Title

Cognitive processes supporting the segmentation, differentiation, and representation of event memories

Author

Vitello, Mary

Publication Date

2024

Peer reviewed|Thesis/dissertation

UNIVERSITY OF CALIFORNIA

Los Angeles

Neurocognitive processes supporting the segmentation, differentiation, and representation of event memories

A dissertation submitted in partial satisfaction of the requirements for the degree Doctor of Philosophy in Psychology

by

Mary Carmella Vitello

2024

ABSTRACT OF THE DISSERTATION

Neurocognitive processes supporting the segmentation, differentiation, and representation of event memories

by

Mary Carmella Vitello

Doctor of Philosophy in Psychology

University of California, Los Angeles, 2024

Professor Jesse A. Rissman, Chair

The human mind is rarely, if ever, inert. We are constantly barraged with external stimuli, but also experience a rich inner life of recollections, planning, and pondering which occur spontaneously throughout our waking hours. In this dissertation, I have aimed to investigate the neurocognitive mechanisms underpinning the segmentation, differentiation, and representation of event memories, acknowledging the ongoing dynamics of internal and external attention. I have taken as a paradigm the dynamic and flexible interplay between internal and external attention as a critical factor in memory encoding and organization. In Chapter 2, I present findings from a series of experiments which demonstrate the ways in which fluctuations in on-going attention (i.e. mind-wandering) act upon the

later recollection of temporal order. In a similar vein Chapter 3 demonstrates how hierarchical contexts which change at different rates instrumentally decrement or benefit later recollection of temporal order memory. Building upon the idea of hierarchical and dynamic representations, in Chapter 4 I present a theoretical account of how attention and mind wandering may play an instrumental role in the alteration of memory organization and recollection in individuals with depression. In this chapter, I critique the canonical theory of overgeneral memory in depression and instead underscore basic long-term memory and attention processes to explain how memories may become blunted in mood disorders. Finally, in Chapter 5, I test this hypothesis by investigating how memory similarity may be derived from semantic representations to demonstrate how personal memory organization is changed in individuals with depression compared to healthy controls. These chapters highlight the theoretical and methodological advancements that have been and should continue to be made in the course of this dissertation.

This dissertation of Mary Carmella Vitello has been approved.

Barbara Knowlton

Michelle Craske

David Clewett

Jesse A. Rissman, Committee Chair

University of California, Los Angeles

2024

Dedication

I dedicate this dissertation to my parents.

Table of Contents

Table of Contents
Chapter 2: When the wandering mind trips: Attentional fluctuations influence memory for temporal structure of experience ***4***
Abstract **4**
Introduction **4**
Experiment 1: Methods 10
Experiment 1: Measures 14
Experiment 1: Results 16
Experiment 1: Discussion 23
Experiment 2 **24**
Experiment 2: Methods 25
Experiment 2: Results 26
Experiment 2: Discussion 28
Experiment 3 **29**
Experiment 3: Methods 29
Experiment 3: Results 30
Experiment 3: Discussion 33
Experiment 4 **33**
Experiment 4: Methods 34
Experiment 4: Results 35
Experiment 4: Discussion 37
Overall Discussion **37**
References 42
Chapter 3: ConTemplate: Dynamic contexts promote memories of hierarchical events ***50***
Introduction 50
Methods 53
Results 54
Discussion 58
References: 59
Chapter 4: Stuck in Reverse: Cognitive and Neural Perspectives on Overgeneral Memory in Depression via Ruminative Mind-wandering ***63***
Background 63
Overgeneral memory in depression 64
Models of Overgeneral Memory in Depression 66
Rumination as sticky mind wandering 75
Depressive rumination is pathological mind wandering 78
Rumination’s effect on memory organization 83

Interim Summary 88
References 90

Chapter 5: Exploring the Multidimensional Nature of Autobiographical Memories: A Representational Similarity Analysis Using Natural Language Processing ***112***

Abstract 112
Introduction 112
Methods 117
Results 121
Discussion 130

Chapter 6: Conclusion ***136***

List of Figures

1 **Figure 2.1 Schematic of the EpiSART paradigm.** **16**
2 **Figure 2.2. Mean RTs for 8 trials Pre and Post either a correct or an erroneous response to a target trial across experiments 1-4, A-D.** **18**
3 **Figure 2.3. Variance Time Course (VTC)** **20**
4 **Figure 2.4: A) Average VTC measure before and after an event boundary or error across all experiments.** **22**
5 **Figure 3.1. mean cued recall accuracy as a function of Cue Level (Shift vs. Stable) and Test Cue Type (NB = Non-Boundary, PB = Pre-Boundary).** **55**
6 **Figure 3.2 Mean source memory accuracy as a function of Cue Level (Stable vs. Shift) and Variable (Scene vs. Character).** **57**
7 **Figure 5.1. ROAM Methods** **119**
8 **Figure 5.2. Feature Ratings** **123**
9 **Figure 5.3. Mean cosine similarity for intra-subject (light orange) and inter-subject (light purple) comparisons.** **126**
10 **Figure 5.4 Mean modularity between control (orange) and depressed subjects (blue).** **127**
11 **Figure 5.5 Mean clustering coefficient between control (orange) and depressed subjects (blue) for positive and negative memories.** **129**

Acknowledgements

Parts of this research were supported by the following:

NSF Graduate Research Fellowship Program
Graduate Summer Research Mentorship Award

I would like to thank my advisor Dr Jesse Rissman for his support, encouragement, and for allowing my interests to manifest. Dr David Clewett for his mentorship, support, patience, and kindness during my time at UCLA.

Most importantly, I would like to thank my parents. Without the unwavering support of my mother and father, I would not have been able achieve this dissertation. I thank my sisters Sophia and Emma for their emotional support and silly group chats that lifted my spirits when I was stressed. I thank Jack Sweeney for his kindness and fortitude. I thank my friends and colleagues Hanna Moon, Mouslim Cherkoui, Raiyhung Lee, Hunter Priniski, Fleming Peck, Samantha Walters, Saul IQM, Mason McClay; you have all made my time at UCLA what it is. Thank you Bubbles, Trinity, and Petunia for being my creature comforts.

Vita

Mary Vitello holds a B.A. in Liberal Arts from Sarah Lawrence College. She was awarded the National Science Foundation Graduate Research Fellow Program in 2021, the UCLA Collegium of Teaching Fellows Award to teach her own class "Navigating the Wandering Mind: The Science of Attention, Creativity, and Thought," and an honorarium from the Templeton Foundation to study at Summer Sessions in Philosophy and Neuroscience at Duke. She currently has two publications in journals such as "History of Psychology" and "Intelligence," and has submitted one further manuscript which is under review.

Chapter One: Introduction

While our experience is continuous, memories are (re)experienced as discrete events. Much work has been done over the last decades to understand which processes are involved in this segmentation of continuous experience into meaningful events (Kurby & Zacks, 2004; Clewett & Davachi, 2017). Segmentation processes not only influence which slices of experience are remembered as events, but also the temporal associations between details of memories. A proposed functional purpose of segmentation is that it aids in defining and organizing memories into meaningful units that prioritize information within a particular context (Radvansky, 2012). While this line of research has enjoyed success in the explanation of highly circumscribed experimental contexts, current frameworks are taxed by the need to explain the dynamic attentional focus of day-to-day life. Outside of the laboratory, people experience a deluge of contextual information from the environment, but also endogenous mental activity. Namely, mind-wandering is a meaningful and significant portion of daily life where internal contexts can override information from the exterior world.

When the mind drifts, it detaches from the present moment and the external environment to simulate situations or concepts other than the here and now. This ability to mind-wander refers to spontaneous thought that most often occurs when not immediately engaged with the outside world (Smallwood & Schooler, 2006). Though the mind wanders, this meandering is not aimless and is instead guided by thematic paths such as self-relevant information and autobiographical experiences: episodic memory guides reflecting on the past, planning future actions, and musing on one's personal traits or social dynamics (Karapanagiotidis et al., 2017). Recent work has demonstrated an overlapping neurocognitive network underlying mental time travel, mind wandering, and episodic memory, pointing towards a functional commonality between these constructs in the (re)construction of personal experience (source). If spatiotemporal representations are key cognitive ingredients shared by mind wandering and memory, we can begin to ask critical questions about the dynamics and function of facets of these internally driven cognitive phenomena.

By framing mind wandering as an adaptive form of internally oriented cognition that allows one to flexibly represent the self across spatiotemporal contexts and to support important self-related functions such as episodic simulation, future thinking, and problem solving, we gain insights into the underlying cognitive and neural mechanisms of self-related information. This perspective widens the scope of our understanding of the functionality of memory representations beyond goal-oriented, effortful retrieval, and instead allows us to consider how ongoing and spontaneous thought influences the representation, organization, and accessibility of memory.

In this series of studies, I ask: first, how fluctuations between internal and external attention influence the ongoing segmentation of event perception and consolidation; second, how attention to levels of structure in complex, hierarchically structured events affect the retrievability of details of experience; third, how, along with mind-wandering's effect on memory encoding, there is ample evidence that periods of mind-wandering contribute to memory (re)consolidation. For example, studies have shown that memories (re)consolidation occurs during times of mind-wandering (Wamsley, 2019). I will take this case and extend it to understanding how memory representations in depression may become over-general. By using mind-wandering as a framework for understanding this relationship clarifies the important role that on-going thought processes have on the structure and accessibility of autobiographical memories. Here, I argue that rumination, or recalcitrant thought focused on personal problems, is a form of aberrant mind wandering which can cause structural changes in the organization of autobiographical memory representations in depression. Finally, I will use this framework to investigate the difference in similarity structure of memory in individuals with and without depression using Natural Language Processing, as well as the neurocognitive networks involved in these organizational processes.

References

1. Clewett, D., & Davachi, L. (2017). The Ebb and Flow of Experience Determines the Temporal Structure of Memory. *Current Opinion in Behavioral Sciences*, *17*, 186–193. https://doi.org/10.1016/j.cobeha.2017.08.013
2. Karapanagiotidis, T., Vidaurre, D., Quinn, A. J., Vatansever, D., Poerio, G. L., Turnbull, A., Ho, N. S. P., Leech, R., Bernhardt, B. C., Jefferies, E., Margulies, D. S., Nichols, T. E., Woolrich, M. W., & Smallwood, J. (2020). The psychological correlates of distinct neural states occurring during wakeful rest. *Scientific Reports*, *10*, 21121. https://doi.org/10.1038/s41598-020-77336-z
3. Kurby, C. A., & Zacks, J. M. (2008). Segmentation in the perception and memory of events. *Trends in Cognitive Sciences*, *12*(2), 72–79. https://doi.org/10.1016/j.tics.2007.11.004
4. Radvansky, G. A. (2012). Across the Event Horizon. *Current Directions in Psychological Science*, *21*(4), 269–272.
5. Radvansky, G. A., Zwaan, R. A., Federico, T., & Franklin, N. (1998). Retrieval from temporally organized situation models. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *24*(5), 1224–1237. https://doi.org/10.1037//0278-7393.24.5.1224
6. Smallwood, J., & Schooler, J. W. (2006). The restless mind. *Psychological Bulletin*, *132*(6), 946–958. https://doi.org/10.1037/0033-2909.132.6.946
7. Wamsley, E. J. (2019). Memory Consolidation during Waking Rest. *Trends in Cognitive Sciences*, *23*(3), 171–173. https://doi.org/10.1016/j.tics.2018.12.007

Chapter 2: When the wandering mind trips: Attentional fluctuations influence memory for temporal structure of experience

Abstract

By drawing attention away from environmental stimuli, mind-wandering may disrupt encoding of sensory information and segmentation of ongoing experiences into discrete events. However, relatively little is known about its consequences for the formation and later recall of temporally structured event memories. To investigate how mind-wandering influences temporal memory, we adapted the Sustained Attention to Response Task (SART) paradigm to give it episodic structure ("EpiSART"). By presenting participants with a continuous series of visual objects and periodically switching the category of these object stimuli to induce event boundaries, we were able to examine the influence of event boundaries on response time variability, a marker of mind-wandering. Across four experiments, we found a significant change in the slope of the response time variance time course (VTC) before versus after an event boundary, with the former having a positive slope (increasing mind-wandering) and the latter having a negative slope (reduction in mind-wandering). Critically, the degree to which participants redirected their focus, indexed by a reduction in the VTC, after an event boundary (Experiment 1 and 2) or after making an error (Experiment 3) predicted subsequent memory for the temporal order of events. However, when task demands increased, and mind-wandering consequently decreased, changes in VTC slope at these critical time points had no relationship with subsequent temporal order memory (Experiment 4). Taken together, these results suggest that event boundaries and errors serve to momentarily reduce mind-wandering in a manner that is consequential for temporal memory.

