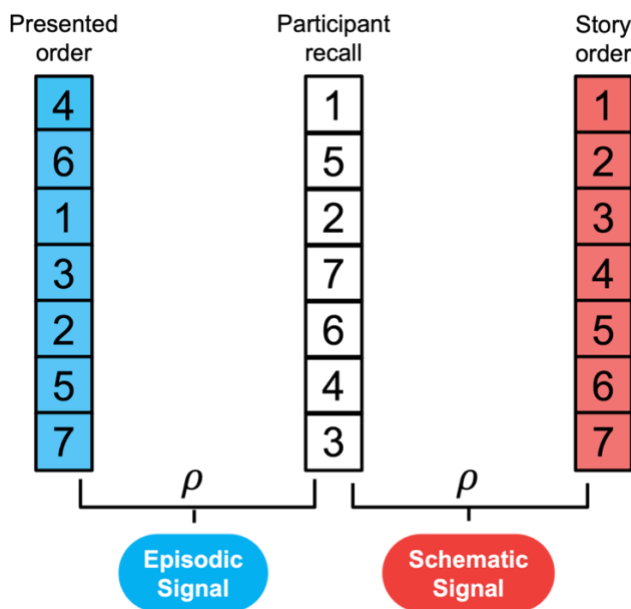
## Analyses

All analyses were performed using R Statistical Software (v4.4.2; R Core Team 2024). Most of our analyses relied on two key dependent variables derived from our temporal order memory test: *episodic signal* and *schematic signal* (Figure 3). Episodic signal refers to the extent to which the temporal order of events from an individual's memory reflects the scrambled order of events that was presented to them during the study phase. This is referred to as *episodic* signal because the only way an individual can remember the scrambled order of events is if they have access to their experience of the study phase in memory. Schematic signal refers to the extent to which the temporal order of events from an individual's memory reflects the true order of events in the story, prior to any scrambling. This is referred to as *schematic* signal because participants

were not exposed to the original story, and thus, the only way participants' memories can show increased schematic signal is if they use their general knowledge and expectations regarding how an event should unfold. Operationally, both episodic and schematic signal were defined as the Spearman rank order correlation of the order of events from the memory test with either the scrambled order of events from the study phase (i.e., episodic signal) or the coherent order of events from the originally published story (i.e., schematic signal). Spearman rank order correlations were tested via the *cor.test()* function in base R and then were Fisher-Z transformed using the *FisherZ()* function in the *DescTools* package (version 0.99.57; Signorell, 2024).

### Figure 3

*Graphic of correlation analysis*



*Note.* This is a summary depiction with only 7 story events; both orders and participant recall consisted of 26 events. Episodic Signal was generated by calculating Spearman correlation between Presented order and Participant recall. Schematic signal was generated by calculating Spearman correlation between Story order and Participant recall.

### ***Proof of Concept***

First, we set out to determine whether our paradigm could reliably elicit episodic and schematic signal. To do this, we examined whether we could use task instructions to specifically increase either episodic or schematic signal. Episodic and schematic signal were calculated from participants in the Episodic (Immediate) or Schematic (Immediate) conditions. In both cases, participants read the same event-scrambled story. However, in the Episodic condition, they were instructed to perform the temporal order memory test by remembering the scrambled order of events they were presented at study – thus boosting episodic signal. In the Schematic condition, participants were asked to sort events into the order they would have most likely been told originally, before scrambling – thus boosting schematic signal. A 2 (*signal type*: episodic, schematic; within-subject) x 2 (*condition*: Episodic, Schematic; between-subject) mixed design ANOVA was conducted. We expected a two-way interaction, where episodic signal would be highest for the Episodic (Immediate) condition and vice versa. Pairwise comparisons were made using the *contrast()* and *emmeans()* functions from the *emmeans* package (version 1.10.4; Lenth et al., 2024).

### ***Signal over time***

For our primary analysis, we wanted to determine how episodic and schematic signal evolved over time, specifically when the explicit goal of the memory test was to retrieve the event-scrambled story (i.e., Episodic condition). We conducted a 2 (*signal type*: episodic, schematic; within-subject) x 5 (*delay*: immediate, 24hr, 48hr, 72hr, and 1-week; between-subject) mixed design ANOVA with signal strength as the dependent variable. ANOVAs were implemented using the *aov\_ez()* function from the *afex* package (version 1.4-1; Singmann et al., 2024), *F*-statistics and *p*-values for model parameter estimates were gathered using the

*summary()* function in base R, and pairwise comparisons were made using the *contrast()* and *emmeans()* function from the *emmeans* package (version 1.10.4; Lenth et al., 2024).

Additionally, we used Pearson correlation to test for any systematic linear relationships between episodic and schematic signal across delays.

### ***Simulations***

To ensure that our experimental results were unlikely to occur by chance or random forgetting, we ran additional simulations. Specifically, we wanted to determine whether or not randomly simulated results for our temporal order memory test that matched our human data in terms of episodic signal could also produce detectable schematic signal. If our simulated results, matched in terms of episodic signal, did not produce detectable schematic signal, we can be more certain that any schematic signal observed in our human data is a function of human memory as compared to some property of our particular analytic method. Our simulation was conducted by generating 10,000,000 randomly shuffled vectors of 1:26, which acted as our simulated results for the temporal order memory test, and then calculated episodic signal for each of these vectors. Then, we selected a subset of  $n$  simulated vectors, where each one exactly matched one human participant's episodic signal from an Episodic delay (prior to Fisher-Z transformation and matched to seven decimal places) and did this for each delay. This resulted in a sample of simulated data that was identical to our sample of human participants in terms of episodic signal. Next, we calculated schematic signal for each simulated vector and calculated the group mean. By repeating the above process 1000 times, we were able to generate a distribution of mean schematic signals calculated from our simulated data, which served as a null distribution to compare against the mean schematic signal calculated from our human participants. Statistical significance was determined using permutation testing. A comparable approach was used to

generate a null distribution of Pearson correlation estimates between episodic and schematic signal.

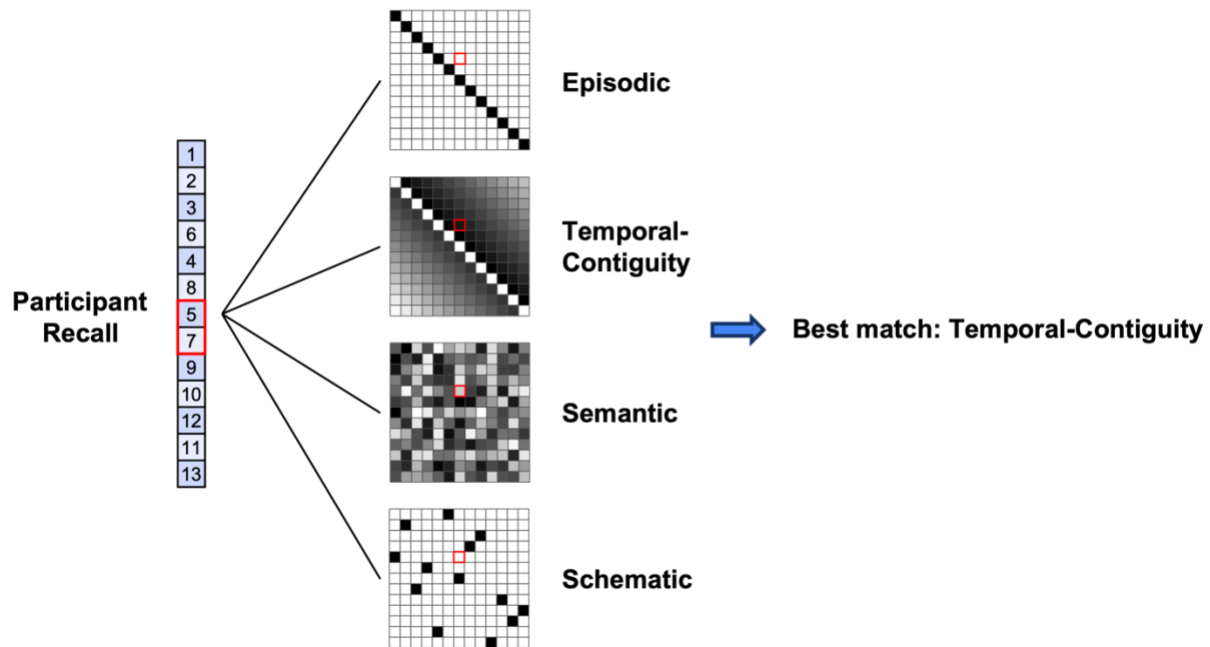
### ***Transition strategy analysis***

Episodic and schematic signal provide a single value that represents the degree to which a participant's performance on the temporal order memory test resembles the true incoherent experience from study (i.e., episodic signal) or the coherent version of events they had never read but could be inferred based on knowledge and schema (i.e., schematic signal). However, the placement of every individual event in the temporal order memory test relies on its own mixture of evidence, differing in terms of episodic and schematic contributions from one event to the next. To explore this, we implemented a template-matching analysis approach inspired by Antony et al. (2024). We generated event-by-event transition matrices that reflected the probability of moving from each event to any other event according to four different strategies:

- Episodic (i.e., perfectly following the order of events presented during the study phase).
- Schematic (i.e., perfectly following the original order of events in the never-before-seen unscrambled story).
- Temporal contiguity (i.e., generally following the Episodic strategy, but rather than perfectly following the presented order of events, one is more likely to transition from a given event to other events that happened at a similar time, reflecting the characteristic forward asymmetric pattern associated with temporal contiguity effects in recall; Kahana, 1996; Kahana et al., 2022).

- Semantic similarity (i.e., generally following the Schematic strategy, but rather than perfectly following the original order of events, one is more likely to transition from a given event to other events that share semantic meaning; Cer et al., 2018).

Each of these transition matrices served as a “template” of what perfect adherence to one of these four memory search strategies might have looked like, where each cell reflected a quantitative estimate, ranging from -1 to 1, indicating the likelihood of transition from one event to the next in memory (Figure 4; for detailed explanations about how each of these templates were calculated, see Appendix A). Using these templates, we were able to take a participant’s event sequence from the temporal order memory test and calculate the most likely strategy for every single contiguous event transition. Transitions where the most likely strategy had less evidence than what would be expected by chance were considered “unassigned” (i.e., the total number of possible event transitions from any given event is twenty-five;  $1/25 = 0.04$ ). We summed the winning strategies across all contiguous event transitions per participant and turned them into proportion scores by dividing each sum by the number of possible transitions (26 events - 1 = 25). Proportions were then fed into a 4 (*strategy*: Episodic, Temporal contiguity, Schematic, Semantic similarity; within-subject) x 5 (*delay*: Immediate, 24 hour delay, 48 hour delay, 72 hour, and 1-week; between-subject) mixed design ANOVA using the *aov\_ez()* function from the *afex* package (version 1.4-1; Singmann et al., 2024), and *F*-statistics and *p*-values for model parameter estimates were gathered using the *summary()* function in base R.

**Figure 4***Transition strategy analysis schematic*

*Note.* White represents low likelihood and black represents high likelihood. Participant recall consisted of 26 events. Best matching strategies were gathered for every event transition in each participant's recall (i.e., 25 event transitions).

### Chapter 3: Results

All plots were created using the *ggplot2* (Wickham, 2016) and *patchwork* (Pedersen, 2024) packages in R.