Introduction

Although we spend much of our day attending to the external world, our waking hours are also rich with an internal monologue: cues from our environment may trigger memories, thoughts on topics, or plans for the future. A task as seemingly simple as preparing our morning cup of coffee involves planning and executing a range of cognitive and motor processes as we engage with the outside world. However, our mind is not only preoccupied with processing the immediate task; the smell of coffee may trigger a memory to a recent trip to a cafe, thoughts about the origins of the coffee, or planning to buy another bag of beans, and may begin trains of thought that carries one's mind far away from the task at hand.

This class of task-unrelated thought constitutes an important, but under-explored aspect of everyday cognition. These fleeting thoughts are not inconsequential - as much as 50% of our waking hours may be filled with "mind-wandering" (Killingsworth & Gilbert, 2010; Smallwood & Schooler, 2006). A unifying feature of these mind-wandering states is that they reflect a decoupling of attention from the processing of incoming perceptual and contextual information from the immediate environment and reflect a shift towards internally generated thoughts (Mason et al., 2007; Smallwood & Schooler, 2006). In this way, they are often classified as task-unrelated and stimulus independent thoughts (McVay & Kane, 2009) and often occur during tasks or situations that are familiar, repetitive, and undemanding tasks (Schooler et al., 2011). This tendency for the mind to wander demonstrates the ways in which ongoing cognitive processes are rarely dedicated to one task at a time and instead may be divided across the external and internal world in dynamic ways.

The onset of mind-wandering carries with it distinct behavioral and neural signatures of a switch from externally focused attention and stimulus processing to internally generated thought. During tasks which require sustained attention, states of mind-wandering are associated with increased error rates (Manly et al., 1999; Robertson et al., 1997) and less vigilant responding (Cheyne et al., 2009; Esterman et al., 2013). On a neural level, mind-wandering is associated with reduced processing of external stimuli (Baird et al., 2014; Smallwood et al., 2008). Smallwood and Schooler (2006) define this feature of mind-wandering as "perceptual decoupling": when performance on a primary task is no longer supervised by exogenous attention but proceeds automatically, and one's thoughts become the focus of awareness.

This proneness of mental context to drift from environmental stimuli to internally generated thoughts bears some theoretical interest for the study of episodic memory. Theories of episodic memory have long emphasized the importance of encoding the context of an event – including its spatial, temporal, emotional, or imaginal details – as a key ingredient for facilitating its subsequent recollection (Burgess et al., 2002; Tulving, 1972). While these theories have been successful in capturing how the *content* of a memory comes to be associated within a *context*, they do not address how shifts in context contribute to the organization of memory as discrete event within a timeline per se.

While our experience is continuous, memories are (re)experienced as discrete events in ordered sequences, each with specific durations. Event Segmentation Theory suggests that ongoing experience is parsed into meaningful events by salient changes in mental context that signal the end of an event and the beginning of a new one (Kurby & Zacks, 2008; Zacks & Swallow, 2007). Given a current context, situation models are created using spatial, perceptual, goal, or other contextual features. This situation model for the event will be terminated if the parameters of the current model do not align with a new changed context, and a new model emerges (G. Radvansky et al., 2005; Zwaan et al., 1998).

In this literature, the points of contextual change are referred to as event boundaries, which are perceptual or conceptual shifts in contextual representation (Ezzyat & Davachi, 2011; Zacks et al., 2001; Zwaan et al., 1995). Such shifts can be perceptually and spatiotemporally defined (Baldassano et al., 2017; DuBrow & Davachi, 2013; G. A. Radvansky & Copeland, 2006), or task-related such as shifting from one task to the next (Aly & Turk-Browne, 2016; Wang & Egner, 2022). Though less attention has been paid to internally generated boundaries, some studies have demonstrated how changes in arousal and emotion (Clewett & McClay, 2021) or during free recall of events in a sequence (Lee & Chen, 2022), contribute to segmenting experience into meaningful units.

Segmentation processes not only influence which slices of experience are remembered as events, but also the temporal associations between details of memories. A proposed functional purpose of segmentation is that it aids in defining and organizing memories into meaningful units that prioritize information within a particular context. This has been demonstrated in the lab in studies where participants are presented with images that are presented in a context such as a particular colored border around a sequence of images (DuBrow & Davachi, 2013). The border color will periodically change, typically indicating the need to perform a new task on the enclosed stimuli. Participants are later asked to recollect the order or temporal relationships between objects presented. When asked to judge which item came later in a list, participants demonstrate greater accuracy in judging the order of objects that occurred within an event compared to across an event boundary. Further, when asked to judge the temporal proximity between items (i.e., how far or close the objects were presented in time) participants tend to judge items within an event as occurring closer in time and objects spanning a boundary as being further apart in a timeline, even when the objective or metric time is held constant (DuBrow & Davachi, 2014, 2016; Ezzyat & Davachi, 2014).

Lastly, event boundaries have been shown to influence the representation of temporal duration. Given a standard interval of time, the number of event boundaries that occurred within that interval is related to how short or long that duration interval is recalled: the more event boundaries that occurred, the longer the duration that is estimated, and vice versa. This effect has been demonstrated in controlled laboratory studies (Faber & Gennari, 2015), but also in a series of more naturalistic studies where individuals wore cameras as they went about their day-to-day life, and were later as to mentally replay specific event sequences. Jeunehomme & D'Argembeau (2019) found that the number of independently rated event boundaries predicted the length of subjects' estimates for the duration of those events.

In sum, theoretical accounts of episodic memory posit that the organization of long-term episodic memories relies on encoding contexts of a given event before a substantial change in that contextual representation. However, mental context may not be simply defined by reactions or interactions with the external environment. Indeed, segmentation has been primarily studied by measuring the representation of memory based on features of externally oriented experience: for example, changes in the spatial (Horner et al., 2016), or perceptual features (Gurguryan et al., 2021; Sols et al., 2017), or changes in how one interacts with the external environment such as when goals are completed and/or changed (Wang & Egner, 2022). While the stream of consciousness may be filled with elements of experience related to the external context, its ebb and flow is determined in some part by internally generated thoughts.

It is important to not only consider the components of context that are related to externally oriented processing, but also internally generated thought. The primary aim of the current study is to address how mind-wandering may influence the segmentation of ongoing experience and the later recollection of that experience's temporal attributes. We hypothesize that mind-wandering will disrupt temporal encoding for the order and the duration of events, such that higher levels of mind-wandering will predict lower accuracy in order and duration judgments.

As there is currently no task designed to capture metrics of both episodic memory and mind-wandering states, it was necessary to create such a task. Mind-wandering is primarily studied by using tasks which are repetitive, attentionally undemanding, and familiar. For example, the Sustained Attention to Response Task (SART) is a well-validated experimental paradigm for measuring failures in sustained attention (Robertson et al., 1997), and it has been used widely in the mind-wandering literature to track lapses of task performance. In a typical SART protocol, participants are required to respond to a sequence of presented digits (1 through 9) and to withhold response to one digit (usually "3"). These no-go target trials are infrequent, and lengthy periods of repetitive responses are associated with high incidence of mind-wandering on off-task topics. Researchers have traditionally relied on phenomenological report by periodically interrupting mind-wandering states with thought probes, which cue participants to respond to the content of their mind in the moments before the cue (Smallwood et al., 2007), or in retrospective surveys (Barron et al., 2011; Kane et al., 2021).

While thought probes have been demonstrated to not decrease the amount of mind-wandering during the SART task (Wiemers & Redick, 2019), random probes can disrupt the flow of performance and thus might increase the frequency of context shifts within the task. However, more indirect measures of mind-wandering have been established by using tasks such as the SART to identify distinct behavioral profiles associated with mind-wandering. Across studies, experimenters find negative correlations between response times (RTs) and error rates (Cheyne et al., 2009; Manly et al., 1999; Robertson et al., 1997), and temporally specific effects before errors where RTs are significantly faster compared to a correct response (Cheyne et al., 2009). Overall RT variability, often summarized as the coefficient of variation (RT CV) is considered to be an index of less vigilant responding and is associated with higher error rates (Esterman et al., 2013) and higher subjective report of MW (Jonker et al., 2013; Seli et al., 2013). Finally, some studies have utilized a smoothed, within-subject measure of RT variability called a variance time course (VTC) to allow for a continuous measure of a subject's fluctuating attentional state (Esterman et al., 2013, 2014; Yamashita et al., 2021).

An endeavor to test the relationship between mind-wandering and temporal memory requires a task that reliably induces mind-wandering *and* incorporates temporal structure. Although the SART reliably induces mind-wandering and has been linked with a range of behaviors associated with attentional disengagement, it lacks any meaningful temporal structure. The typical SART protocol involves presenting participants with a long series of single-digit numbers in a pseudo-random order, making the task essentially one extended event. To address this limitation, we introduce a new variant of this paradigm that we call the Episodic SART (EpiSART), a temporally structured response inhibition task that captures measures of episodic memory as well as mind-wandering. Like in the original SART task, participants are asked to make speeded button-press responses to stimuli presented on their computer screens for all images except those they are told are the critical and infrequent “targets”, for which they should withhold their response. The EpiSART task design differs from the original on key features to enhance attention to the defined episodic contexts. For example, participants are presented with stimuli from different common categories of objects within a sequence, such as toys, tools, fruits and vegetables, electronics, etc. Here, we use the EpiSART framework across four experiments to test the effect of mind-wandering on temporal memory, while varying the goal relevance of the event boundary and the identity of the target stimulus.

Due to the decreased encoding of the external context during mind-wandering, we predict that higher measures of overall mind-wandering will be associated with less accurate temporal memory for category order and duration. Further, due to the apparent criticality of event boundaries as periods of time which are associated with event updating, we expect that participants’ ability to cease mind-wandering and reorient attention at event boundaries will predict more successful encoding of contextual information integral for subsequent temporal recollection.

Experiment 1: Methods

Participants

140 participants were recruited via the University of California, Los Angeles (UCLA) human subject pool and completed the experiment for course credit. Participants were excluded if they met any of the following criteria: 1) they failed to respond to more than 8 trials in a row; 2) they were identified as an outlier on one or more of our key predictor variables such as response time (RT) or variability (VTC, RT CV); or 3) who indicated that we should not use their data during the post-task survey. After exclusion of 22 ineligible participants, 118 participants remained for analysis (77 females; age, M = 20.35, SD = 1.37). Confirmation of informed consent was obtained from participants before starting the experiment in accordance with the UCLA Internal Review Board. This study was not pre-registered. Data and analysis code is available by contacting the corresponding author.