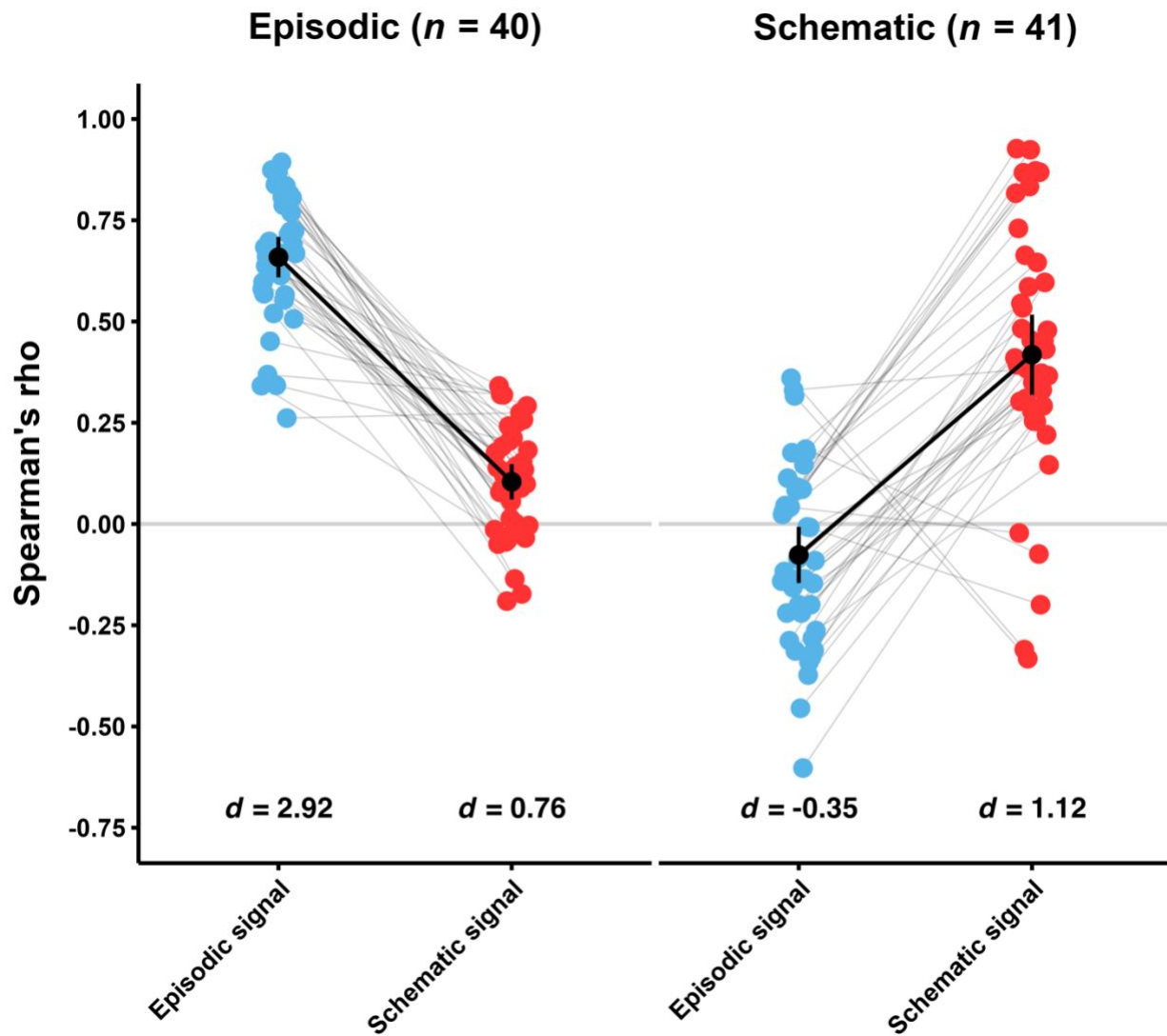
#### Proof of Concept

To validate our measures of episodic signal and schematic signal, we tested whether we could boost each signal independently via targeted instruction. Specifically, participants given the Episodic instruction (i.e., sort events according to the scrambled order in which they were presented) should show greater episodic signal. Participants given the Schematic instruction (i.e., sort events according to the order in which the story was likely to have been originally told)

should show greater schematic signal. This is precisely what we observed (Figure 5). A 2 (*signal type*: episodic, schematic; within-subject) x 2 (*condition*: Episodic, Schematic; between-subject factor) mixed-design ANOVA produced a significant interaction between signal type and condition ( $F(1, 79) = 190.73, p < .001, \eta^2_G = 0.55$ ). Pairwise comparisons with Bonferroni corrected  $p$ -values indicated that participants in the Episodic (Immediate) condition ( $n = 40$ ) had significantly greater episodic signal than schematic signal ( $M_{\text{episodic}} = 0.84, SD_{\text{episodic}} = 0.29$ ;  $M_{\text{schematic}} = 0.11, SD_{\text{schematic}} = 0.14$ ;  $t = 10.60, p < 0.001, 95\% \text{ CI} = [0.60, 0.87], d = 2.02$ ). On the other hand, participants in the Schematic (Immediate) condition ( $n = 40$ ) had significantly greater schematic signal than episodic signal ( $M_{\text{episodic}} = 0.08, SD_{\text{episodic}} = 0.23$ ;  $M_{\text{schematic}} = 0.53, SD_{\text{schematic}} = 0.47$ ;  $t = 8.92, p < 0.001, 95\% \text{ CI} = [0.47, 0.75], d = 1.22$ ). See Table B4 in Appendix B for descriptive statistics; see Table B5 in Appendix B for complete one-sample  $t$ -test results; see Table B6 in Appendix B for within-signal, between-condition pairwise comparisons; see Table B7 in Appendix B for between-signal, within-condition pairwise comparisons.

Figure 5

*Proof of concept results*



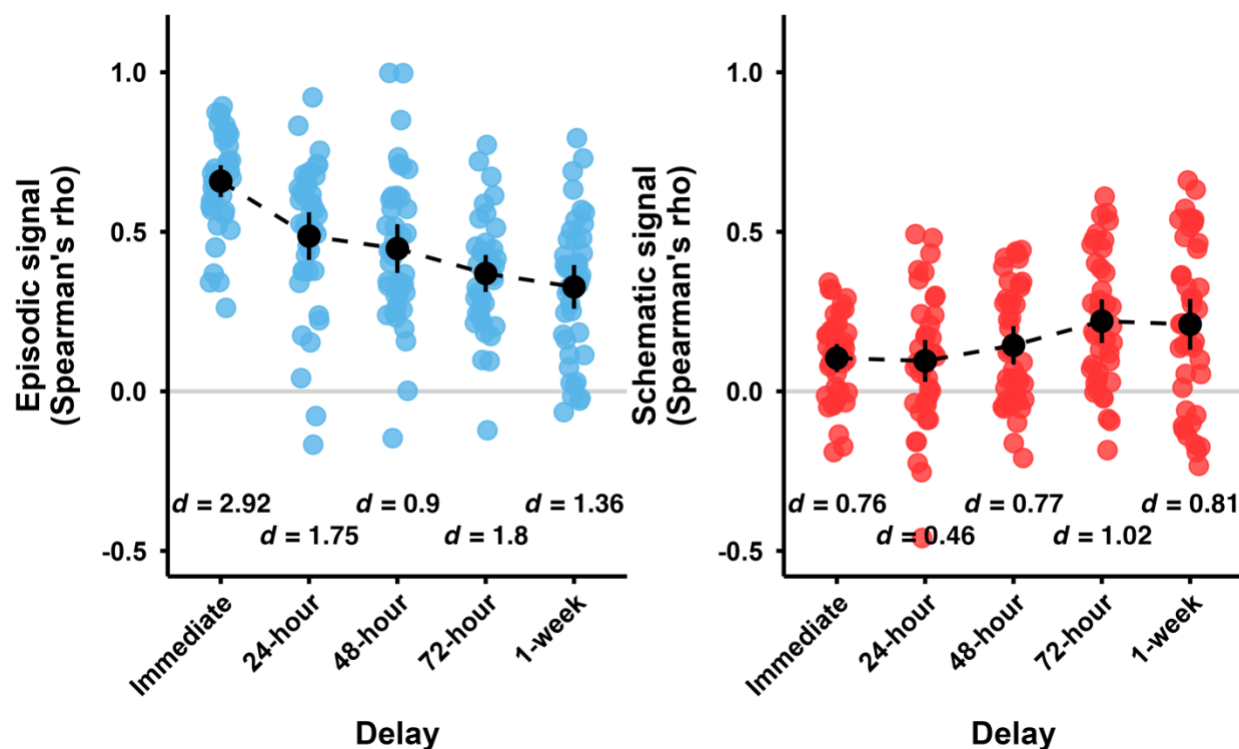
*Note.* Blue dots represent each participant's Episodic signal. Red dots represent each participant's schematic signal. Faint grey lines connect each participant's Episodic signal to their Schematic signal. Black dots represent group means. Error bars represent 95% confidence intervals. Cohen's *d* effect sizes represent differences from zero.

### Episodic and Schematic Signal Over Time

Next, we examined how episodic and schematic signal changed over time when participants were explicitly trying to retrieve the scrambled order of events (i.e., Episodic instruction). We predicted that episodic signal would decrease over time (i.e., increasingly so over longer delays) and that schematic signal would increase over time. Our results supported both hypotheses (Figure 6). A 2 (*signal type*: episodic, schematic; within-subject) x 5 (*delay*: immediate, 24hr, 48hr, 72hr, 1-week; between-subject) mixed-design ANOVA produced a significant interaction between signal type and delay ( $F(4, 196) = 10.33, p < .001, \eta^2_G = 0.11$ ). To unpack the interaction, we tested for simple effects of delay within episodic and schematic signal separately, resulting in significant effects of delay for both signal types (*episodic signal*:  $F(4, 196) = 9.29, p < .001, \eta^2_G = 0.16$ ; *schematic signal*:  $F(4, 196) = 3.59, p = .007, \eta^2_G = 0.07$ ). See Table B8 in Appendix A for descriptive statistics of episodic and schematic signal over time; see Table B9 in Appendix A for complete one-sample  $t$ -test ( $\mu = 0$ ) results and effect sizes; See Table B10 in Appendix A for complete within-signal, between-delay pairwise comparisons; See Table B11 in Appendix A for complete between-signal, within-delay pairwise comparisons. We then applied polynomial contrasts to investigate how episodic and schematic signal changed over delay. Polynomial contrasts indicate that episodic signal is best described as a linear decrease across delays ( $t(196) = -5.72, p < .001$ ), while schematic signal increases linearly ( $t(196) = 3.53, p < .001$ ). To determine how episodic and schematic signal relate to one another, we conducted a Pearson correlation between episodic and schematic signal, collapsing across all delays. Episodic and schematic signal were negatively correlated ( $r(199) = -0.27, p < .001, 95\% \text{ CI } [-0.39, -0.13]$ ), suggesting that participants with low episodic signal tended to have high schematic signal, and vice versa.

Figure 6

Performance on temporal order memory test (Episodic instruction) over time



Note. Blue dots represent each participant's Episodic signal. Red dots represent each participant's schematic signal. Black dots represent group means. Error bars represent 95% confidence intervals. Cohen's  $d$  effect sizes represent differences from zero.

### Simulation Analysis

Next, we conducted a simulation to determine whether the increase in schematic signal over time could occur by chance. To this end, we randomly generated vectors of 1 to 26 to simulate our temporal order memory test, and then randomly selected vectors to match each participant in our human data in terms of episodic signal. Then we calculated schematic signal from our episodic signal-matched simulated data. In doing so, we could test whether the above chance schematic signal could be observed in randomly generated memory data, or whether it was a specific property of human memory performance.

We generated 10,000,000 randomly scrambled vectors and calculated their episodic and schematic signals. We then randomly selected simulated vectors that had identical episodic signals to one human participant, across all participants in all delays. This resulted in a simulated dataset that was 1-to-1 matched in terms of 1 episodic signal with our human data. We then calculated the mean episodic and schematic signal in this simulated sample. Next, we repeated this process 1000 times, resulting in 1000 simulated episodic signal group means and 1000 simulated schematic signal group means for each of the five delays.

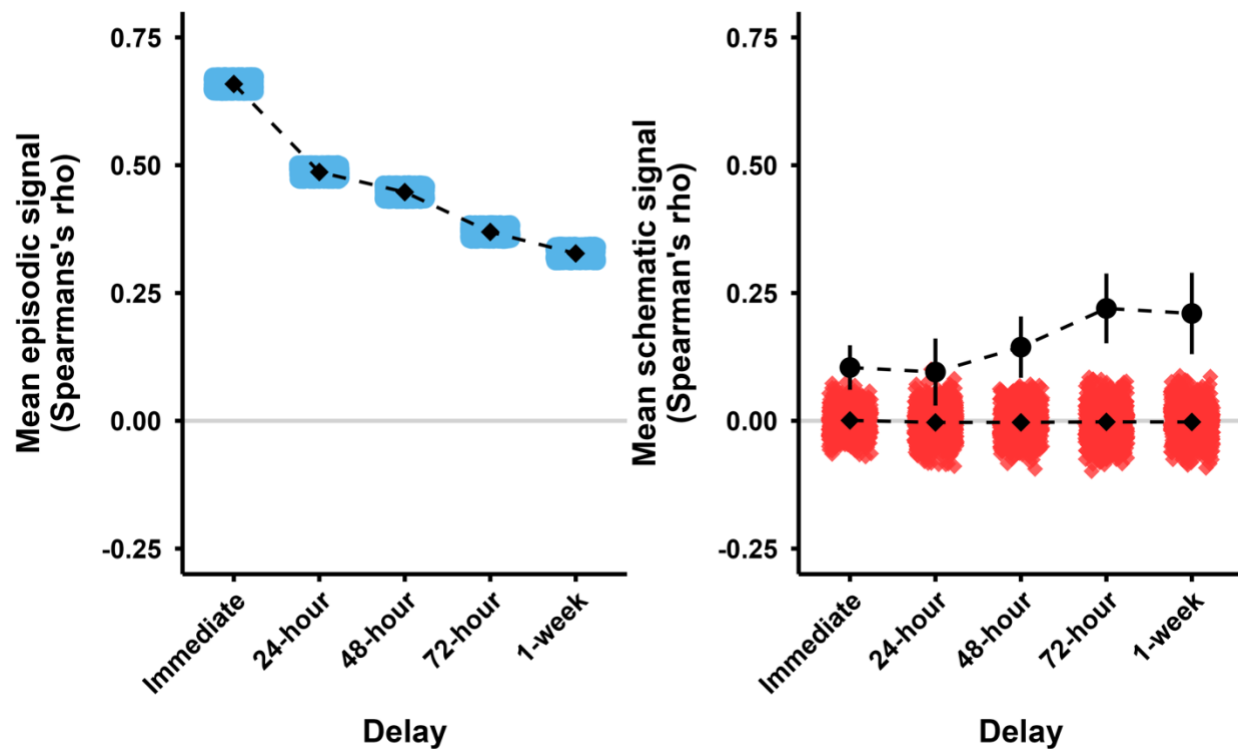
Using the simulated schematic signal as a null distribution, we used permutation testing to determine whether the schematic signal observed in our human data was likely to have occurred by chance. Specifically, we calculated how many times a simulated schematic signal group mean was equal to or greater than our observed human group mean for each delay and divided this number by the total number of simulations ( $n = 1000$ ), resulting in a  $p$ -value. Across all delay conditions, we found that our human data had significantly higher schematic signal than our simulated data, despite being matched for episodic signal (Immediate, 48-hour, 72-hour, and 1-week:  $p < .001$ ; 24-hour:  $p = .001$ ) (Figure 8).