Based on previous studies (Robertson et al., 1997; Smallwood et al., 2004), we sought to collect 60 participants for each of our experiments. Due to anticipated problems of participant drop-out or technical issues with online data collection, we recruited 70 participants to allow for some attrition. For Expt 1, the higher sample size is due to our decision to collapsed two separate samples of 70 participants who completed the EpiSART task. The EpiSART task and the subsequent memory tests were the same in both samples, with the exception of an additional item recognition test performed at the end of the second sample. We do not report the findings from that recognition task here. A series of Student's two-sample t-tests were run on the our measures of interest for each sample and showed the two samples were not significantly different for RTs ($t(116) = -.94$, $p = .35$), RT CV ($t(116) = 1.61$, $p = .11$), or VTC ($t(116) = .81$, $p = .42$).

Materials

Participants performed all experimental tasks on Pavlovia (Peirce et al., 2019). Due to the remote presentation of the experiment on individual participants' personal devices, we required that all participants use laptops or desktop computers and disallowed the use of tablets or cell phones.

Stimuli were gathered from Google image searches (filtered for images tagged for non-commercial reuse) and various online databases including: Object Interaction Envelope Stimuli (Bainbridge & Oliva, 2015), "Large and Small Items" (Konkle & Oliva, 2012), and "Massive Memory" Unique Object images (Brady et al., 2008). All images were resized to be 350 by 350 pixels. However, presentation online was scaled to the size of the participant's computer screen, such that each stimulus was presented in proportion to each participant's browser window.

Procedure

The EpiSART task is a temporally structured response inhibition task that captures measures of episodic memory as well as mind-wandering. Participants make speeded responses to stimuli presented on their computer screens for all images except those they are told are the critical and infrequent no-go "targets" which they should withhold their responses to. To allow us a means to later probe episodic memory for the content experienced during the task, the stimuli were temporally clustered into distinct categories of objects, and these categories periodically changed. The categories constituted events and changes between categories were considered event boundaries. To increase the discernibility of distinct events, a colored border was presented around each stimulus within a category, such that one category was associated with one color for each category. The "target" stimulus was indicated by having a border of a pre-specified color that was not one of the colors that would define a category within the block. Targets comprised about 7% of the stimuli or 20 targets (see Figure 1).

At the beginning of the experiment, seven categories of everyday objects were selected out of nine possible categories (toys, musical instruments, electronics, animals, clothing items, food, household objects, sports items, and fruits/vegetables). Categories were randomly assigned to sets of 16, 24, 32, 40, 48, 56, or 64 stimuli long, and these sets were presented in random order for a total of 280 stimuli. Each trial began with a 250 ms fixation of a cross in the center of the screen. The stimuli were presented for 750 ms with a 1 s inter-trial interval. The trials lasted 2 s each and categories lasted between 32 to 124 s. Because the duration of stimulus presentation was fixed, the length of a category was determined solely by the number of stimuli of that category that were shown. The length of the categories was varied to investigate how the length of an event interacts with both the level of mind-wandering and duration estimation. Furthermore, by having variability in when event boundaries occurred, participants would be prevented in predicting when the category would change. Because memory for each category's duration would later be tested, participants were instructed not to explicitly count the stimuli nor look at any clock either on their computer or phone.

Before beginning the EpiSART task, participants completed a short practice block consisting of 4 separate categories of images that would not appear in the subsequent EpiSART task. They were required to achieve 80% accuracy or complete 50 trials, whichever came first. They then completed the Retrospective Mind-Wandering Survey (described below). They were provided with additional instructions and told the target color for the main experimental session. They then completed an attention check to ensure they knew which color was the target color that they should NOT respond to.

Retrospective Mind-Wandering Survey. Immediately after the EpiSART task was completed, participants were given a brief survey about their level of mind-wandering throughout the previous session. They first were asked to rate how much they experienced mind-wandering from 1 ("not at all") to 7 ("very much.") They then were asked to report on the content of off-task thought such as "about a problem you have", "about a past experience", "about something that may happen in the future", "planning something", "about someone you know", "about your feelings or mood", "a passing thought", and "their performance on the task" (Ottaviani et al., 2015). They were reminded prior to beginning the survey that their reported level of engagement with the task would not determine the level of their compensation. Finally, participants were asked to report their levels of engagement or meta-awareness of the off-task thought: they were asked to report if they were "aware of the thoughts", "not aware of the thoughts but also not aware of the task", or "completely dissociated from the task."

Category Order Task. After encoding, participants performed a category order task. The task was a drag-and-drop task where boxes with the text label of each category where randomly ordered on the screen in a line. Participants dragged and dropped each category label into 7 empty gray boxes at the bottom of the screen according to the order in which they remember them being presented.

Overall Duration Estimation Task. Next, participants were asked to estimate the total amount of time that that the SART took to complete in minutes and seconds. They were instructed to make their best guess and not to refer to any external clocks (e.g., on their computer, watch, or phone) to judge the amount of elapsed time. They were reminded that their accuracy would not influence their level of compensation. Next, they were asked to estimate the number of images that they had viewed in the previous EpiSART task.

Category Duration Estimation Task. Finally, participants were shown labels of the seven categories in the order that they had reported them to be presented in. Next to each label, they were presented with a slider that ranged from 1 to ¼ of the total number of images they had previously estimated that they viewed. This ratio was chosen based on the longest possible sequence (64) is ¼th of the total number of presented stimuli (280). For each category, participants were instructed to move the slider to represent their best guess estimate of how many images they thought they had seen from that category. They were instructed to manipulate all seven of the sliders until the sum of all the sliders equaled the number they estimated in the overall duration estimate task.

Experiment 1: Measures

Response time measures

Response times (RTs) were calculated from the beginning of each trial when the fixation cross was presented. Responses were coded as anticipations if the response was made before the image was presented (under 250 ms). Responses were coded as correct unless the image was surrounded by the no-go target border color, in which case a response would be coded as a commission error. Correct omissions occurred when participants withheld a response to an image with a target border color and omission errors were any trials where no response was made but the image was surrounded by a standard category border color.

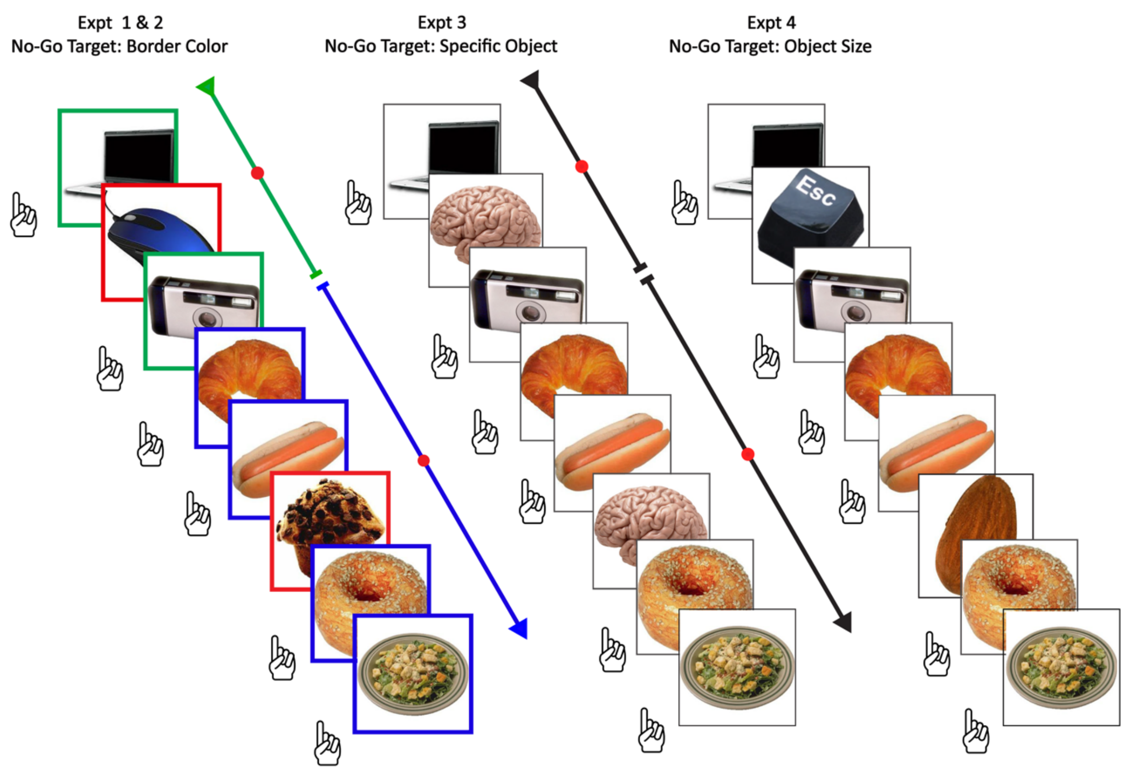
Response time variance was calculated using the Coefficient of Variation (RT CV = SD of RT/Mean RT) to assess the variability of the 8 trials before and after an error of commission or a correct omission. To assess trial-by-trial variation in RT, we used the variance time course (VTC) (Esterman et al., 2012). VTCs were computed by z-transforming the RTs within each subject's run to normalize the scale of the VTC. A VTC value was assigned to each trial representing the absolute deviation of that trial's RT from the mean RT of the run. Trials without a response were linearly interpolated from the surrounding trials. The VTC was then smoothed using a Gaussian Kernel of 9 trials full width at half maximum using the gausswin function from signal R package (https://cran.r-project.org/web/packages/signal/citation.html), therefore including information from the surrounding 20 trials via a weighted average. The benefit of using this procedure is that is allows for both uncharacteristically short and uncharacteristically long RTs to be accounted for as deviant or variable responding, indicating potential task disengagement or inattention (Esterman et al., 2013; Yamashita et al., 2021)

Temporal Order Deviation Score

To measure the memory for the temporal order of events, individuals placed the labels of the categories that were presented to them in the order in which they remembered experiencing them. The temporal order deviation score was derived by taking the sum of the absolute differences between each category's actual and reported position for each participant. In this case, the greater the score, the more deviations there were between the actual order and the reported order of the categories. A score of 0 would be considered perfect memory for the order, while a score of 36 would represent the poorest possible temporal order memory (i.e. the most maximally different order).

Relative Duration Judgment

The Relative Duration Judgment score is a measure of relative accuracy in duration estimation. At the end of the experiment, each participant estimated the total number of images they recalled seeing, and next was asked to distribute that total number across each of the categories. In this way, the number of reported images in each category for each subject were converted into ranks from the shortest to the longest. The rank differences were calculated by summing the absolute differences between each category's actual rank duration and the reported so that we could calculate the tendency for a participant to rank the shortest category as the shortest and vice versa. A score of 0 would be considered perfect memory for the relative order of events from shortest to longest based on their duration, while a score of 36 would represent reporting the most maximally different order.



1 Figure 2.1 Schematic of the EpiSART paradigm. Participants were presented with a long series of images of objects from different categories. Participants were instructed to make a button-press response (illustrated with the hand icon) to every image except those which were designated as a no-go target, such as those with a specific border color (Expt 1& 2: "Press button unless border color is red,), a specific object identity (Expt 3: "Press button unless object is a brain"), or a specified real-world size (Expt 4: "Press button unless object would fit in a ring box").

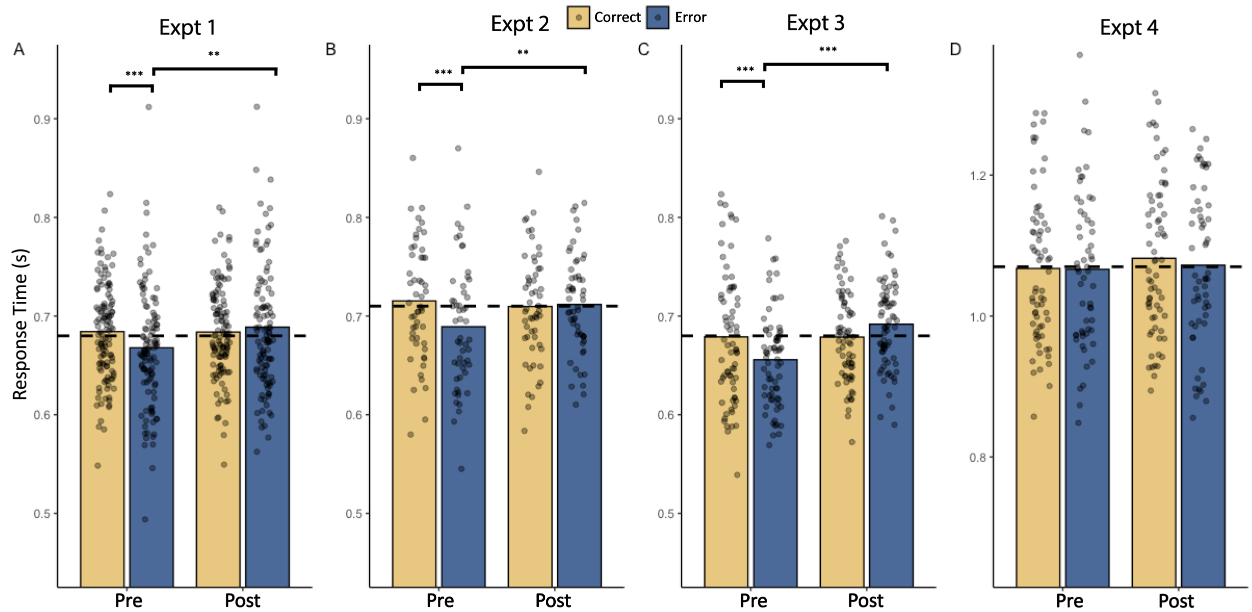
Experiment 1: Results

Although the EpiSART shares the underlying task structure of the original SART, the EpiSART includes more complex features such as meaningful object stimuli of changing categories, which we introduced to create a temporal structure. The added complexity has the potential to make the EpiSART more cognitively demanding than the traditional SART, which could diminish its monotony and thus mind-wandering. Therefore, the first aim of this experiment was to confirm that commonly used SART-based measures of mind-wandering were still present in our data, such as RT speeding, correlations between behavioral indices of mind-wandering, and distinct periods of higher response variability.

Pre-error speeding

The average rate of errors of commission was 24.00% (SD = 14.68%, range: 0% – 63.64%). The average rate of errors of omission was 1.01% (SD = 1.54%, range: 0 – 10.92%). The average RT across all responses was .68 s (SD = .04).

To investigate evidence of pre-error speeding, the RTs of the 8 trials immediately before or after a target stimulus was presented were analyzed in a 2 (Order; pre vs post) by 2 (Accuracy; incorrect vs correct) repeated-measure ANOVA (RM-ANOVA). Note that the degrees of freedom are reduced due to some participants not making any commission errors. The RM-ANOVA revealed significant main effects of order and accuracy, as well as a significant interaction between the two predictors, $F(1,109) = 7.866$, $p = .005$ $\eta^2 p = .067$), see Figure 2a. Post-hoc paired t-tests with Bonferroni correction for multiple comparisons revealed that the interaction was driven by faster responding before an error compared to a correct omission ($t(109) = 3.94$, $p < .001$, $d = .37$, 95% CI [-.57 -.18]) and faster responding before an error compared to after an error ($t(109) = 3.03$, $p = .003$, $d = .29$, 95% CI [-.48 -.10]). These results are consistent with previous studies which have shown a pattern of RT speeding before an error compared to before a correct response to a target, as well as a post-error slowing of the response, indicating a return to more deliberate task attention.



*2 Figure 2.2. Mean RTs for 8 trials Pre and Post either a correct or an erroneous response to a target trial across experiments 1-4, A-D. The dashed horizonal line represents the mean RT for all trials. Brackets with asterisks indicate significant pairwise differences, *P < .05, **P < 0.01, ***P < .001.*

Correlation between mind-wandering indices

To examine the relationship between behavioral measures of attentional disengagement (RT CV, omission errors, anticipations, and reported measures of mind-wandering (Retrospective Mind-Wandering Survey), we computed Pearson correlations between all indices, with a false discovery rate (FDR) correction to account for multiple comparisons. All measures of mind-wandering were positively correlated with each other (all r's > .25, all p's < .05), except: Retrospective Mind-Wandering Survey, which was not strongly related to any behavioral measure of mind-wandering (all r's < .06, all p's > .70), and the correlation between anticipations and omissions (r = .10, p = .36), see Supplement Figure 2. Critically, RT CV was highly correlated with errors of commission (r = .43, p < .001), as well as with speeded anticipations (r = .25, p < .001) suggesting that overall variability in RTs is related to a participant's overall ability to attend the task.

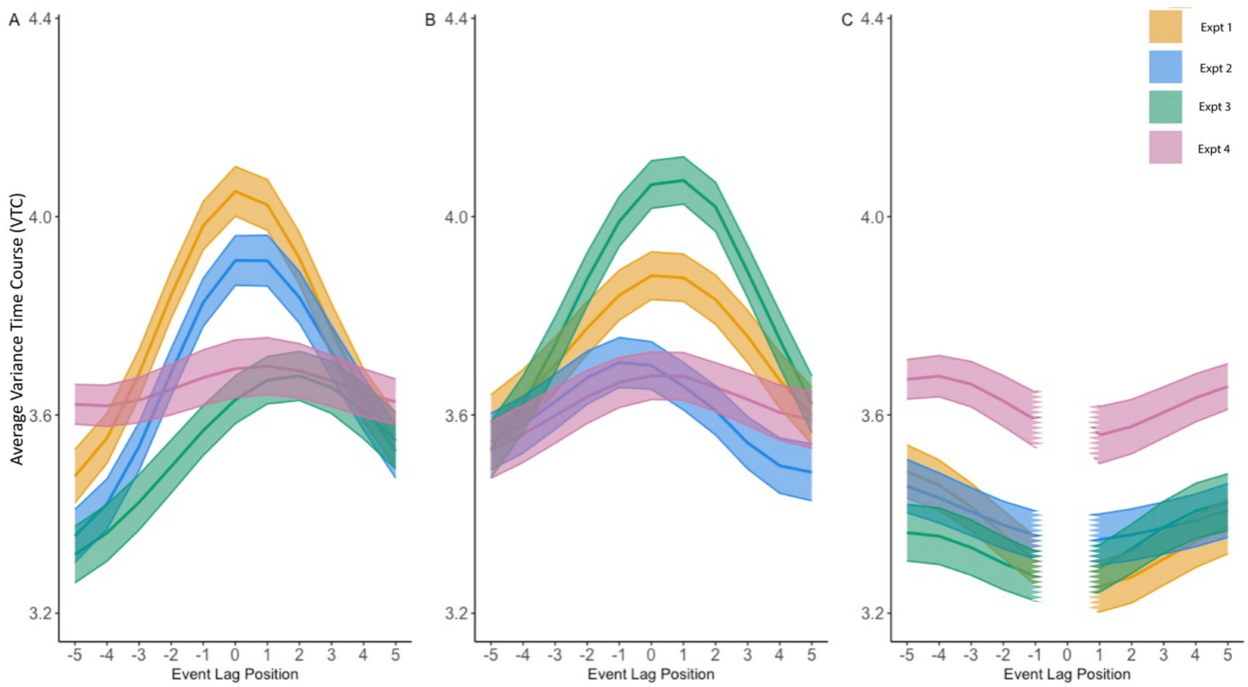
Error rates in and out of the zone

After calculating the trial-wise VTC measure (described above), each subject's smoothed VTC time course was divided into periods of low and high variability by assigning periods of being "out of the zone" as above the subject's specific VTC value at the 50th percentile, and periods of time with VTC under the 50th percentile as being "in the zone" (Esterman et al., 2013, 2014). As predicted, the mean error rate for targets while "out of the zone" ($M = 13.22\%$, $SD = 10.77\%$) was elevated compared to periods of being "in the zone" ($M = 10.80\%$, $SD = 8.03\%$), $t(117) = 2.19$, $p = .02$, $d = .25$, CI = [.20% 4.60%].

VTC at salient events

In the previous analysis, the VTC predicted attentional disengagement by increased error rates during periods of high response variability. To assess the impact of mind-wandering on memory for the temporal structure of the experience, we next examined event-related changes to the VTC that occurred at two types of salient events: category shifts and performance errors. While category shifts constituted experimentally determined changes in perceptual and conceptual context, we also reasoned that performance errors (i.e. commission responses to the rare no-go targets or omission of responses to the frequent go stimuli) could also induce a change in attentional context. Although errors were not signaled to participants with any feedback, the simplicity of this task means that participants will often realize they have made an error shortly after that have made one, especially in the case of commission errors. The change in attentional focus from a putative mind-wandering state that precedes an error to the restoration of task-based attention after the realization that an error has been made could constitute a context change from internal attention to external attention.

To quantify the impact of a momentary event (category shift or error) on the VTC, we derived a measure we refer to as "delta VTC slope". This is calculated by subtracting the pre-event VTC slope (the linear fit of the VTC for the 5 trials before the event of interest) from the post-event VTC slope (linear fit of the VTC relative to the 5 trials after). Because we were interested in the relative change in response variability before and after a given salient event, the delta VTC slope was used rather than using the VTC curve's quadratic fit, which would only capture the amount of non-linearity at the event.

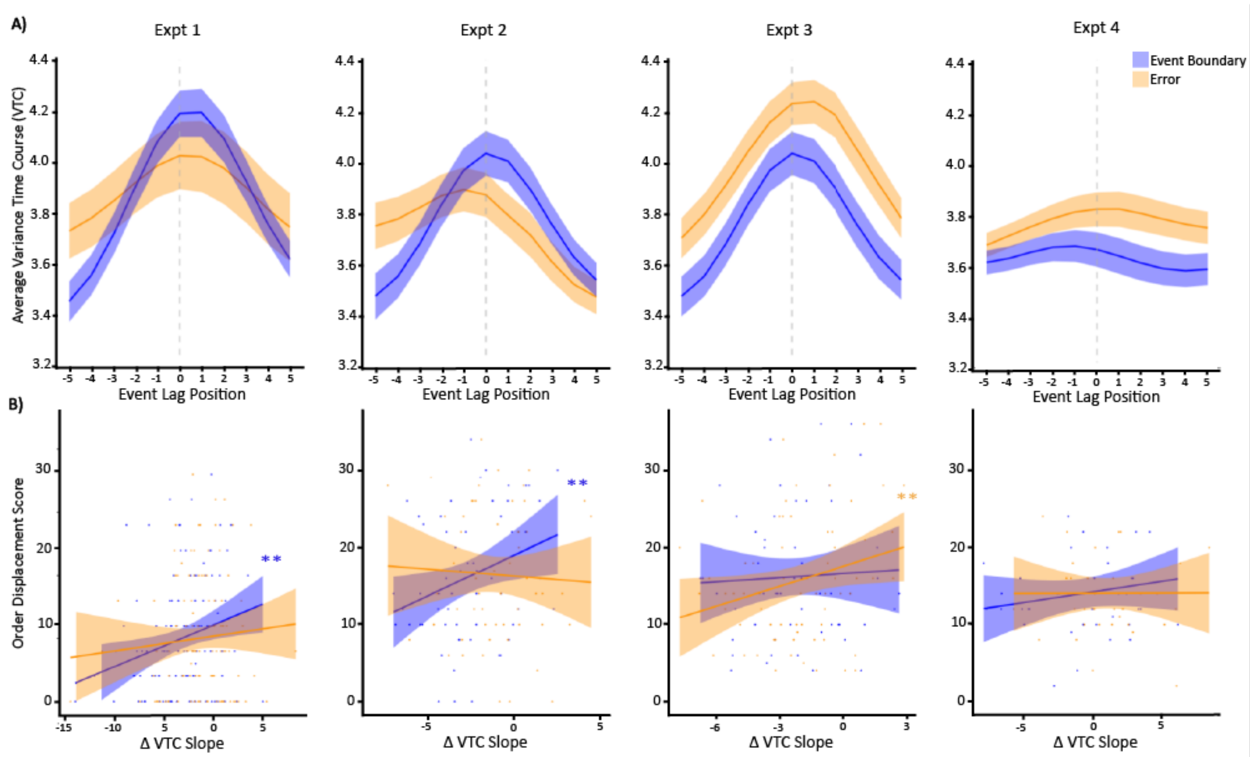


3 Figure 2.3. A) Variance Time Course (VTC) at trials leading up to and after a category change across 4 experiments. Event lag position represents the position of the trial leading up to and after the event (category change, error, or correct omission), where 0 represents the target trial. B) VTC at trials leading up to and after an omission error across 4 experiments. C) VTC at trials leading up to and after a correct omission to a target. Event lag position 0 has been excluded because these were trials where participants did not make a response. Shaded regions indicate SEM.