Using the same simulated data, we were also able to determine whether the negative correlation between episodic and schematic signal in our human data could be observed by chance. To this end, we calculated the Pearson correlation between episodic and schematic signals within each one of the simulation samples and compared these correlation values to the overall episodic-schematic correlation found in the human data. Again, we found that the negative correlation between episodic and schematic signal in humans was not observed in our simulated data ( $p < .001$ ) (Figure 9). These results further confirm that the above-chance schematic signal observed in our human memory data are unlikely to be an artifact of our

experimental design or to have occurred by chance. Instead, the immediate presence of schematic signal and its increase over time is a characteristic of human memory performance.

**Figure 7**

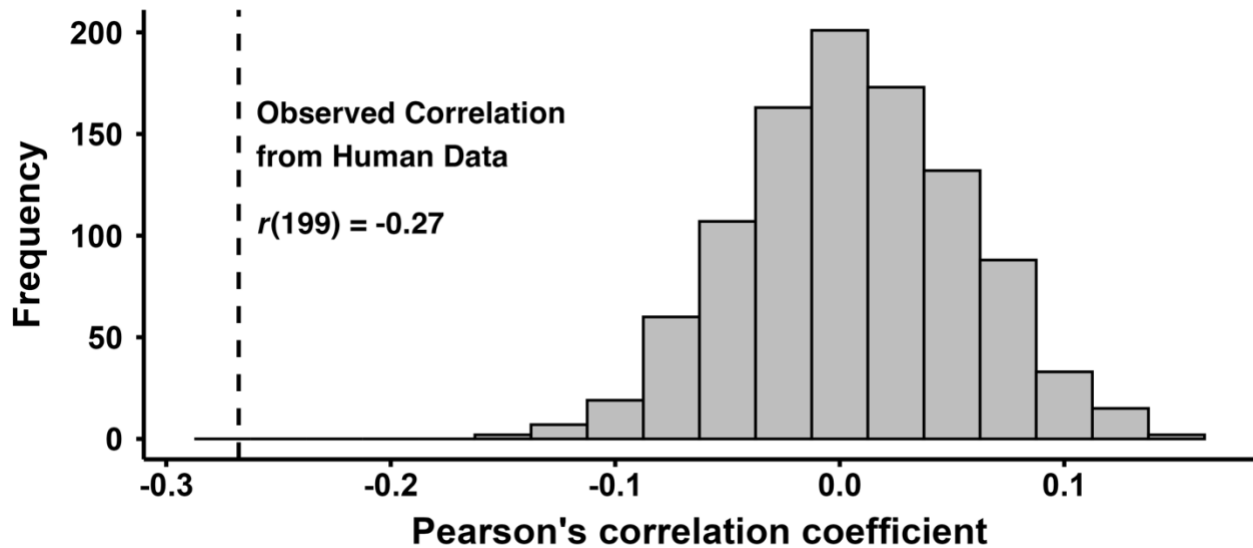
*Results from simulation analysis of episodic and schematic signal over time*



*Note.* Blue dots represent simulation Episodic signal group means (jittered for visualization purposes; all Episodic signal group means are identical). Red dots represent simulation Schematic signal group means (not jittered). Black diamonds represent the mean of the 1000 simulation group means. Black dots represent Schematic signal group means from human participants.

**Figure 8**

*Results from simulation analysis of episodic-schematic Pearson correlation*



*Note.* Grey bars of the histogram represent the frequency of episodic-schematic correlations observed in the simulation data. The dashed line represents the episodic-schematic correlation observed from human participants ( $r(199) = -0.27$ ).

### **Transition Strategy Over Time**

Our previous analyses relied on a single estimate of episodic and schematic signal from the temporal order memory task. However, one could conceptualize the placement of every event as its own decision, and the placement of each contiguous event would be best explained by its own strategy. To this end, we conducted a transition-wise strategy analysis where we estimated the most likely strategy for every pair of contiguous events within an individual's sequence of remembered events from the temporal order memory test. The analysis approach was inspired by Antony et al., (2024), where it was applied to free recall of a narrative film. In brief, the analysis hinges on creating event-by-event transition matrices which reflect how an individual would

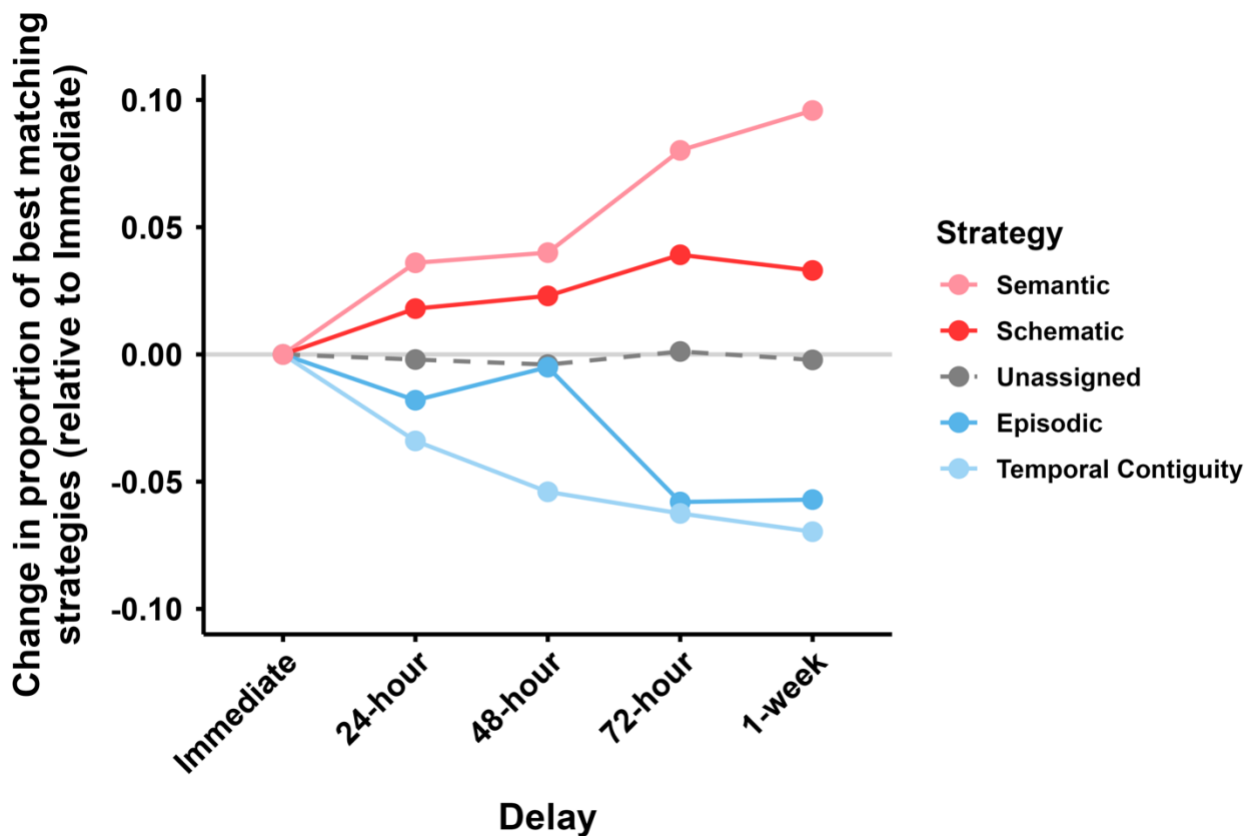
perform the temporal order memory if they were perfectly following a specific strategy (Figure 10). Then, for every pair of contiguous events within an individual's temporal order memory test, we can compute the most likely strategy to have been used. In this way, we can quantify an individual's memory performance in terms of the proportion of transitions that were best explained by each of the predefined strategies. Templates were generated for four different strategies: (i) Episodic (i.e., perfectly following the order of events presented during the study phase); (ii) Schematic (i.e., perfectly following the original order of events in the never-before-seen unscrambled story); (iii) Temporal contiguity (i.e., a graded version of the Episodic strategy, inspired by temporal contiguity effects in recall; Kahana, 1996; Kahana et al., 2022); and (iv) Semantic (i.e., a graded version of the Schematic strategy, where transitions are determined by semantic similarity between events; Cer et al., 2018).

A 4 (*strategy*: episodic, temporal contiguity, schematic, semantic; within-subject) x 5 (*delay*: immediate, 24hr, 48hr, 72hr, 1-week; between-subject) mixed-design ANOVA resulted in a significant interaction between strategy and delay,  $F(8.65, 423.92) = 3.74, p < .001, \eta^2_G = 0.07$ . Significant simple effects of delay were observed for the episodic ( $F(4, 196) = 3.27, p = .013, \eta^2_G = 0.06$ ), temporal-contiguity, ( $F(4, 196) = 4.84, p = .001, \eta^2_G = 0.09$ ), and semantic similarity ( $F(4, 196) = 4.1, p = .003, \eta^2_G = 0.08$ ) strategies, however, there was no simple effect of schematic strategy ( $F(4, 196) = 2.02, p = .093, \eta^2_G = 0.04$ ). Polynomial contrasts indicated that the episodic and temporal contiguity strategies were best described as a linear decrease over delay (*Episodic*,  $t(196) = -3.15, p = .002$ ; *Temporal contiguity*,  $t(196) = -4.19, p < .001$ ) while the schematic and semantic strategies increased over delay (*Schematic*,  $t(196) = 2.61, p = .01$ ; *Semantic*,  $t(196) = 3.96, p < .001$ ). Overall, our transition-wise strategy analysis replicated our earlier conclusions. Memory for an event-scrambled story becomes less faithful to the original

experience over time. Instead, our memory increasingly resembles the never-presented unscrambled version of the story.

**Figure 9**

*Results of transition strategy analysis*



*Note.* Event transitions were deemed ‘unassigned’ if the likelihood of any strategy was less than what would be expected by chance ( $1/25 = 0.04$ ).

#### Chapter 4: Discussion

How does the composition of an episodic memory change over time? In this thesis, participants were presented with an event-scrambled story and were asked to perform a temporal order memory test where they would sort the events into the temporally scrambled order in which they were presented during study. Then, by correlating a participant’s remembered sequence of events with the event-scrambled story itself and the original never-read unscrambled

version of the story, we could estimate episodic and schematic contributions respectively. Over the course of a week, we found that (i) episodic signal decreased, (ii) schematic signal increased, and (iii) episodic and schematic signal showed a weak negative correlation with one another. Simulation and follow-up analyses confirmed that these effects are unlikely to occur by chance. Therefore, over time our memories for experiences lose episodic details and gain contributions from schema and general knowledge – so much so that incoherent experiences become increasingly coherent just by holding it in memory.

### **Forgetting Over Time**

We found that participants' ability to preserve the event-scrambled story significantly diminished as retention interval increased. With increasing delays, participants were less able to place the story events into the order in which they had been presented to them. This finding is not surprising. It has been well over a century since Ebbinghaus characterized our tendency to rapidly forget details from an experience (Ebbinghaus, 1885). However, one aspect of our results that is somewhat surprising is that forgetting over time is best fit by a linear function. Typically, forgetting over time resembles a curve defined by an immediate steep drop followed by a gradual plateau that can be defined using a power-law function (Kahana, 2022; Rubin, 1982). It's worth noting that there were two participants in the 48-hour delay condition that did exceptionally well and when they are excluded from the polynomial function contrasts analysis, the loss of episodic detail over time is fit by both a linear and a quadratic function. However, another explanation may be found in considering the memory tests used. Our paradigm does not involve free recall - where the typical forgetting curve and power-law of forgetting are most often seen. Instead, participants were presented with all the events of the story and are required to sort them all into their response on the temporal order memory test. Therefore, participants were unable to

completely forget details, events in this case. Additionally, the environmental support associated with a recognition-like task as compared to explicit recall of discrete event details may provide additional rationale for a linear decrease in episodic signal as opposed to a power-law curve (Haist et al., 1992; Kahana et al., 2022). Considering this in context of research on the decay of memory in recognition or cued-recall paradigms, a one-week delay may not provide sufficient time for memory decay to fit a power-function (Kahana et al., 2022).