VTC at salient events and errors

Within each subject, the average linear slope of the 5 trials preceding or following each of the 7 category changes was calculated. No change in the VTC slope would indicate that category shifts did not have any measurable effect on behavioral response variability. This was a plausible outcome because neither the category of the stimuli nor the border colors were actually task relevant - the minimum requirement of the participant was merely to attend to stimuli border color. On the other hand, a significant change in the behavioral response variability would suggest that a consequential attentional adjustment occurred at the event boundary, such as a redeployment of attention to the task and an ensuing reduction of response variability.

We found a significant change in VTC slope when comparing trials leading up to an category change to those following it, with the former having a positive slope on average ($M = .88$, $SD = 1.76$) and the latter having a negative slope on average ($M = -.76$, $SD = 1.81$), as assessed by a paired t-test, $t(115) = 5.35$, $p < .001$, $d = .49$, 95% CI [.95 2.01]. Further, there was a significant change in VTC slope when comparing the 5 trials leading up to an error of commission to the 5 following it, with the former having a positive slope ($M = .37$, $SD = 1.62$) and the latter having a negative slope ($M = -.67$, $SD = 1.97$), $t(115) = 3.82$, $p < .001$, $d = .35$, 95% CI [.43 1.47], see Figure 3. As lower values of VTC reflect lower variability and are associated with more vigilant task-based attention, the increase in variability prior to the category change is mostly likely due to time on task effects seen in SART procedures, where mind-wandering increases with the time since a salient event (error, thought probe, etc.). When a category change occurs, the perceptual and conceptual change may snap individuals back into task-based attention and consequently reduce variability in response patterns. Further, because this effect of rapidly decreasing variability after an event boundary is specific to category changes compared to randomly selected points throughout the session (see Supplement 1.1) it is likely not simply an ambient reduction in mind-wandering.



4 Figure 2.4***:*** *A) Average VTC measure before and after an event boundary or error across all experiments. B) Scatter plots display participants' delta VTC slope and order displacement score with regression lines demonstrating the relationship between the two variables (shaded region represents 95% CI). Asterisks indicate significant relationships and color represents which response type is significant.*

Temporal order memory

Temporal order memory was assessed using the Temporal Order Deviation Score described above. As the most maximally incorrect response would receive a score of 36, the average score achieved by the participants demonstrates relatively accurate memory for the order of categories, with scores ranging from 0 to 18 (M = 5.02, SD = 4.55).

To assess the relationship between states of mind-wandering and temporal memory, we examined how the slope of the VTC changed at salient events. Each participant's mean delta VTC slope at category changes and their mean delta VTC slope at errors were inputted into a multiple linear regression to compare the relative contribution of each to subsequent memory for the temporal order of the categories. The results indicate that the delta VTC slope at category changes significantly predicted better temporal order memory (β = .33, t = 2.48, p = .01), see Figure 4. No such relationship was observed between the delta VTC slope at errors and temporal order memory (β = .15, t = 1.05, p = .30). The difference in the predictive value of delta VTC slope at category changes and errors was significant (F(3,112) = 3.02, delta Adj-R^2= .075, p = .03). The positive sign of the effect indicates that a more negative delta VTC slope (more event-related change) at category changes is associated with a decrease in the temporal order deviation score (more accurate memory).

Temporal duration memory

To assess whether the magnitude of change with which participants returned to task-based attention after an event boundary was also related to the accuracy of the duration estimation of the experience, every participant's Relative Duration Judgment score was inputted into a multiple linear regression where duration accuracy was predicted by the average delta slope at category changes and errors. The analysis showed no significant relationship between either measure of delta VTC slope (F(3,112) = .88, Adj-R^2 = .02, p = .42) at category changes (β = .033, t, = .19, p = .85) or errors (β = .22, t = 1.30, p = .19). In sum, participants' ability to recollect which categories contained more or fewer stimuli (and hence the categories' relative durations) was not related to our measures of mind-wandering or attentional fluctuation.

Experiment 1: Discussion

By drawing attention away from the environmental stimuli, mind-wandering may disrupt encoding of recent information and segmentation of ongoing experiences into discrete events. To investigate how temporal memory is influenced by mind-wandering, we adapted a sustained attention task to index changes in ongoing RT variability as participants experienced a temporally structured task. We found a significant change in the VTC slope before and after an event boundary, with the former having a positive slope (indicative of progressively increasing mind-wandering) and the latter having a negative slope (indicative of progressively diminishing mind-wandering). Critically, the degree to which participants redirected their focus after a category change (as indexed by their average delta VTC slope for such events) was predictive of their ability to later recall the temporal order of the stimulus categories they had experienced. This suggests that perceptual context shifts, or event boundaries, serve to momentarily reduce mind-wandering in a manner that is consequential for subsequent temporal order memory.

Against our predictions, we found no relationship between the level of mind-wandering and subsequent temporal duration judgments. In fact, as we also do not find significant effects on temporal duration judgments in any of the following 3 experiments, we will address this null finding in the general discussion. Further, the lack of correlation between the Retrospective Mind-Wandering Survey and behavioral performance-based indices of mind-wandering was surprising. While previous studies have found that retrospective surveys were correlated with probe-caught mind-wandering reports during the task (Barron et al., 2011; Esterman et al., 2013; Frances Finnigan et al., 2007), one key feature change between the EpiSART and traditional SART tasks is the lack of thought probes during our task. In prior SART studies, participants become aware that their attention is being monitored by these probes and may thus have a better assessment of their attention state. Our participants completed the entire EpiSART task without interruption, and this may have resulted in more poorly calibrated meta-cognitive judgments about how much mind-wandering had occurred during the task.

Experiment 2

In the first experiment, we found that we could index the degree to which participants redeployed their task-directed attention after a salient event, such as a sudden switch in the category of presented objects, by measuring how quickly they reduced the variability in their RTs. Furthermore, we found that the average slope of this VTC measure predicted their ability to subsequently recall the order in which the categories had been presented. However, there was no effect of attentional fluctuations on subsequent memory for the relative temporal durations of the categories. In this next experiment, we no longer had variable duration lengths for the task categories such that we could look at the experimental effects on subjective estimates of event durations, while holding the objective durations constant.

Experiment 2: Methods

Participants

Based on Expt 1, we conducted a power analysis for repeated measures, within factors sensitivity test on our pre-error speeding analysis using G * Power (Faul et al., 2007). The analysis revealed that effect size of η_p^2 = .017 at alpha level =.05, and power of .80, a sample size of 60 was necessary to replicate our previous findings.

70 participants were recruited via the UCLA Human Subject Pool. 11 subjects were excluded via the same procedure as described in Expt 1. After excluding these participants, 59 participants (45 female; age M = 20.72, SD = 1.18), completed the experiment for course credit.

Materials

All materials were the same as in Expt 1.

Procedure

The design of experiment 2 was identical to that of experiment 1 except for the following critical changes: because of our interest in finding changes in duration memory, in this version of the experiment all the categories were made the same length so that any differences in duration estimation could be more directly attributable to levels of attention during the EpiSART task. In addition, the overall length of the experiment was longer in Expt 2. There were 9 categories which were each 40 items long such that the entire session contained 360 unique images. The categories were randomly selected for presentation without replacement, such that there were no categories that were repeated in the sequence.

Experiment 2: Results

In this second experiment, we constrained all categories to have an equivalent number of items (i.e. matched durations) so that we could more accurately assess if changes in behavioral variability are tied to retrospective category duration judgment. Because all categories were the same duration, any perceived differences in durations could be attributed to subjective dilation or compression of the categories in memory.

Pre-error speeding

The average rate of errors of commission was 31.05% (SD = 15.05%, range: 0% – 60%). The average rate of errors of omission was 1.43% (SD = 2.08%, range: 0% – 10.45%). The average RT across all responses was .71 s (SD = .05).

Like in the previous experiment, the RTs of the 8 trials immediately before or after a target trial were analyzed in a 2 (Order; pre vs post) by 2 (Accuracy; incorrect vs correct) RM-ANOVA. The RM-ANOVA revealed significant main effects of order and accuracy, as well as a significant interaction, $F(1,56) = 31.09$, $p < .001$, $\eta_p^2 = .24$, see Figure 2b. Post-hoc paired t-tests with Bonferroni correction for multiple comparisons revealed that the interaction was driven by faster responding before an error compared to a correct omission ($F = 5.27$, $p < .001$) and faster responding before an error compared to after an error ($F = 6.61$, $p < .001$), consistent with the previous experiment.

Correlation between mind-wandering indices

To examine the relationship between behavioral measures (RT CV, omissions, anticipations, number of errors) and reported measures of mind-wandering (Retrospective Mind-Wandering Survey), we computed Pearson correlations between all indices with FDR correction for multiple comparisons. Most of the indices of mind-wandering were strongly correlated with each other (see Supplement Figure

3). RT CV correlated strongly with the number of commission errors (r = .41, p = .005) and omissions (r = .44, p = .002), and the number of anticipations (r = .39, p = .008). Like in the previous experiment, the Retrospective Mind-Wandering Survey was not significantly correlated with any behavioral measure of mind-wandering (all r's < .15, all p's > .50). Again, these results demonstrate that some measures of behavioral variability are highly related to canonical indices of attentional disengagement.

Error rates in and out of the zone

It was confirmed that errors rates were higher in the periods deemed "out of the zone" by a 50^{th} percentile split of the VTC (M = 14.57%, SD = 11.23%), compared to "in the zone" periods below the 50^{th} percentile (M = 9.71%, SD = 9.23%), t(54) = 5.43, p < .001, d = .61, 95% CI [2.63% 7.07%].

VTC at salient events and errors

The attentional response at salient events was analyzed with the same method as in Expt 1, by the delta VTC slope. The effect of the VTC response at category changes found in the first experiment was replicated by a significant difference in VTC slope immediately before and after the category change, t(54) = 8.66, p < .001, d = 2.04, 95% CI [1.22 2.86], as well as at errors, where VTC slope prior to an error was significantly different from VTC slope after the error, t(52) = 2.64, p = .005, d = .89, 95% CI [.56 1.18], see Figure 3.

Temporal order memory

As with the previous experiment, we investigated if a participant's change in VTC slope at salient events predicted their ability to later recall the order of the categories. We examined each participant's mean delta VTC slope at category changes and errors. The analysis revealed a significant relationship between the rate of attentional fluctuation at category changes (β = -1.63, t = -3.12, p = .003) but not at errors (β = .12, t = .26, p = .79). The difference in the predictive value of delta VTC slope at category changes and errors was significant (delta Adj-R^2 = .13, F(3, 53) = 4.90, p = .004, see Figure 4. The relationship was such that the more positive delta slopes (i.e., slower return to task-based attention), the worse the memory for the temporal order.

Temporal duration memory

The subsidiary aim of this follow-up experiment was to test if equalizing the length of categories would create experimental effects on subjective estimates of event durations. To assess whether the magnitude with which participants returned to task-based attention was also related to the accuracy of relative duration estimation, each individual's Relative Duration Judgment score was inputted into a multiple linear regression to assess the relationship with the average delta VTC slope at category changes and errors. However, the analysis did not find an overall significant effect of the predictors on duration rank memory ($F(2,50) = 2.13$, $p = .13$ Adj-$R^2 = .04$), such that neither at delta VTC slope at category changes ($\beta = 1.45$, $t = 1.93$, $p = .06$) nor errors ($\beta = .48$, $t = .71$, $p = .48$).

Experiment 2: Discussion

In Experiment 2, the length of the categories was equalized to investigate more clearly the relationship between mind-wandering and event duration estimation. The data replicated across all many of the critical effects. First, delta VTC slope was significant at event boundaries and errors. Second, the delta VTC slope at the event boundaries was predictive of the accurate binding of temporal events in sequence, as seen in better temporal order task scores. However, despite our decision to equate the actual number of items (and thus duration) of each category, which was done to make this study more sensitive to subjective distortions of temporal duration memory, we found no evidence that any measure of mind-wandering predicted changes in the estimated duration of the events.

There are limitations to the first two experiments. Namely, while errors were based solely on perceptual features (the color of the stimulus border), the task-based event boundaries at category changes constituted both perceptual and conceptual switches. This is because the border color and category type always changed simultaneously. Our finding that one's ability to correctly order events is related to the degree of fluctuation in attention at these critical points is interesting because it suggests that a time-specific role of temporal binding at event boundaries requires task-focused attention. However, it is possible that attention to either perceptual features (border color) or conceptual features (category type) drove this effect, and are unable to disentangle their respective roles. Therefore, in Experiment 3, we address these issues by creating a version of the EpiSART task where the border colors are eliminated and the category shifts are task irrelevant.

Experiment 3

In the prior experiments, we found that temporal order memory was linked to attentional fluctuations at event boundaries. However, based on the design of the previous experiments, it is hard to interpret which feature of the task participants were attending to because a category change was always coincident with a border color change. Even though only the border color was task relevant, it was perfectly correlated with changes in the semantic content of the images. So, in this next experiment, we attempted to dissociate these features by removing the borders entirely and instead making the task relevant feature (the no-go target) a specific image stimulus. This design change meant that participants had to attend to every image in order to evaluate whether or not it was the no-go target, which should result in more attention devoted to image identity information and thus might accentuate the temporal structure of the successive image categories.

Experiment 3: Methods

Participants

75 participants were recruited via the UCLA Human Subject Pool. 70 participants completed the experiment for course credit. 6 participants were excluded because they met one or more of the following criteria: 1) they failed to respond to more than 8 trials in a row; 2) they were identified as an

outlier on a variable used for analyses such as RT or variability (VTC, RT CV); or 3) who indicated that we should not use their data during the post-task survey. After excluding these participants, 69 participants (49 female; age, M = 20.35, SD = 1.37) completed the experiment for course credit.

Materials

All materials were the same as in Expts 1 & 2.

Procedure

In the previous versions of the EpiSART, the task relevant feature (the border color) and the event boundary feature overlapped. To be able to dissociate the task relevant feature and the event boundary, we removed the colored borders that were previously used as context boundaries. Instead of the goal of avoiding responses to a target border color, participants were instructed to avoid responding whenever a specific target image was presented. For all participants, the no-go target was an image of a human brain.

All nine categories were used in this experiment, and for each participant they were presented in random order with 40 items in each category. Thus, the entire session contained 360 unique images. All other presentation protocols were the same as the previous two experiments.

After the EpiSART task, participants completed the same procedure for all temporal memory tests: order, metric duration, and category length estimation. Afterwards they completed the Retrospective Mind-Wandering Survey.

Experiment 3: Results

Pre-error speeding

The average rate of errors of commission was 32.73% (SD = 19.10%, range: 0% – 80.00%). The average rate of errors of omission was 1.06% (SD = 1.39%, range: .29% – 9.85%). The average RT across all responses was .68 s (SD = .045).

Again, we analyzed the RTs of the 8 trials immediately before or after a target in a 2 (Order; pre vs post) by 2 (Accuracy; incorrect vs correct) RM-ANOVA to assess the data for evidence of pre-error speeding. The RM-ANOVA revealed significant main effects of order and accuracy, as well as a significant interaction between the two predictors, $F(1,67) = 47.93$, $p < .001$, see Figure 2c. Post-hoc paired t-tests with Bonferroni correction for multiple comparisons revealed that the interaction was driven by faster responding before an error compared to a correct omission ($t = 9.68$, $p < .001$) and faster responding before an error compared to after an error ($t = 5.25$, $p < .001$), consistent with the two previous experiments of the current study.

Correlation between mind-wandering indices

To examine the relationship between behavioral measures *(*RT CV, omissions, anticipations, number of errors) and reported measures of mind-wandering (Retrospective Mind-Wandering Survey), we computed Pearson correlations between all indices with FDR correction to account for multiple comparisons. RT CV correlated strongly with the number of errors ($r(68) = .51$, $p < .001$) and omissions ($r(68) = .46$, $p < .001$). However, it was not correlated with the number of anticipations ($r(68) = .09$, $p = .45$). In this version of the experiment, the Retrospective Mind-Wandering Survey was significantly correlated with two other measures of mind-wandering, RT CV ($r(68) = .31$, $p = .009$) and errors ($r(68) = .41$, $p < .001$).

We successfully replicated the same pattern of results from the previous experiment by demonstrating that behavioral indicators of mind-wandering were strongly correlated with each other (RT CV, anticipations, omission errors, and commission errors) (all s's > 19, p's < 01, see Supplement Figure 4). Notably, we found that in this version of the experiment, the Retrospective Mind-Wandering Survey was significantly related to indices of mind-wandering such anticipations, commission errors, RT CV (all r's > .26, p's < .04), but not with omissions ($r = .20$, $p = .09$). The methodological changes in this version of the experiment may aid in explaining why the subjective rating measures and behavioral task measures were significantly related in Expt 3. For example, the method of this EpiSART version more closely mirrors the traditional SART task. In the SART, the critical decision to be made is whether each numeral stimulus is the specified target number, and in this version of the EpiSART the critical decision to be made is whether each image stimulus is the specified target image.

Error rates in and out of the zone

Errors rates were higher in the “out of the zone” periods of high VTC based on a 50^{th} percentile split ($M = 3.84\%$, $SD = .02\%$) compared to “in the zone” periods of low VTC ($M = 2.09\%$, $SD = .02\%$), $t(71) = 8.31$, $p < .001$, $d = .79$, 95% CI [.57% 2.79%].

VTC at salient events

The average linear VTC slope before and after category changes was significantly different ($t(58)= 4.38$, $p < .001$), as well as at errors ($t(56) = 6.82$, $p < .001$).

Temporal order memory

The delta VTC slopes at category changes and errors were submitted to a multiple regression analysis to test if the rate of attentional fluctuations at salient events predicted memory for the temporal order of categories. The results of the multiple regression ($F(3, 64) = 2.82$, $p = .04$, Adj-$R^2 = .12$) indicated reduction of the delta VTC slope at errors was the only variable that significantly predicted temporal order memory ($\beta = .86$, $t = 2.48$, $p = .02$), see Figure 3. Meaning that the faster that an individual returns to task-focused attention following an error, the better they tend to be at correctly ordering the categories in their presented order. On the other hand, the delta VTC slope at category changes ($\beta = .42$, $t = .84$, $p = .40$) was not significantly related to temporal order memory, see Figure 4.

Temporal duration memory

Like for the temporal order memory test, we used the same predictors (VTC response at category changes and errors) to examine the relationship between attentional fluctuations and relative duration memory. The multiple regression showed that attention at errors was significant in predicting duration memory (β = -.95, t = -1.99, p = .049).

Experiment 3: Discussion

In Experiment 3, the EpiSART task was updated to dissociate the perceptual and conceptual features of the category changes. In the prior two experiments, the stimulus border color was changed at both targets and category changes. Therefore, the explicit requirements of the task (i.e., don't respond to a pre-specified target border color) were partially relevant to the color change that occurred at an event boundary. In this new version of the experiment, participants responded to images of all categories, except when the image was a brain (the no-go target). The category change event boundaries were thus completely task irrelevant, as participants could complete the task by only judging whether each individual image was a brain.

Whereas in the prior two experiments, the level of mind-wandering at category changes predicted poorer temporal order memory, in the present experiment, mind-wandering at errors predicted poorer temporal order memory. Conversely, the faster that participants returned to attention after an error (i.e., a reduction in variable responding) predicted better category order memory. One interpretation of these findings is that at moments of mental context change, such as mind-wandering before an error vs attention to task after, act as event boundaries which aid individuals to bind temporal information in the absence of strong perceptual boundaries. However, in this design, the task relevant feature of the EpiSART is perceptual (do not respond to an image if it is a brain), while memory recall requires tracking conceptual features of the task, such as the category of images that are presented.

Experiment 4

In the previous experiments, the task relevant feature was based on a perceptual decision (is the border around the image a specific color? (Expts 1 and 2) or is the image a specific object? (Expt 3)), while the event boundary was conceptually defined (category change). In Expts 1 and 2, the event boundary's task relevance was inferentially limited by a change in both conceptual (category) and perceptual features (color) of the stimuli that defined the experimentally defined events. In Expt 3, the event boundary was not task relevant, as the category was completely irrelevant to the task of not responding to the target image of a brain. In Expt 4, the task target feature and event boundary were both made conceptual, rather than perceptual.

Experiment 4: Methods

Participants

75 participants were recruited via Prolific (Palan & Schitter, 2018). 9 subjects were excluded because they met one or more of the following criteria: 1) they failed to respond to more than 8 trials in a row; 2) they were identified as an outlier on a variable used for analyses such as RT or variability (VTC, RT CV); or 3) who indicated that we should not use their data during the post-task survey. After excluding these participants, 66 participants (45 female; age, M = 32.27, SD = 13.23). Participants were compensated at a rate of $7.50/hour.

Materials

All materials were the same as in Expts 1-3, except for the category of "musical instruments" was replaced with "hardware/tools" to align with the size judgment task requirement.

Procedure

In Expt 4, the task target feature and event boundary were both made conceptual, rather than perceptual. As before, participants saw a sequence of 6 categories of equal lengths. Instead of responding to a target border color, or target image, participants made judgments of size. They were instructed to press the spacebar for every image except those which depicted an object that could fit inside of a ring box. We curated all images such that each category was made up of 90% of objects which could not fit into a ring box, and 10% could. We took lengths to find objects within each category which were unambiguous so as to reduce the incident of false target commissions simply because the participant thought that the item could fit within a ring box.

Due to the longer processing time to make a size judgment, the duration of each trial was elongated. Each trial began with a 250 ms fixation of a cross in the center of the screen. The stimuli were presented for 1750 ms with a 1 second inter-trial interval. The trials lasted 3 s each and categories switched every 120 s (40 objects per category). All other aspects of stimuli presentation remained the same.

After the EpiSART session, participants completed the Retrospective Mind-Wandering Survey. Participants completed the same procedure for all temporal memory tests: order, metric duration, and category length estimation.