### **Rationalization Over Time**

A more striking finding was that schematic signal increased linearly over time. This suggests that the passage of time does not only result in the loss of episodic details (Tulving, 1972). Instead, participants systematically filled in the gaps in memory with their general understanding of how stories and events unfold. If participants were only losing episodic detail, we would not expect to see increases in schematic signal (See Results: Simulation; Figure 8). This distorted recall corresponds to Bartlett's notion of rationalization wherein idiosyncratic details of an experience are replaced in memory by general or stereotypical details (Bartlett, 1932; Bergman & Roediger, 1999). However, in our experiment participants weren't freely recalling their experience and therefore were unable to distort specific details. Rather, they were presented with all the information needed to accurately recall their experience, including awareness that the events of the story they read were presented in a random order. Given that participants were aware that their task was to order the events into the incoherent and random order that they read them, and that they were at no point presented the unscrambled/coherent version of the story, it is striking that some level of coherence is present and increases over time.

One possibility may have been that memories were not undergoing rationalization. Perhaps participants may not have tried to recall the experience as it was, and instead, they were

explicitly using their knowledge to guess where forgotten events belonged in the sequence. I believe this is unlikely. Participants were explicitly told twice that the story they read was out of order, with only three participants out of the total sample ( $N = 201$ ) stating that they didn't realize the story was scrambled. They also performed a practice test with a scrambled 4-sentence story to ensure they understood that they were being asked to place the events into the scrambled order in which they were presented. Therefore, participants knew that relying on knowledge for how events typically should unfold would not be an optimal strategy. Furthermore, we only included participants in our sample if they explicitly endorsed that they “arranged the events in line with how [they] remembered them being shown to [them]” during the temporal order memory test. Despite participants understanding that relying on their general knowledge of stories would not be helpful, schematic signal was reliably above zero, even increasing with longer delays. Therefore, despite knowing that the story was incoherent and explicitly trying to recreate the incoherent story from memory, participants' memory for the story became increasingly coherent.

### **When Does Rationalization Take Place?**

The presence of above-zero schematic signal in the Episodic (Immediate) condition suggests that some level of rationalization occurs rapidly – either during encoding or immediately after. Considering these results in tandem with schema theory and notions of schema-mediated encoding (Alba & Hasher, 1983; Anderson, 1984; Antony et al., 2017; Baldassano et al., 2018; Bellana et al., 2021; Gilboa & Marlatte, 2017) it may be possible that reading the event-scrambled story elicits activation of scripts and schema which in turn may result in restructuring of episodic information during encoding. This notion also gains support from text comprehension literature (Kintsch & van Dijk, 1978; Kintsch, 1992; Kintsch, 1993;

Mandler & Johnson, 1977; van Dijk & Kintsch, 1983) as well as related situation model literature (Brownstein & Read, 2007; Radvansky & Zacks, 2011; Zacks, 2020; Zwaan & Radvansky, 1998). Mandler & Johnson (1977) propose that knowledge of typical story structure (i.e., story schema, Bartlett, 1932) is used to guide both encoding and recall of stories. Van Dijk and Kintsch (1983; Kintsch, 1992) propose a text comprehension theory that argues that comprehension of text information occurs at different levels and one of these levels involves integration of the text content with the reader's prior knowledge. According to both of these ideas, it may be that as participants read the event-scrambled story the content is integrated with their prior knowledge of how stories typically unfold, influencing how the content is encoded. Related situation model literature suggests that as people undergo an experience causal and temporal connections are important features that guide the development and evolution of an ongoing situation model (Brownstein & Read, 2007; Song et al., 2021; Zwaan & Radvansky, 1998). Song et al. (2021) found that as participants watched a temporally scrambled movie, a network of brain regions known to be involved in narrative engagement (i.e., default mode network) underwent activity reconfigurations as new causal connections were discovered, suggesting that these causal connections between narrative events were guiding the integration and comprehension of the temporally scrambled story. When considering our findings, this literature may suggest that as readers are building a situation model of the event-scrambled story, temporal and causal connections between story events are influencing the overall structure of the ongoing situation model and altering the state of the event representation that will be encoded.

While there is theoretical support for rationalization occurring during or immediately following encoding, the possibility that rationalization occurs primarily during memory maintenance or retrieval/construction cannot be ignored. The increase in rationalization over

time provides some indication that this process does not occur strictly at encoding. It suggests that factors are influencing either how the information is maintained in memory or how the memory is retrieved and constructed in order to recall. One possibility is that as participants are attempting to recall and reconstruct the order of events from the event-scrambled story and they have less access to episodic details over time, they increasingly rely on schema and prior knowledge to fill in the gaps of their memory. This possibility aligns with a stream of cognitive aging literature that proposes that prior knowledge and schema are leveraged to compensate for impaired episodic memory function associated with age (Castel, 2005; Ramey et al., 2024; Umanath & Marsh, 2014). According to this work, schemas are relied upon to compensate for impaired episodic memory associated with cognitive aging, however, this notion doesn't seem to necessitate age as the limiting factor on episodic memory performance. If reliance upon schema is used as a compensatory mechanism when episodic memory is impoverished, this provides another rationale as to why rationalization occurs, especially when faced with a difficult recall task, and why it can increase over time. This proposal aligns with recent literature outside of cognitive aging that indicate that regions of the brain that are associated with schema activation are instantiated both during encoding and retrieval of narratives (Masís-Obando et al., 2022).

Another factor that may influence rationalization is causal, temporal and semantic connections between narrative events (Antony et al., 2024; Chen & Bornstein, 2024; Frisoni et al., 2024; Lee & Chen, 2022). Chen & Bornstein (2024, p. 772) highlight the "privileged status of causal associations in memory retrieval" by presenting both behavioural and neuroimaging research that demonstrate how our memories are guided and shaped by causal connections between events. For example, Lee & Chen (2022) demonstrate that events with high causal-centrality (events that are highly causally related to other events) were better remembered than events with low causal-

centrality and recall of events with high semantic-centrality (events that highly semantically related with other events) was associated with stronger activation of regions in the default-mode network and higher inter-subject correlation during event reinstatement. This privileged status of causal and semantic relationships in memory provides additional rationale as to why memory for an event-scrambled story becomes increasingly coherent over time as accurate episodic details are forgotten and causal and semantic relationships between events remain salient in memory.

### **Why Might Rationalization Take Place?**

Whether episodic memory is primarily preservative or constructive in nature, it seems odd that a system that helps us remember the past should be so susceptible to distortions or inaccuracies. One explanation for the utility of rationalization comes from an economical perspective. The basis of this perspective is that resources allocated to long-term memory are finite and therefore it is impractical or impossible to preserve all of our experiences as they occurred. Along these lines, we may employ a sort of data compression approach where reductions in resource demand on our episodic memory system are achieved by allowing for a loss of detail (i.e., rationalization; Nagy et al., 2020; Nagy et al., 2025). Memory compression in this case can be thought of as discarding irrelevant and idiosyncratic details of an experience, reducing certain details to gist-like representations that can be abstracted based on prior knowledge of regularities upon reconstruction, and if necessary, maintaining detailed representation of critical details. Nagy et al. (2025) suggest that semantic memory maintains a constant and ever-adapting model that guides our experience and how our episodic memory functions - what information will be discarded, what information should be maintained with minimal compression, and what information can be heavily compressed to be later abstracted and reconstructed. In this sense, prior knowledge is leveraged to find a balance between fidelity of

episodic memories and resource allocation for remembering. Based on our data, it seems possible that while reading the event-scrambled story - a relatively complex narrative that deviates from prior knowledge of how stories unfold - the exact order of events undergo compression to reduce resource demands on memory. This, in turn, could result in a rationalized memory of the story that better corresponds to prior knowledge. Along these lines, literature has shown that different features of information can influence the resource demand of remembering. For example, new information that strongly corresponds with prior knowledge may be more easily encoded or integrated into prior knowledge (Antony et al., 2017; DeWitt et al., 2012), information that lends itself to techniques such as chunking can be more effectively remembered (Cowan, 2001; Mathy & Feldman, 2012), or expertise in a subject that is relevant to the ongoing experience may lead to better encoding strategies (Gobet & Simon, 1996, 1998). Therefore, it seems that information that requires fewer resources to encode seems to be better remembered.

Another potential explanation for why rationalization and memory distortions are common in episodic memory becomes clearer when we consider what episodic memory is for. Intuitively, it seems that the fundamental role of episodic memory is to preserve the past. However, episodic memory is also critical for generalization and decision-making (McClelland et al., 1995; Richards & Frankland, 2017; Schacter et al., 2017) as well as simulating novel future experiences (Addis et al., 2007; Schacter & Addis, 2007; Schacter et al., 2007). Theory and research on generalization from episodic experiences has long emphasized the importance of forgetting alongside remembering (Bjork & Bjork, 1992; James, 1890; McClelland et al., 1995; Richards & Frankland, 2017; Sweegers & Talamini, 2014). If we are to use past experiences to guide and shape our ongoing experience, we ideally want to extract useful knowledge from statistical regularities that we can predict and forget ‘outlier’ experiences that will not hold

practical implications for our future. Considering the task of reading an event-scrambled story in this light highlights the utility of extracting the statistical regularities of the story, aspects of the story that somewhat align with schema and prior knowledge, to be encoded and discarding 'outlier' details of the experience such as the particular scrambled order of events to be forgotten. A similar idea may be applied when we consider the utility of episodic memory for imagining novel experiences. The constructive episodic simulation hypothesis proposes that we have a system that performs constructive episodic simulation by flexibly using event information from past experience to construct episodic simulations of the past (i.e., episodic memory), present, or future (Schacter & Addis, 2007). According to this notion, if details from episodic memory form the building blocks from which an imaginative version of the future is constructed, it again seems impractical to store an exact episode of an incoherent story. Rather, by extracting gist-like features from the story that efficiently coincide with prior knowledge it seems more feasible and applicable to use that information to simulate a future experience. This gist-like representation may even be an extraction that the story was incoherent and event-scrambled without necessarily maintaining an accurate memory of the exact sequence of events. This notion applied to our task would predict impaired recall of the exact order of events and a likelihood of systematic distortion that coincides with prior knowledge of how similar experiences (i.e., stories) have unfolded. Therefore, it may be impractical to spend finite memory resources on high fidelity recall of an incoherent experience that does not coincide with prior knowledge nor will be useful for generalization and decision-making in the future.

### **Limitations and Future Directions**

While this paradigm is well suited to efficiently capture metrics of episodic and schematic memory composition it poses several limitations. First and foremost is the memory

test format and the non-naturalistic recall. Presenting participants with the 26 event descriptions and forcibly asking participants to reorder all of them allowed for the simple correlation analyses, however, this test format does not accurately reflect typical recall. This format does not allow for true forgetting because all details of the experience are available to the participants. By presenting participants with all of the events of the story, it may introduce some form of memory distortion wherein events that would have been entirely forgotten now need to be assimilated into what the participant does recall occurring. A free recall paradigm would allow for more accurate representations of recall and forgetting but do not provide the computational simplicity that this paradigm offers.

A second limiting factor is the use of only a single story. As discussed throughout my thesis, narrative information (e.g., causal and semantic connections) can have a large influence on how an experience is remembered (Kintsch & van Dijk, 1978; Mandler & Johnson, 1977). Emotionality of an experience can also have a strong influence on how an experience is recalled (Kensinger, 2004). The story we used, *The Paper Menagerie* by Ken Liu, contains many causally and semantically related events and is highly emotional. A future direction or next step is to reproduce this research with narrative stimuli that differ in the number and strengths of causal and semantic connections as well as emotionality (Grall & Finn, 2022). Additionally, it may be worth investigating how a less narrative stimulus is remembered, perhaps an engaging but non-narrative non-fiction text.

Another future direction is to apply this paradigm to a context where episodic memory function may be altered. One such context is cognitive aging. This is an interesting avenue to explore because there are several reasons why we might expect younger and older adults to perform differently on this task. One such reason is that episodic memory is typically impaired in

older adults, relative to younger adults (Addis et al., 2008; Levine et al., 2002; McIntyre & Craik, 1987). Levine et al. (2002) and Addis et al. (2008) demonstrate that when recalling autobiographical events older adults tend to produce fewer internal (i.e., episodic) details than younger adults and a greater number of external (i.e., semantic) details than younger adults. This age-related change has been described as older adults producing more gist-like episodic memories (Grilli & Sheldon, 2022). These studies suggest that older adults fill in the gaps of their episodic memories with schematic knowledge (i.e., increased external details). Other research suggests that schema may not necessarily be used to compensate for forgotten details but rather may provide a scaffold to support better memory for schema-consistent information (Umanath & Marsh, 2014; Whatley et al., 2021). According to these two ideas, we would expect older adults to show stronger rationalization over time than younger adults as they more readily rely on schematic knowledge to assist in recalling the order of events from their experience reading the event-scrambled story. On the other hand, a study by Naveh-Benjamin and colleagues (2007) found that older adults tend to use less relational strategies during encoding and retrieval which may suggest that in our paradigm older adults may not be as influenced by the causal and semantic connections inherent throughout the event-scrambled story. This provides a rationale to hedge our expectations about how much stronger the effect of rationalization may be in older adults compared to younger adults in this paradigm.

Another interesting context to explore with this paradigm is how participants with damage to certain brain regions perform on our task. The hippocampus is well known for being critical for episodic memory (Moscovitch & Winocur, 1992; Nadel & Moscovitch, 1997; Scoville & Milner, 1957) and lesions to the hippocampus are known to result in significant episodic memory impairments (Andelman et al., 2010; Rosenbaum et al., 2005; Rosenbaum et

al., 2014; Scoville & Milner, 1957). Following this, we may expect to see that hippocampal amnesics would show exceptionally low episodic signal and increased schematic signal due to compensatory mechanisms as compared to healthy controls. This investigation could shed light on when rationalization takes place; if rationalization is primarily a result of how an experience is encoded, we should see low levels of rationalization, whereas if rationalization is primarily a result of retrieval processes, we would expect to see normal or increased levels of rationalization. Another region of the brain that would be worth investigating is the medial prefrontal cortex (mPFC). The mPFC has been implicated in schema-related processes (Baldassano et al., 2018; Richards et al., 2014; van Kesteren et al., 2010a; van Kesteren et al., 2010b; van Kesteren et al., 2012) and lesions to the mPFC are associated with deficits in schema-related processing (Berkers et al., 2017; Ghosh et al., 2014; Melo et al., 1999; Warren et al., 2014). Following the notion that part of the mPFC's role in episodic memory is schema-related, we might suspect that participants with damage to the mPFC would present reduced rationalization over time compared to healthy controls, stemming from the idea that mPFC damage would result in reduced influence of schema during both encoding and retrieval of the event-scrambled story. These investigations into how participants with different patterns of brain damage perform on the task could shed light on the underlying processes behind rationalization of episodic memories.

## **Conclusion**

The current study has provided an efficient and effective technique to quantify the episodic and schematic composition of memories and has shed light on the course of how these properties of episodic memory change over the course of seven days. This study has demonstrated that forgetting of meaningful content (i.e., stories) is not random but presents as systematic distortions that are influenced by the meaning of the content. We captured patterns of

forgetting in episodic memory that correspond to our predictions and detected that recall took on a more schematic form as the delay between the study phase and test phase increased. We found that the sequence of events of an event-scrambled story tended to be recalled in a more coherent order and this increased coherence became more substantial at longer delays - like the story was becoming unscrambled over time. While our findings do not necessarily uncover the mechanisms underlying rationalization they provide valuable insight into the relationship between forgetting, rationalization, and time. Future studies using this experimental paradigm will be able to investigate the extent to which rationalization occurs at encoding or retrieval and future studies using a modified version of this paradigm will be able to uncover details of the relationship between forgetting and rationalization with a more naturalistic memory task.

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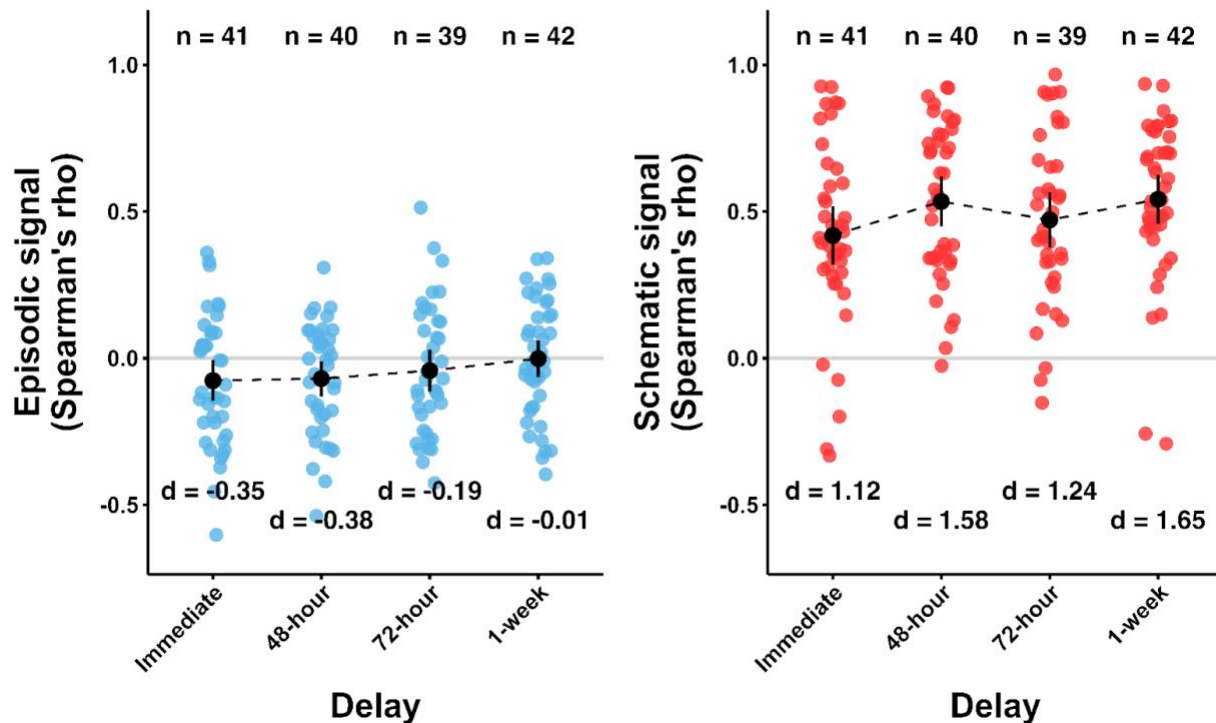
## Appendix A

### Supplementary Analyses

**Signal over time.** My secondary time analysis investigates how episodic and schematic signals change over time when participants are asked to infer the order of events in the original unscrambled story (schematic test; Figure A1). A 2 (signal type: episodic, schematic) x 4 (delay: immediate, 48hr, 72hr, 1-week) mixed-design ANOVA resulted in a significant main effect of signal-type  $F(1, 158) = 351.75, p < .001, \eta^2_G = 0.48$ , however, neither the main effect of delay ( $F(3, 158) = 1.35, p = .26, \eta^2_G = 0.02$ ) nor the interaction between signal-type and condition ( $F(3, 158) = 0.76, p = .52, \eta^2_G = 0.01$ ) were significant. No simple main effects were found. Simple main-effects were then tested for episodic signal ( $F(3, 158) = 1.13, p = .34$ ) and schematic signal ( $F(3, 158) = 1.09, p = .35$ ) and neither were significant.

**Figure A1**

*Schematic Test Results Over Time*



*Note.* Blue dots represent each participant's Episodic signal. Red dots represent each participant's schematic signal. Black dots represent group means. Error bars represent 95% confidence intervals. Cohen's *d* effect sizes represent differences from zero.

***Detailed description of transition strategy analysis.*** To begin this analysis, we defined four strategies that we suspected might be present in participant recall. First, if a participant could remember what event immediately followed the current selected event, they would select said event and this we call the *Episodic strategy*. Second, if a participant couldn't remember exactly what event occurred next in the scrambled story but recall an event that happened around the same time, they might select this event and that we'll call *Temporal contiguity strategy*. The third strategy we theorized is called *Semantic strategy* and would predict moving from the current event to a semantically similar event. Finally, the fourth strategy we considered would predict transitioning from the current event to the event they believed would logically follow according to the story's structure, what we label *Schematic strategy*. Using these conceptual strategies, we produced templates that consisted of transition probabilities for every single move that was possible in the memory test for each of the four strategies (e.g., the probability of moving from *event x* to *event y* according to each of the four strategies). We then investigated the event transitions in participant recall determining which strategy each transition best aligned with and then analyzed how strategy-use differed across conditions.

Episodic strategy was defined as moving from the current event to the event that occurred next in the scrambled story. In the strategy template event transitions that occurred in the scrambled story are assigned values of 1 (i.e., Event 8 followed by Event 21) and all other transitions are assigned a zero (i.e., Event 8 followed by anything other than Event 21).

How we defined and quantified the *temporal contiguity strategy* reflects a modified version of Lag-Conditional Response Probability scores (Lag-CRP; Kahana, 1996; Kahana et al., 2022). The memory test in our experiment is not a free recall task and therefore the calculations involved in generating Lag-CRP scores were not well-suited for our data. To accommodate this, we modified the calculations (detailed below) to produce scores that highly reflect the core properties of the typical Lag-CRP curve, showing higher likelihood for small lags than big lags, and a presence of forward-asymmetry where forward lags are more likely than backward lags. The steps for developing a template for this strategy are outlined here. First, we calculated transition lags for every participant where Event  $n$  was subtracted from Event  $n+1$  (e.g., if a participant placed Event 10 first, immediately followed by Event 13, this would result in a transition lag of +3 ( $13 - 10 = 3$ )). We then counted the number of actual occurrences of all transition lag values separately for each condition (e.g., how many times did a lag of +3 occur in the one-week delay condition?). We then generated and counted all the possible transition lags that could have occurred in participant recall for each condition (e.g., if two participants placed Event 26 anywhere before Event 1 in their recall, there would be two possible opportunities for a transition lag of -25). We then generated mean actual transition lag values and mean possible transition lag values across the five conditions (e.g., the mean actual transition lags for -25 across conditions, and the mean possible transition lags for -25 across conditions). We then calculated a CRP-likelihood score by multiplying the mean actual lags with the mean possible lags, and then scaled these values by dividing by the maximum value to produce scores that range from zero to one. Using these scaled CRP-likelihood values we produced a matrix that contained likelihood values for each possible transition in the memory test.

The third strategy, semantic strategy, is theoretically defined as moving from the current event in the memory test to the most semantically similar event present, based on the event descriptions available to participants. The steps for quantifying the semantic similarity between event descriptions and generating a strategy template are outlined here. First, we used the Universal Sentence Encoder (USE; Cer, 2018) to produce vectors that represented the semantic content of each event description. Then, we calculated the cosine similarity between all the vectors and filled a cosine-similarity matrix – this is the metric that represents semantic similarity between event descriptions. We then normalized the matrix column-wise – we subtracted the minimum value and then divided by the resulting maximum value (ignoring similarity values between an event and itself (e.g., Event 8 and itself)). This resulted in a matrix of semantic similarity values between all events. Cells where an event lined up with itself were assigned values of zero. The matrix was then transposed because our transition strategy analysis searched templates in a row-wise fashion but normalization was done column-wise.

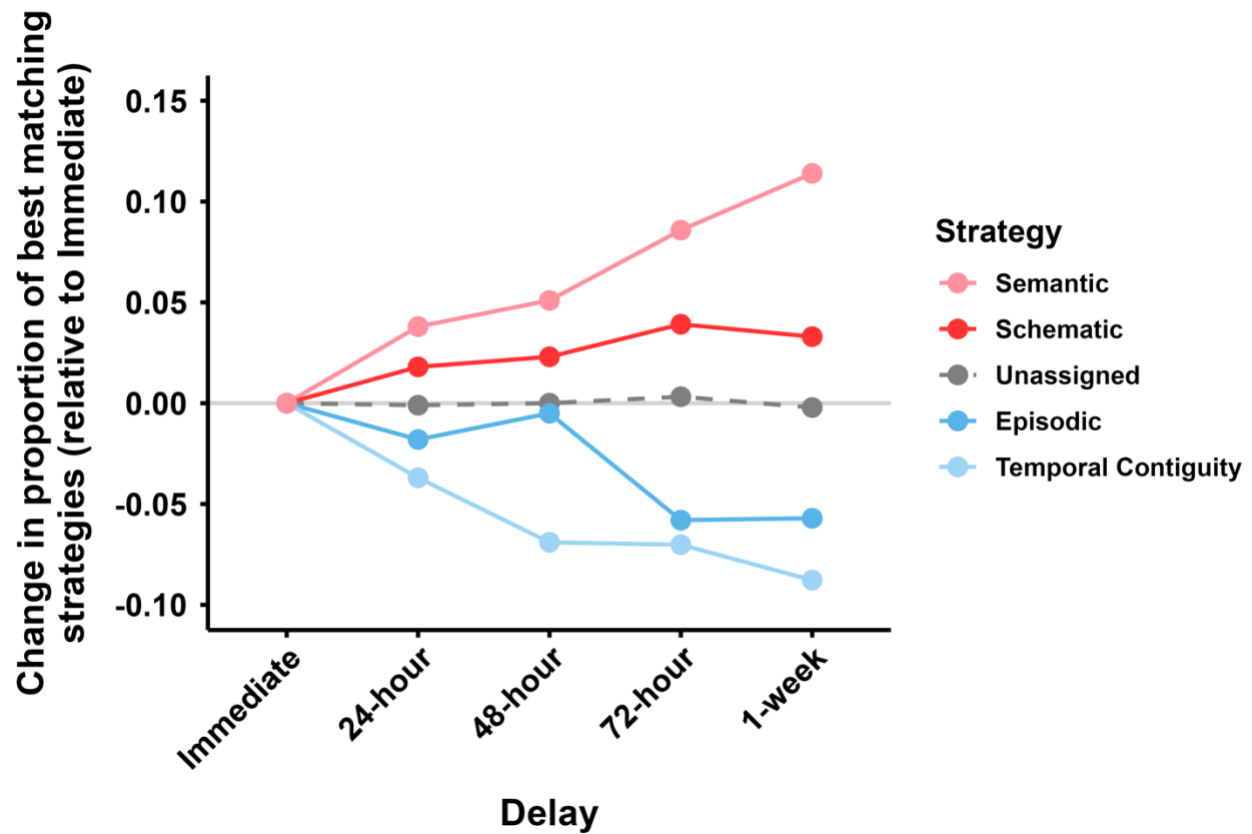
The fourth strategy type, schematic strategy, is defined as moving from the current event to the event that immediately followed in the original, unscrambled story. In the strategy template, transitions that occurred in the unscrambled story were assigned values of one, and all other transitions were assigned values of zero.