Experiment 4: Results

Pre-error speeding

The average rate of errors of commission was 39.69% (SD = 22.00%, range: 8.00% – 70.00%). The average rate of errors of omission was 5.60% (SD = 4.15%, range: 1.5% - 24.18%). The average RT across all responses was 1.07 s (SD = .11).

Response times of the 8 trials immediately before or after a target in a 2 (Order; pre vs post) by 2 (Accuracy; incorrect vs correct) RM-ANOVA to assess the data for evidence of pre-error speeding, see Figure 2d. The RM-ANOVA revealed no significant main effects of order ($F(1, 65) = 0.98$, $p = .32$ and accuracy ($F(1, 65) = .15$, $p = .70$), and no interaction between the two variables, $F(1, 65) = 1.47$, $p = .24$

Correlation between mind-wandering indices

To examine the relationship between behavioral measures (RT CV, omissions, anticipations, number of errors) and reported measures of mind-wandering (Retrospective Mind-Wandering Survey), we computed Pearson correlations between all indices with FDR correction for multiple comparisons.

We replicated the similar pattern of results from the previous experiment by demonstrating that behavioral indicators of mind-wandering were strongly correlated with each other (RT CV, anticipations, omission errors, and commission errors) (all r's > .19, p's < .05, see Supplement Figure 5). However, all correlations with the Retrospective Mind-Wandering Survey failed to reach significance (all r's < .20, all p's > .26, see Supplement Figure 5).

Error rates in and out of the zone

Subjects' RT time series were converted into the VTC measure and divided into periods of high and low variability. There were no differences between errors rates "out the zone" (M = 14.30%, SD = 12.03%) than those "in of the zone," (M = 13.09%, SD = 9.99%), t(65) = .95, p = .34, d = .11, 95% CI [-1.30% 3.77%].

VTC at salient events

The linear VTC slope before and after category changes was not significantly different, t(65) = 1.44, p = .16, but was at errors, t(65) = 2.81, p = .003, d = .67, 95% CI [.12 1.28], as it has been in the previous experimental results, see Figure 3.

Temporal order memory

The delta VTC slope at category changes and errors were submitted to a multiple regression analysis to test if the rate of attentional fluctuations at salient events predicted memory for the temporal order of categories. Neither the delta VTC slope at event boundaries (β = .34, t = .75, p = .47) nor errors (β = -.001, t = .00, p = .99) were significant, F(3, 63) = .291, p = .75, Adj-R^2 = .01, see Figure 4.

Temporal duration memory

Like for the temporal order memory test, the same predictors (VTC response at category changes and errors) were used to examine the relationship between attentional fluctuations and relative duration memory. The multiple regression was not significant (F(3,63) = .40, p = .73), nor any of the predictors (all p > .18).

Experiment 4: Discussion

We again observed evidence for mind-wandering in several behavioral indices, including speeding of RTs before errors, correlations between indices of attentional disengagement, and increased errors in periods of high response variability. However, in contrast to our prior experiments, here we observed no significant change in the VTC at category changes or errors. While the previous experimental designs included presentation of stimuli which required a trial-wise response, the decision we required participants to make in this version of the experiment was exceptional in that it was relational. In the previous designs, the participants made judgments on the stimuli as being a target or not based on basic perceptual features (e.g., *is this border color the target border color? or is this image a picture of a brain?*), while in Expt 4, the participants had to process each object and then make the decision as to whether in the real-world this depicted entity would be smaller than a ring box. The increased attentiveness to the object identity and attributes presumably eliminated the relationship between both event boundaries and errors with the overall tracking of temporal context. By making the task demands object-specific, participants may have been unable to bind the category level contextual information into their ongoing experience.

Overall Discussion

In the present study, we investigated the effects of mind-wandering on subsequent memory for temporal information, and reciprocally, the impact of temporally punctate experiences (such as event boundaries or errors) on momentary mind-wandering. Participants performed a newly developed task paradigm—the EpiSART—which harnessed the ability of the standard SART procedure to measure lapses of stimulus-directed attentional focus, while also incorporating just enough temporal structure to allow us to examine the influence of event boundaries and to later probe participants' memory for the order and duration of stimulus categories.

The time course of the normalized variance in response times (VTC) provided a continuous measure for the estimation of trial-by-trial attentional focus, where low VTC scores indicate more task-directed attention, and high VTC scores indicate more mind-wandering (Esterman et al., 2013). This VTC measure revealed systematic fluctuations in attention at moments of contextual shifts (event boundaries) and at spontaneous errors. Across Experiments 1, 2, and 3, we found significant peaks of this VTC measure at both event boundaries and errors, suggesting that periods of increased variability due to mind-wandering (an increase in VTC slope) were followed by a decrease in mind-wandering (a decrease in VTC slope) immediately after these salient experiences. One interpretation of these data is that peaks of variability indicate that both shifts in task context and spontaneous errors alert individuals to reorient their attention back to the task, thus diminishing any non-task-related mind-wandering that was occurring.

By computing the difference between the pre-event and post-event VTC slopes, we were able to quantitatively index the degree to which individuals “snapped back” to attention via the delta VTC slope. Each participants’ average delta VTC slope across all event boundaries was used to predict their temporal order memory score. In Experiments 1 and 2, we found that the faster that participants reduced their mind-wandering at event boundaries (i.e. high delta VTC slope), the more accurate they were in subsequently being able to remember the sequential order of the object categories.

One important consideration for the influence of mind-wandering and event boundaries on temporal memory is the task relevance of each feature manipulated in our paradigm. In Experiments 1 and 2, the stimulus context was defined by both a perceptual and conceptual feature, a border color and category identity, respectively. The EpiSART task demands were locked to a particular border color, so the coincidence of border color change and category change was salient, even though the category change was not goal-relevant. Indeed, in these experiments, attentional flexibility to reorient task focus at these salient change points predicted subsequent temporal order memory above and beyond attentional fluctuations at errors. However, in Experiment 3, a target image was used instead of a target border color, and all borders were removed to decrease the task relevance of the category change. In Experiment 3, only attentional fluctuations at errors, rather than at category changes, predicted temporal order memory. One interpretation of errors being consequential to temporal order memory is to consider the error-induced switch from being off-task to on-task as a salient context change, or event boundary. Indeed, recent work has shown that task demand shifts create event boundaries in memory (Wang & Egner, 2022). From this perspective, when environmental changes are less task relevant (as was the case in Experiment 3), task-driven context changes may become particularly salient features of experience that aid in binding representations of events in sequence. Once mind-wandering is diminished by increasing task demands, such as in Experiment 4, the relationship between mind-wandering and temporal order memory goes away. One interpretation of these results is that the salient context changes from off-task to on-task attunes the participant to the context and they are able to bind information about temporal order. Notably, the VTC slopes at event boundaries and errors in Experiment 4 are markedly flatter, indicating fewer fluctuations or mind-wandering periods.

Across all four experiments, we observed significant correlations between traditional behavioral indices of mind-wandering, such as error rate, RT variability, and response speeding before errors. However, we did not find consistent evidence for an association between these behavioral indices of mind-wandering and participants' subjective ratings of how much they felt their minds were wandering during the task. This may be in part due to our choice to use a retrospective mind-wandering survey rather than thought probes that query participants in the moment. We opted against the use of thought probes in our experiments because we felt that their occurrence would constitute another form of event boundary, and thus complicate our planned analyses. However, we acknowledge that the time elapsed between the EpiSART task and the retrospective survey may have limited the metacognitive precision of participants' memories for how much they had mind-wandered.

It should be noted that our design differs from studies focused on the effects of event boundaries on item-to-item associations. Many studies show how item-to-item associations bound to the same or different context are modulated by event boundaries (DuBrow & Davachi, 2013, 2014). In contrast, our experiments were designed to investigate higher order event structure—the binding of contexts in the stream of experience—rather than lower level, item-to-item associations. For example, Jayakumar and colleagues (2023) found that attention at event boundaries had limited effects on item-to-item order memory. However, in our paradigm, participants had to rely on representational stability of contexts to bind the sequence of categories. Some recent work on the importance of the post-event boundary period for contextual binding may help explain why we found that mind-wandering was predictive of temporal memory. For example, in the period directly after an event boundary, one electroencephalography study found evidence of rapid neural replay of the previous event (Sols et al., 2017). Further, they found that the representational similarity between the neural replay and previous event predicted the temporal order memory. One interpretation of the data in the current study is that slowness to reorient attention to the task at context shifts disrupts binding of one context (or "event") to the next.

One might have predicted that a higher percentage of time spent "in the zone," or in a state of focused attention, would result in improved memory for the order of stimuli. However, our findings suggest a more nuanced picture. We did not find a direct correlation between overall attentional fluctuations and subsequent temporal order memory. Instead, our results indicated that the timing of attentional reorientation, specifically at event boundaries and/or errors, had a pronounced effect on memory accuracy. This suggests that it is not merely the quantity of focused attention, but the timing and context in which this attentional focus is regained that are crucial for temporal memory.

Across all experiments we found no evidence that any measure of mind-wandering related to any durational estimate of the stimulus categories. Although a unified account of how event durations are encoded and retrieved in memory storage has yet to be realized in the literature, most empirical work has previously proposed that retrospective duration judgments rely on the accumulation of recalled information during an interval. For example, stimulus complexity (Ornstein, 1969), and contextual change (Block, 1989) such as a shift in the way that presented information is processed (Block & Reed, 1978), have been shown to increase the recalled duration of intervals. It could be the case that attentional fluctuations were relatively constant in our series of experiments, and therefore were invariant to the experimental manipulation.

In sum, the findings here expand our theoretical understanding of how attentional states interact with memory processes. In particular, we operationalize attention in more naturalistic terms drawing from the mind-wandering literature. Outside of the lab, our findings suggest some practical applications in educational and occupational settings; strategies that introduce semi-structured breaks or tasks changes may mimic the "reorienting" effect of event boundaries found in these data, potentially enhancing focus and memory for order and content of material.

It is important to consider the limitations of our paradigm. The experimental setting, though carefully designed to reflect fluctuations in attention which may occur in the everyday world, may not fully capture the complexities of mind-wandering in everyday life. Future research could explore the ecological validity of these findings by employing experience sampling paradigms which track the locus of attention in real-world tasks.

In conclusion, these findings help to clarify the interplay between mind-wandering, event boundaries, and memory and suggest that the strategic management of attention, particularly around salient events, can enhance our ability to remember temporal sequences. Our results underscore the importance of context shifts in modulating mind-wandering and their impact on memory for temporal event structure, but also demonstrate that mind-wandering may not be catastrophic to all expressions of memory. Our ability to reconstruct the temporal order of events seems not to depend as much on the amount that our mind wandered, but rather on the flexibility with which we are able to snap out of our off-task thinking and rapidly re-orient our attention to the present moment.