***Transition strategy analysis replication.*** A secondary strategy analysis was performed using a different metric for our semantic strategy (Figure A2). In the initial analysis semantic similarity was calculated using USE embeddings that were generated from event description content. In this analysis we used USE embeddings generated from the complete and unaltered event content. Similar to our initial analysis, this 4 (*strategy*: episodic, temporal contiguity, schematic, semantic; within-subject) x 5 (*delay*: immediate, 24hr, 48hr, 72hr, 1-week; between-subject)

mixed-design ANOVA resulted in a significant interaction between strategy and delay,  $F(8.84, 433.29) = 4.79, p < .001, \eta^2_G = 0.09$ . Significant simple effects of delay were observed for the episodic ( $F(4, 196) = 3.27, p = .013, \eta^2_G = 0.06$ ), temporal-contiguity ( $F(4, 196) = 7.39, p < .001, \eta^2_G = 0.13$ ), and semantic ( $F(4, 196) = 5.47, p < .001, \eta^2_G = 0.1$ ) strategies and there was no simple effect of story strategy ( $F(4, 196) = 2.02, p = .093, \eta^2_G = 0.04$ ). Polynomial contrasts again indicated that the presented and temporal-contiguity strategies were best described as a linear decrease over delay (*episodic*,  $t(196) = -3.15, p = .002$ ; *temporal contiguity*,  $t(196) = -5.18, p < .001$ ) while the story and semantic strategies were best described as a linear increase over delay (*schematic*,  $t(196) = 2.61, p = .009$ ; *semantic*,  $t(196) = 4.64, p < .001$ ). Overall, this transition-wise strategy analysis replicated our initial strategy analysis with the main difference being a stronger interaction effect and stronger simple effects of temporal contiguity and semantic strategies.

Figure A2

Results of transition strategy analysis using event content USE embeddings

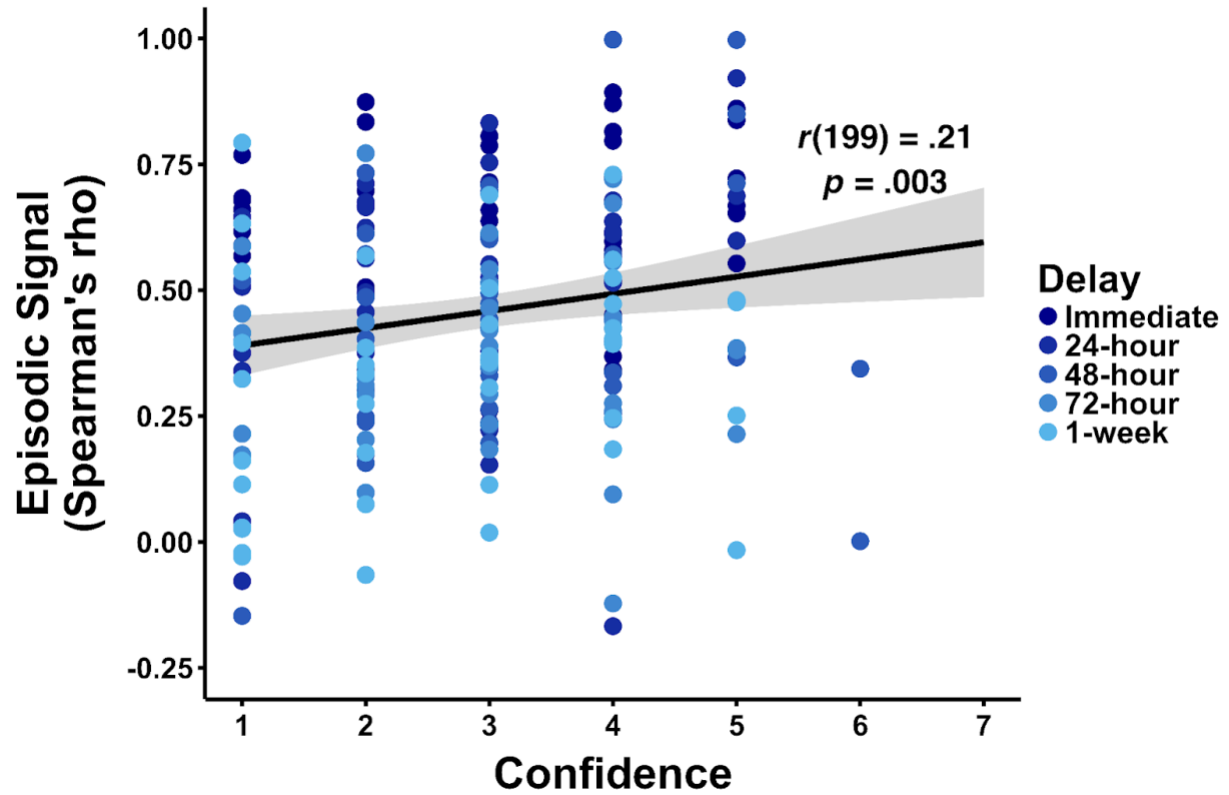


*Note.* Event transitions were deemed ‘unassigned’ if the likelihood of any strategy was less than what would be expected by chance ( $1/25 = 0.04$ ).

*Correlations with self-report measures.* During the experiment participants answered several self-report questions. Here we present graphs that illustrate correlations between episodic and schematic signals and these self-report items.

**Figure A3**

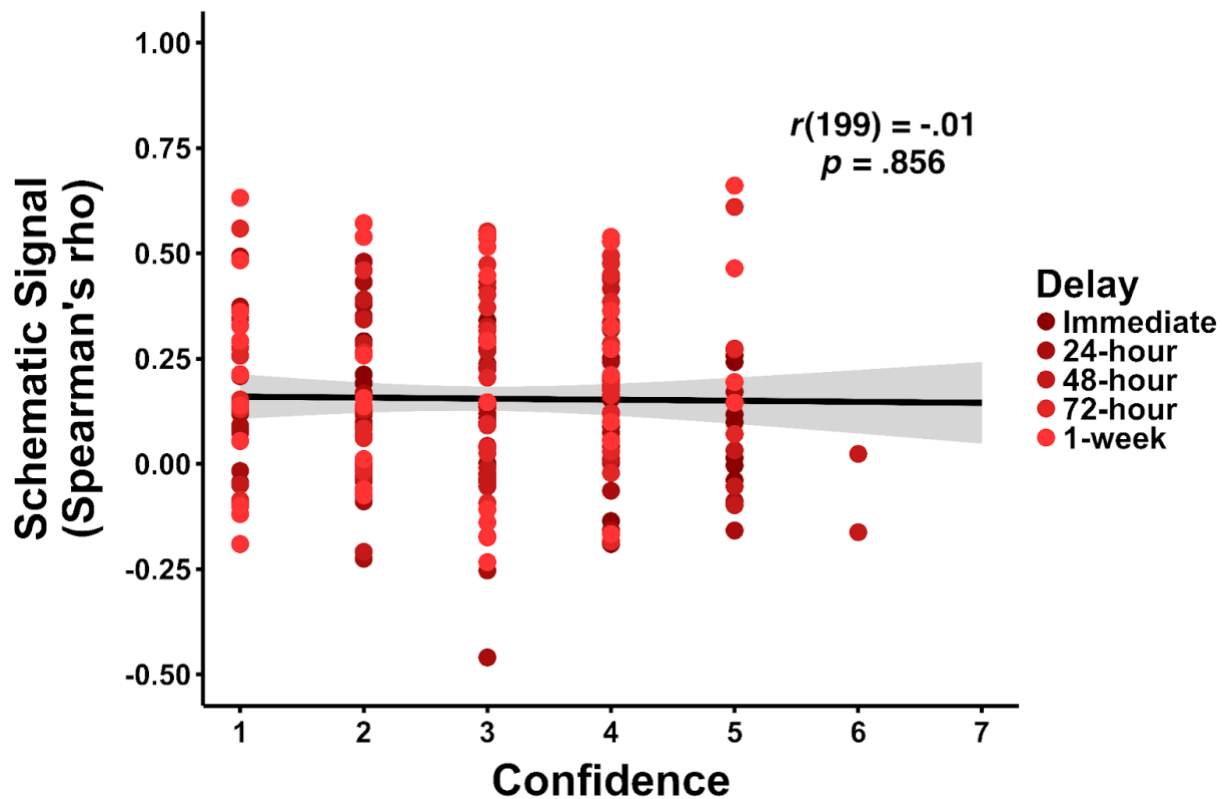
*Correlation between Episodic signal and self-reported confidence in temporal order memory test performance*



*Note.* Confidence as measured by asking participants “how confident are you that you ordered the events correctly in the memory test?” Participants responded on a 7-point Likert-scale where 1 was ‘not at all’ and 7 was ‘very confident’.

**Figure A4**

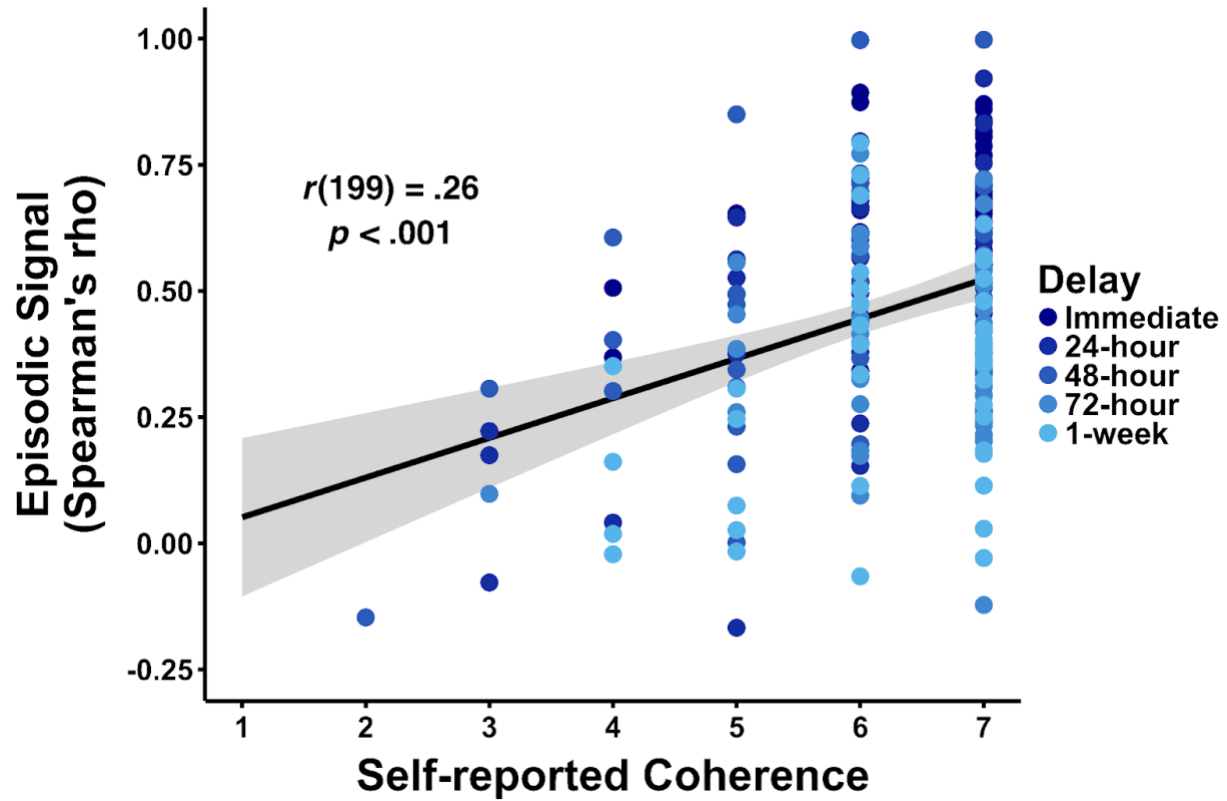
*Correlation between Schematic signal and self-reported confidence in temporal order memory test performance*



*Note.* Confidence as measured by asking participants “how confident are you that you ordered the events correctly in the memory test?” Participants responded on a 7-point Likert-scale where 1 was ‘not at all’ and 7 was ‘very confident’.

Figure A5

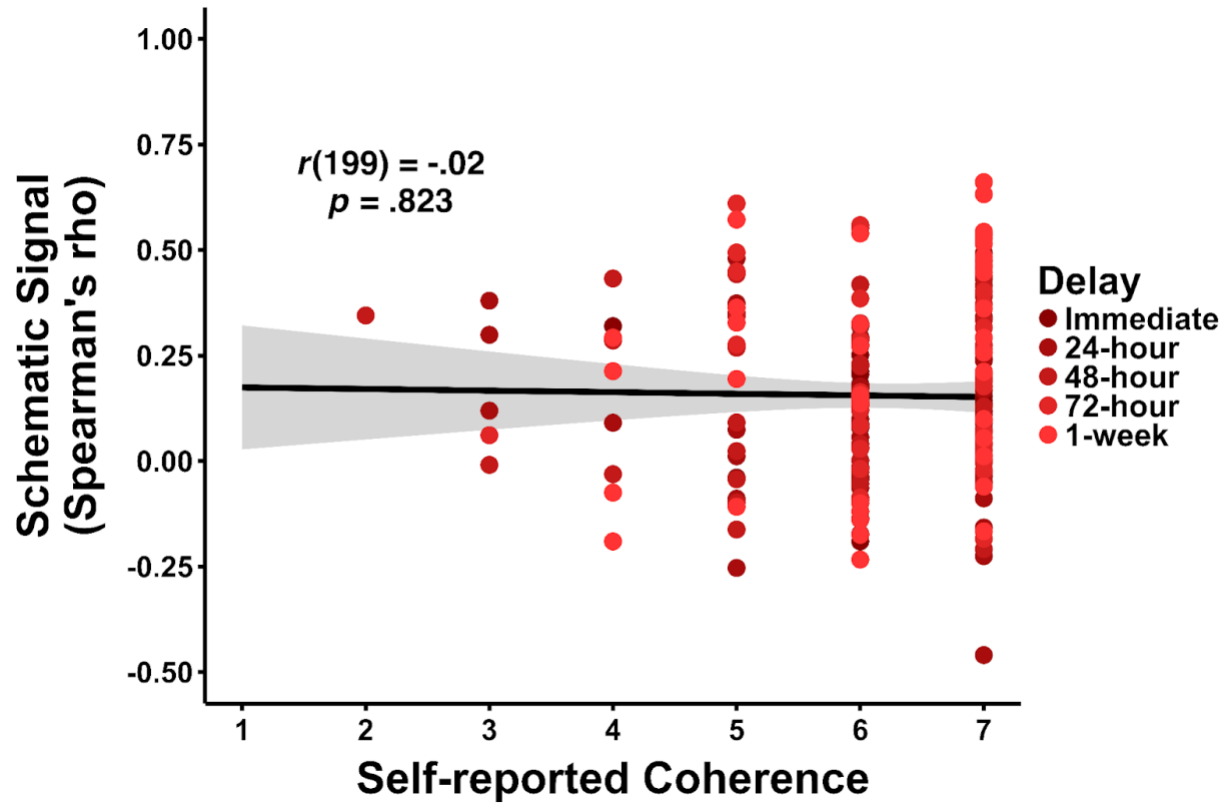
Correlation between Episodic signal and self-reported coherence of the event-scrambled story



*Note.* Coherence as measured by asking participants “despite the scrambled order, were you able to make sense of the story?” Participants responded on a 7-point Likert-scale where 1 was ‘not at all’ and 7 was ‘very much’.

Figure A6

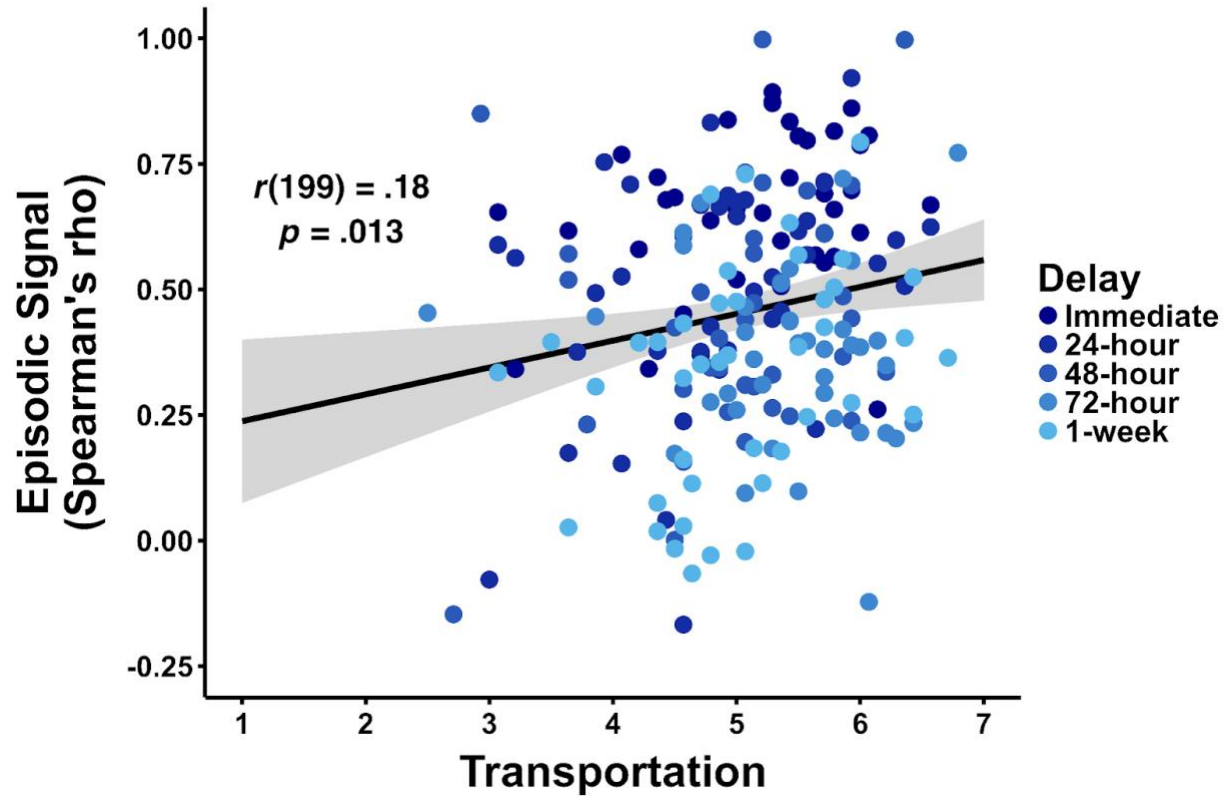
Correlation between Schematic signal and self-reported coherence of the event-scrambled story



*Note.* Coherence as measured by asking participants “despite the scrambled order, were you able to make sense of the story?” Participants responded on a 7-point Likert-scale where 1 was ‘not at all’ and 7 was ‘very much’.

**Figure A7**

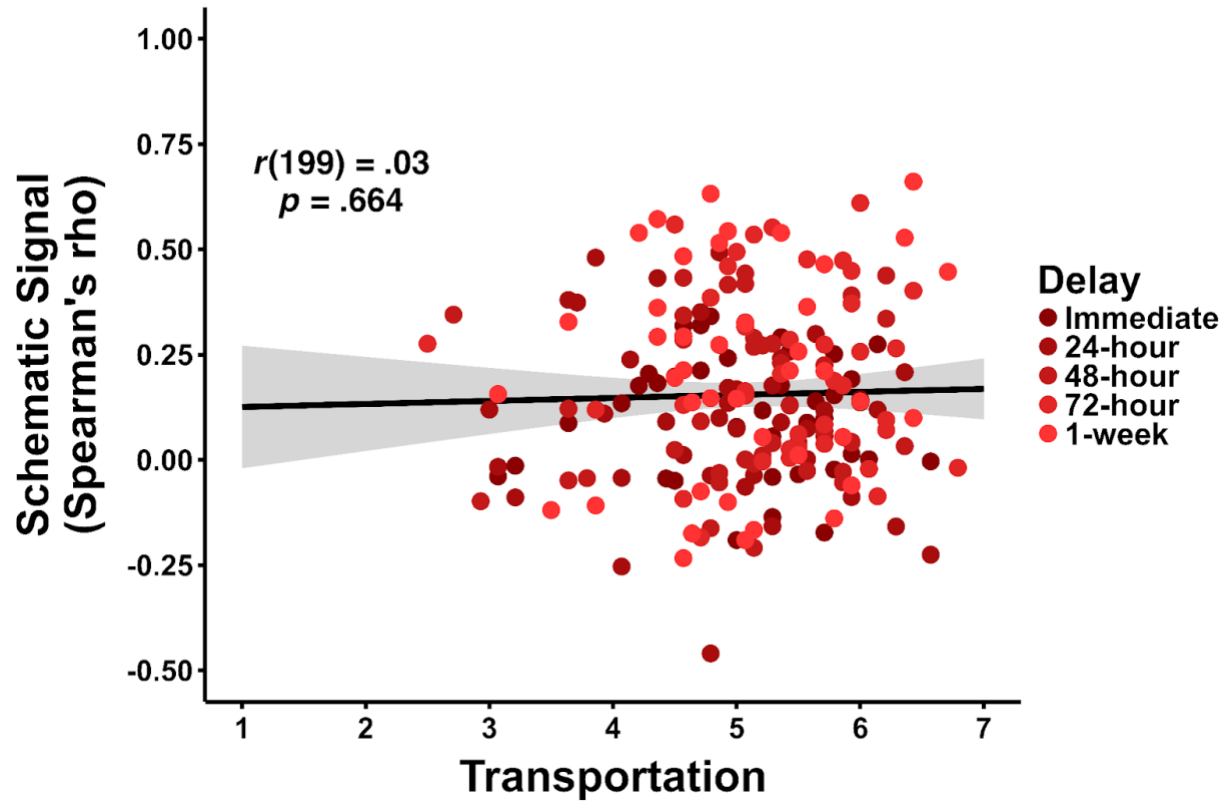
*Correlation between Episodic signal and self-reported transportation into the event-scrambled story*



*Note.* Transportation is a score aggregated from participants' responses to the Narrative Transportation Questionnaire (Green & Brock, 2000). See Methods: Materials: *Narrative Transportation*.

**Figure A8**

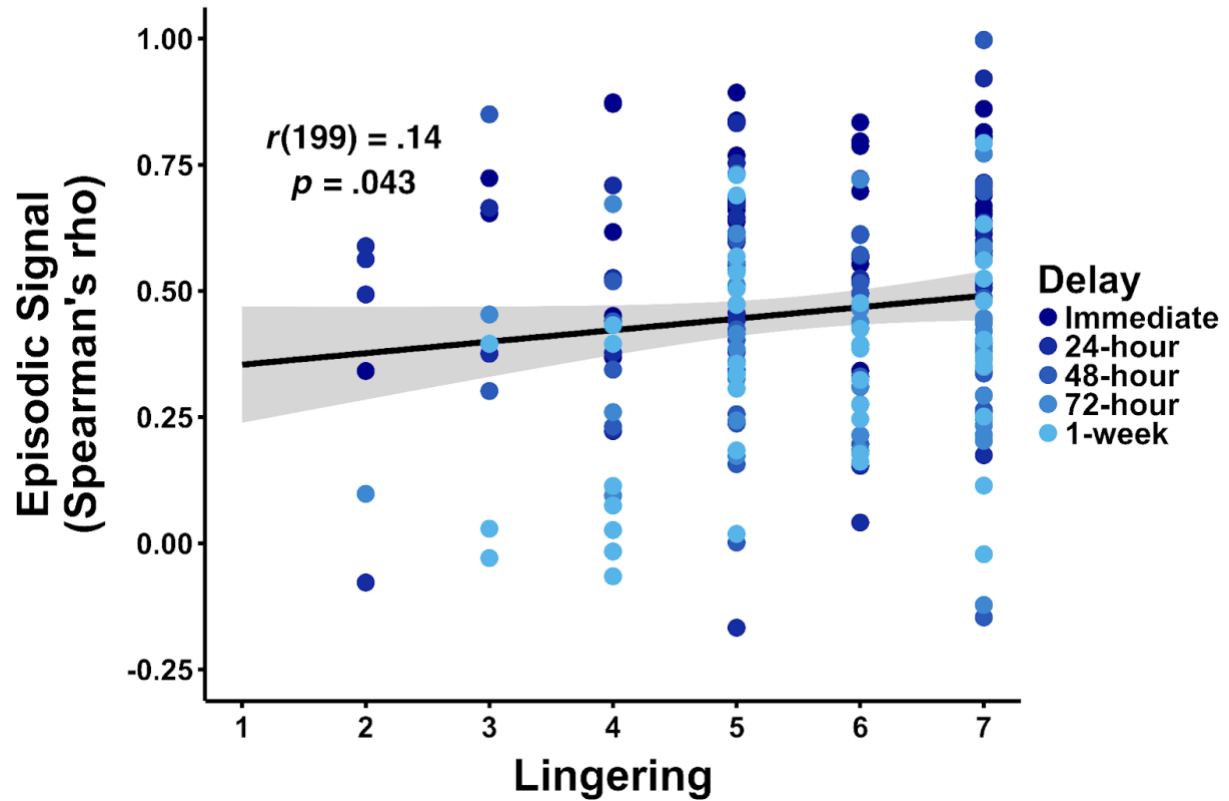
*Correlation between Schematic signal and self-reported transportation into the event-scrambled story*



*Note.* Transportation is a score aggregated from participants' responses to the Narrative Transportation Questionnaire (Green & Brock, 2000). See Methods: Materials: *Narrative Transportation*.

Figure A9

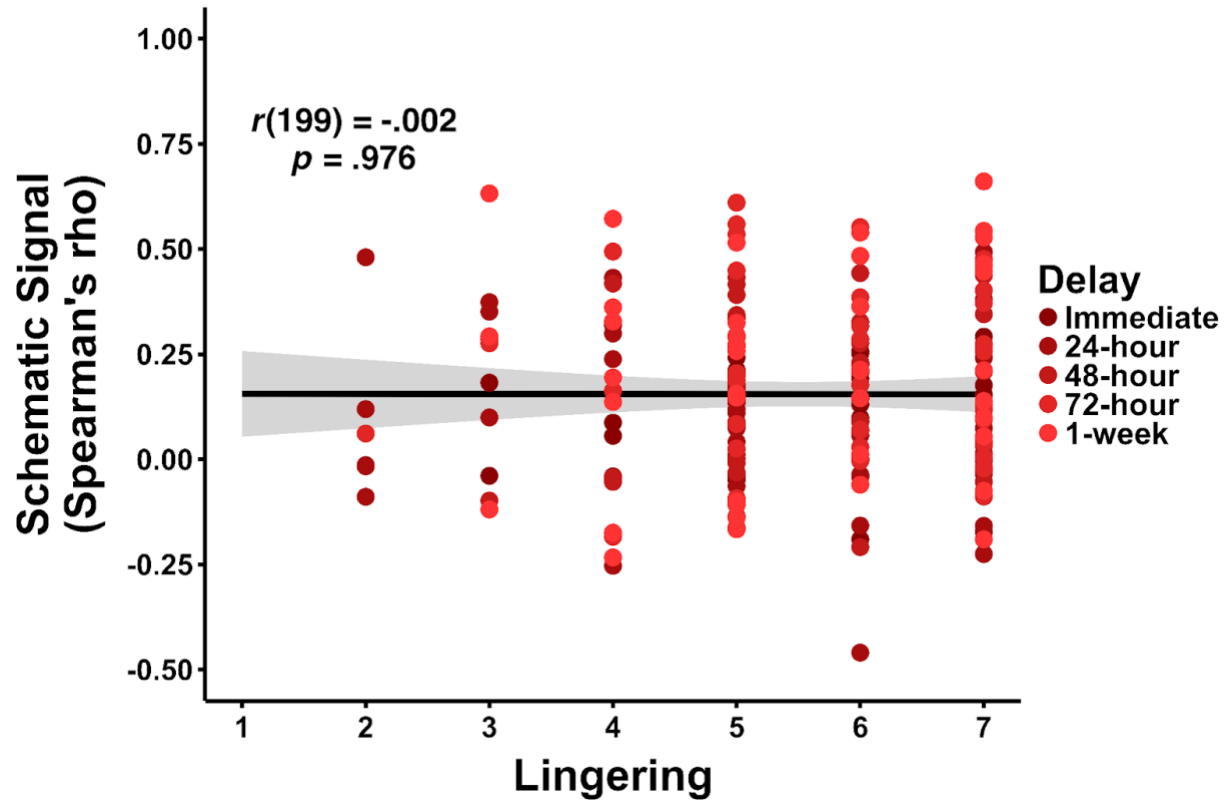
Correlation between Episodic signal and self-reported lingering of the event-scrambled story



*Note.* Self-reported lingering as measured by participants' responses to: "Some stories have a tendency to leave a lasting impression. These stories stick in your mind long after reading them. To what extent did this story stick in your mind?" Participants responded on a 7-point Likert-scale where 1 was 'not at all' and 7 was 'very much'.

Figure A10

Correlation between Schematic signal and self-reported lingering of the event-scrambled story



*Note.* Self-reported lingering as measured by participants' responses to: "Some stories have a tendency to leave a lasting impression. These stories stick in your mind long after reading them. To what extent did this story stick in your mind?" Participants responded on a 7-point Likert-scale where 1 was 'not at all' and 7 was 'very much'.

**Appendix B**  
**Supplemental Tables**

**Table B1***Distribution of gender identities across delays*

Gender	Immediate	24-hour	48-hour	72-hour	1-week
Female	29	21	20	19	24
Male	11	17	18	19	17
Non-binary	0	3	3	1	1
Prefer to Self-describe	0	0	0	0	1

**Table B2***Distribution of age across delays*

Age	Immediate	24-hour	48-hour	72-hour	1-week
18-19	0	1	1	3	1
20-24	4	8	6	3	8
25-29	11	4	4	8	10
30-34	6	8	10	6	5
35-39	5	6	9	10	4
40-44	6	5	1	2	4
45-49	1	2	1	4	1
50-54	0	4	3	1	6
55-59	3	1	4	0	1
60-64	3	1	1	2	2
65-69	0	1	1	0	1
70-74	1	0	0	0	0

**Table B3***Distribution of education across delays*

Education	Immediate	24-hour	48-hour	72-hour	1-week
Some high school or less	0	0	2	1	0
High school diploma or equivalent	5	7	2	4	5
Some college but no degree	7	5	6	6	10
Associate or technical degree	7	5	5	4	4
Bachelor's degree	17	18	15	18	22
Master's degree	3	6	11	5	1
Doctoral degree	1	0	0	1	1

**Table B4***Descriptive statistics of proof of concept results*

Condition	Signal	<i>n</i>	Mean	<i>SD</i>	95% CI
Episodic Test	Episodic	40	0.84	0.29	[0.75, 0.94]
	Schematic		0.11	0.14	[0.06, 0.15]
Schematic Test	Episodic	41	-0.08	0.23	[-0.15, -0.01]
	Schematic		0.53	0.47	[0.38, 0.68]

*Note.* Statistics are reported in Fisher-Z transformed Spearman rho values.

**Table B5***Proof of concept one-sample t-test results*

Condition	Signal	Estimated Mean Difference	<i>df</i>	<i>t</i>	<i>p</i>	95% CI	Cohen's <i>d</i>
Episodic Test	Episodic	0.84	39	18.44	< .001	[0.75, 0.94]	2.92
	Schematic	0.11	39	4.83	< .001	[0.06, 0.15]	0.76
Schematic Test	Episodic	-0.08	40	4.84	< .001	[-0.15, -0.01]	-0.35

Schematic	0.53	40	7.17	< .001	[0.38, 0.68]	1.12
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*Note.* One-sample *t*-tests assessing the difference of group means from a population mean of zero. Statistics are reported in Fisher-*Z* transformed Spearman rho values. Reported *p*-values are adjusted using the Bonferroni correction method. See Methods: Analyses: *Proof of concept* for a description of the proof of concept analysis.

**Table B6**

*Between-condition, within-signal estimated marginal means pairwise comparisons for proof of concept 2x2 ANOVA*

Variable	Pairwise Comparison	Estimated Mean Difference	<i>SE</i>	<i>df</i>	<i>t</i>	<i>p</i>	95% CI
Episodic Signal	Episodic Schematic Immediate Immediate	0.92	0.06	79	15.87	< .001	[0.81, 1.04]
Schematic Signal		0.42	0.08	79	5.44	< .001	[0.27, 0.58]

*Note.* Statistics are reported in Fisher-*Z* transformed Spearman rho values. Estimated mean differences represent absolute mean differences. Reported *p*-values are adjusted using the Bonferroni correction method.

**Table B7**

*Within-condition, between-signal estimated marginal means pairwise comparisons for proof of concept 2x2 ANOVA*

Condition	Pairwise Comparison	Estimated Mean Difference	<i>SE</i>	<i>df</i>	<i>t</i>	<i>p</i>	95% CI
Episodic Immediate	Episodic Schematic Signal Signal	0.74	0.07	79	10.60	< .001	[0.60, 0.87]

Schematic	0.61	0.07	79	8.92	< .001	[0.48, 0.75]
Immediate						

*Note.* Statistics are reported in Fisher-Z transformed Spearman rho values. Estimated mean differences represent absolute mean differences. Reported *p*-values are adjusted using the Bonferroni correction method.

**Table B8**

*Descriptive statistics of Episodic and Schematic signal over time*

Signal	Delay	<i>n</i>	Mean	<i>SD</i>	95% CI
Episodic	Immediate	40	0.84	0.29	[0.75, 0.94]
	24-hour	40	0.58	0.33	[0.47, 0.68]
	48-hour	40	0.62	0.69	[0.40, 0.84]
	72-hour	39	0.41	0.23	[0.33, 0.48]
	1-week	42	0.36	0.27	[0.28, 0.45]
Schematic	Immediate	40	0.11	0.14	[0.06, 0.15]
	24-hour	40	0.10	0.22	[0.03, 0.17]
	48-hour	40	0.15	0.20	[0.09, 0.21]
	72-hour	39	0.24	0.23	[0.16, 0.31]
	1-week	42	0.23	0.28	[0.14, 0.32]

*Note.* Statistics are reported in Fisher-Z transformed Spearman rho values.

**Table B9**

*Episodic Test group mean one-sample t-test results*

Signal	Delay	Estimated Mean Difference	<i>df</i>	<i>t</i>	<i>p</i>	95% CI	Cohen's <i>d</i>
Episodic	Immediate	0.84	39	18.44	< .001	[0.75, 0.94]	2.92
	24-hour	0.58	39	11.08	< .001	[0.47, 0.68]	1.75
	48-hour	0.62	39	5.66	< .001	[0.40, 0.84]	0.90

	72-hour	0.41	38	11.26	< .001	[0.33, 0.48]	1.80
	1-week	0.36	41	8.80	< .001	[0.28, 0.45]	1.36
Schematic	Immediate	0.11	39	4.84	< .001	[0.06, 0.15]	0.76
	24-hour	0.10	39	2.91	.006	[0.03, 0.17]	0.46
	48-hour	.15	39	4.85	< .001	[0.09, 0.21]	0.77
	72-hour	0.24	38	6.34	< .001	[0.16, 0.31]	1.02
	1-week	0.23	41	5.27	< .001	[0.14, 0.32]	0.81

*Note.* One-sample *t*-tests assessing the difference of group means from a population mean of zero. Statistics are reported in Fisher-Z transformed Spearman rho values. Reported *p*-values are adjusted using the Bonferroni correction method.

**Table B10**

*Between-delay, within-signal estimated marginal means pairwise comparisons for Episodic Test*  
*5x2 ANOVA*

Variable	Pairwise Comparison	Estimated Mean Difference	SE	df	<i>t</i>	<i>p</i>	95% CI	
Episodic Signal	Immediate	24-hour	0.26	0.09	196	2.96	.03	[0.01, 0.52]
		48-hour	0.22			2.49	.14	[-0.03, 0.47]
		72-hour	0.44			4.87	< .001	[0.18, 0.69]
		1-week	0.48			5.44	< .001	[0.23, 0.73]
	24-hour	48-hour	0.04			-0.47	.99	[-0.30, 0.21]
		72-hour	0.17			1.92	.56	[-0.08, 0.43]
		1-week	0.22			2.45	.15	[-0.03, 0.46]
	48-hour	72-hour	0.21			2.39	.18	[-0.04, 0.47]
		1-week	0.26			2.93	.04	[0.01, 0.51]
	72-hour	1-week	0.04			0.48	.99	[-0.21, 0.29]

Schematic Signal	Immediate	24-hour	0.01	0.05	0.14	.99	[-0.13, 0.14]
		48-hour	0.05		-0.91	.99	[-0.18, 0.09]
		72-hour	0.13		-2.62	.09	[-0.27, 0.01]
		1-week	0.12		-2.55	.11	[-0.26, 0.01]
	24-hour	48-hour	0.05		-1.05	.99	[-0.19, 0.09]
		72-hour	0.14		-2.76	.06	[-0.28, 0.004]
		1-week	0.13		-2.70	.08	[-0.27, 0.01]
	48-hour	72-hour	0.09		-1.72	.87	[-0.22, 0.05]
		1-week	0.08		-1.63	.99	[-0.22, 0.06]
		72-hour	0.01		0.12	.99	[-0.13, 0.14]

*Note.* Statistics are reported in Fisher-Z transformed Spearman rho values. Estimated mean differences represent absolute mean differences. Reported *p*-values are adjusted using the Bonferroni correction method.

**Table B11**

*Within-delay, between-signal estimated marginal means pairwise comparisons for Episodic Test 5x2 ANOVA*

Delay	Pairwise Comparison	Estimated Mean Difference	SE	df	t	p	95% CI
Immediate	Episodic Signal Schematic Signal	0.74	0.08	196	9.46	< .001	[0.58, 0.89]
24-hour		0.48			6.16	< .001	[0.32, 0.63]
48-hour		0.47			6.04	< .001	[0.32, 0.62]
72-hour		0.17			2.16	.03	[0.01, 0.33]
1-week		0.13			1.75	.08	[-0.02, 0.28]

*Note.* Statistics are reported in Fisher- $Z$  transformed Spearman rho values. Estimated mean differences represent absolute mean differences. Reported  $p$ -values are adjusted using the Bonferroni correction method.