References

Aly, M., & Turk-Browne, N. B. (2016). Attention Stabilizes Representations in the Human Hippocampus. *Cerebral Cortex*, *26*(2), 783–796. https://doi.org/10.1093/cercor/bhv041

Bainbridge, W. A., & Oliva, A. (2015). A toolbox and sample object perception data for equalization of natural images. *Data in Brief*, *5*, 846–851. https://doi.org/10.1016/j.dib.2015.10.030

Baird, B., Smallwood, J., Lutz, A., & Schooler, J. W. (2014). The Decoupled Mind: Mind-wandering Disrupts Cortical Phase-locking to Perceptual Events. *Journal of Cognitive Neuroscience*, *26*(11), 2596–2607. https://doi.org/10.1162/jocn_a_00656

Baldassano, C., Chen, J., Zadbood, A., Pillow, J. W., Hasson, U., & Norman, K. A. (2017). Discovering Event Structure in Continuous Narrative Perception and Memory. *Neuron*, *95*(3), 709-721.e5. https://doi.org/10.1016/j.neuron.2017.06.041

Barron, E., Riby, L. M., Greer, J., & Smallwood, J. (2011). Absorbed in thought: The effect of mind wandering on the processing of relevant and irrelevant events. *Psychological Science*, *22*(5), 596–601. https://doi.org/10.1177/0956797611404083

Block, R. A. (1989). Chapter 9 Experiencing and Remembering Time: Affordances, Context, and Cognition. In I. Levin & D. Zakay (Eds.), *Advances in Psychology* (Vol. 59, pp. 333–363). North-Holland. https://doi.org/10.1016/S0166-4115(08)61046-8

Block, R. A., & Reed, M. A. (1978). Remembered duration: Evidence for a contextual-change hypothesis. *Journal of Experimental Psychology: Human Learning and Memory*, *4*, 656–665. https://doi.org/10.1037/0278-7393.4.6.656

Brady, T. F., Konkle, T., Alvarez, G. A., & Oliva, A. (2008). Visual long-term memory has a massive storage capacity for object details. *Proceedings of the National Academy of Sciences*, *105*(38), 14325–14329. https://doi.org/10.1073/pnas.0803390105

Burgess, N., Maguire, E. A., & O'Keefe, J. (2002). The human hippocampus and spatial and episodic memory. *Neuron*, *35*(4), 625–641. https://doi.org/10.1016/s0896-6273(02)00830-9

Cheyne, J. A., Solman, G. J. F., Carriere, J. S. A., & Smilek, D. (2009). Anatomy of an error: A bidirectional state model of task engagement/disengagement and attention-related errors. *Cognition*, *111*(1), 98–113. https://doi.org/10.1016/j.cognition.2008.12.009

Clewett, D., & McClay, M. (2021). *Emotional arousal ripples across time to bind subsequent episodes in memory*. PsyArXiv. https://doi.org/10.31234/osf.io/ne5vs

DuBrow, S., & Davachi, L. (2013). The influence of context boundaries on memory for the sequential order of events. *Journal of Experimental Psychology: General*, *142*(4), 1277–1286. https://doi.org/10.1037/a0034024

DuBrow, S., & Davachi, L. (2014). Temporal Memory Is Shaped by Encoding Stability and Intervening Item Reactivation. *Journal of Neuroscience*, *34*(42), 13998–14005. https://doi.org/10.1523/JNEUROSCI.2535-14.2014

DuBrow, S., & Davachi, L. (2016). Temporal binding within and across events. *Neurobiology of Learning and Memory*, *134*, 107–114. https://doi.org/10.1016/j.nlm.2016.07.011

Esterman, M., Noonan, S. K., Rosenberg, M., & Degutis, J. (2013). In the zone or zoning out? Tracking behavioral and neural fluctuations during sustained attention. *Cerebral Cortex (New York, N.Y.: 1991)*, *23*(11), 2712–2723. https://doi.org/10.1093/cercor/bhs261

Esterman, M., Rosenberg, M. D., & Noonan, S. K. (2014). Intrinsic Fluctuations in Sustained Attention and Distractor Processing. *The Journal of Neuroscience*, *34*(5), 1724–1730. https://doi.org/10.1523/JNEUROSCI.2658-13.2014

Ezzyat, Y., & Davachi, L. (2011). What Constitutes an Episode in Episodic Memory? *Psychological Science*, *22*(2), 243–252. https://doi.org/10.1177/0956797610393742

Ezzyat, Y., & Davachi, L. (2014). Similarity Breeds Proximity: Pattern Similarity within and across Contexts Is Related to Later Mnemonic Judgments of Temporal Proximity. *Neuron*, *81*(5), 1179–1189. https://doi.org/10.1016/j.neuron.2014.01.042

Faber, M., & Gennari, S. P. (2015). In search of lost time: Reconstructing the unfolding of events from memory. *Cognition*, *143*, 193–202. https://doi.org/10.1016/j.cognition.2015.06.014

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. https://doi.org/10.3758/BF03193146

Frances Finnigan, Daniela Schulze, & Jonathan Smallwood. (2007). Alcohol and the wandering mind: A new direction in the study of alcohol on attentional lapses. *International Journal on Disability and Human Development*, *6*(2), 189–200. https://doi.org/10.1515/IJDHD.2007.6.2.189

Gurguryan, L., Dutemple, E., & Sheldon, S. (2021). Conceptual similarity alters the impact of context shifts on temporal memory. *Memory*, *29*(1), 11–20. https://doi.org/10.1080/09658211.2020.1841240

Horner, A. J., Bisby, J. A., Wang, A., Bogus, K., & Burgess, N. (2016). The role of spatial boundaries in shaping long-term event representations. *Cognition*, *154*, 151–164. https://doi.org/10.1016/j.cognition.2016.05.013

Jayakumar, M., Balusu, C., & Aly, M. (2023). Attentional fluctuations and the temporal organization of memory. *Cognition*, *235*, 105408. https://doi.org/10.1016/j.cognition.2023.105408

Jeunehomme, O., & D'Argembeau, A. (2019). The time to remember: Temporal compression and duration judgements in memory for real-life events. *Quarterly Journal of Experimental Psychology*, *72*(4), 930–942. https://doi.org/10.1177/1747021818773082

Jonker, T. R., Seli, P., Cheyne, J. A., & Smilek, D. (2013). Performance reactivity in a continuous-performance task: Implications for understanding post-error behavior. *Consciousness and Cognition*, *22*(4), 1468–1476. https://doi.org/10.1016/j.concog.2013.10.005

Kane, M. J., Smeekens, B. A., Meier, M. E., Welhaf, M. S., & Phillips, N. E. (2021). Testing the construct validity of competing measurement approaches to probed mind-wandering reports. *Behavior Research Methods*, *53*(6), 2372–2411. https://doi.org/10.3758/s13428-021-01557-x

Killingsworth, M. A., & Gilbert, D. T. (2010). A Wandering Mind Is an Unhappy Mind. *Science*, *330*(6006), 932–932. https://doi.org/10.1126/science.1192439

Konkle, T., & Oliva, A. (2012). A real-world size organization of object responses in occipitotemporal cortex. *Neuron*, *74*(6), 1114–1124. https://doi.org/10.1016/j.neuron.2012.04.036

Kurby, C. A., & Zacks, J. M. (2008). Segmentation in the perception and memory of events. *Trends in Cognitive Sciences*, *12*(2), 72–79. https://doi.org/10.1016/j.tics.2007.11.004

Lee, H., & Chen, J. (2022). A generalized cortical activity pattern at internally generated mental context boundaries during unguided narrative recall. *eLife*, *11*, e73693. https://doi.org/10.7554/eLife.73693

Manly, T., Robertson, I. H., Galloway, M., & Hawkins, K. (1999). The absent mind: Further investigations of sustained attention to response. *Neuropsychologia*, *37*(6), 661–670. https://doi.org/10.1016/s0028-3932(98)00127-4

Mason, M. F., Norton, M. I., Horn, J. D. V., Wegner, D. M., Grafton, S. T., & Macrae, C. N. (2007). Wandering Minds: The Default Network and Stimulus-Independent Thought. *Science*, *315*(5810), 393–395. https://doi.org/10.1126/science.1131295

McVay, J. C., & Kane, M. J. (2009). Conducting the train of thought: Working memory capacity, goal neglect, and mind wandering in an executive-control task. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *35*, 196–204. https://doi.org/10.1037/a0014104

Ornstein, R. E. (1969). *On the Experience of Time*. Harmondsworth.

Ottaviani, C., Shahabi, L., Tarvainen, M., Cook, I., Abrams, M., & Shapiro, D. (2015). Cognitive, behavioral, and autonomic correlates of mind wandering and perseverative cognition in major depression. *Frontiers in Neuroscience*, *8*. https://doi.org/10.3389/fnins.2014.00433

Palan, S., & Schitter, C. (2018). Prolific.ac—A subject pool for online experiments. *Journal of Behavioral and Experimental Finance*, *17*, 22–27. https://doi.org/10.1016/j.jbef.2017.12.004

Peirce, J., Gray, J. R., Simpson, S., MacAskill, M., Höchenberger, R., Sogo, H., Kastman, E., & Lindeløv, J. K. (2019). PsychoPy2: Experiments in behavior made easy. *Behavior Research Methods*, *51*(1), 195–203. https://doi.org/10.3758/s13428-018-01193-y

Radvansky, G. A., & Copeland, D. E. (2006). Walking through doorways causes forgetting: Situation models and experienced space. *Memory & Cognition*, *34*(5), 1150–1156. https://doi.org/10.3758/BF03193261

Radvansky, G., Copeland, D., & Zwaan, R. (2005). A novel study: Investigating the structure of narrative and autobiographical memories. *Memory*, *13*(8), 796–814. https://doi.org/10.1080/09658210444000412

Robertson, I. H., Manly, T., Andrade, J., Baddeley, B. T., & Yiend, J. (1997). `Oops!': Performance correlates of everyday attentional failures in traumatic brain injured and normal subjects. *Neuropsychologia*, *35*(6), 747–758. https://doi.org/10.1016/S0028-3932(97)00015-8

Schooler, J. W., Smallwood, J., Christoff, K., Handy, T. C., Reichle, E. D., & Sayette, M. A. (2011). Meta-awareness, perceptual decoupling and the wandering mind. *Trends in Cognitive Sciences*, *15*(7), 319–326. https://doi.org/10.1016/j.tics.2011.05.006

Seli, P., Cheyne, J. A., & Smilek, D. (2013). Wandering minds and wavering rhythms: Linking mind wandering and behavioral variability. *Journal of Experimental Psychology. Human Perception and Performance*, *39*(1), 1–5. https://doi.org/10.1037/a0030954

Smallwood, J., Beach, E., Schooler, J. W., & Handy, T. C. (2008). Going AWOL in the Brain: Mind Wandering Reduces Cortical Analysis of External Events. *Journal of Cognitive Neuroscience*, *20*(3), 458–469. https://doi.org/10.1162/jocn.2008.20037

Smallwood, J., Davies, J. B., Heim, D., Finnigan, F., Sudberry, M., O'Connor, R., & Obonsawin, M. (2004). Subjective experience and the attentional lapse: Task engagement and disengagement during sustained attention. *Consciousness and Cognition*, *13*(4), 657–690. https://doi.org/10.1016/j.concog.2004.06.003

Smallwood, J., McSpadden, M., & Schooler, J. W. (2007). The lights are on but no one's home: Meta-awareness and the decoupling of attention when the mind wanders. *Psychonomic Bulletin & Review*, *14*(3), 527–533. https://doi.org/10.3758/BF03194102

Smallwood, J., & Schooler, J. W. (2006). The restless mind. *Psychological Bulletin*, *132*(6), 946–958. https://doi.org/10.1037/0033-2909.132.6.946

Sols, I., DuBrow, S., Davachi, L., & Fuentemilla, L. (2017). Event Boundaries Trigger Rapid Memory Reinstatement of the Prior Events to Promote Their Representation in Long-Term Memory. *Current Biology*, *27*(22), 3499-3504.e4. https://doi.org/10.1016/j.cub.2017.09.057

Tulving, E. (1972). Episodic and semantic memory. In *Organization of memory* (pp. xiii, 423–xiii, 423). Academic Press.

Wang, Y. C., & Egner, T. (2022). Switching task sets creates event boundaries in memory. *Cognition*, *221*, 104992. https://doi.org/10.1016/j.cognition.2021.104992

Wiemers, E. A., & Redick, T. S. (2019). The influence of thought probes on performance: Does the mind wander more if you ask it? *Psychonomic Bulletin & Review*, *26*(1), 367–373. https://doi.org/10.3758/s13423-018-1529-3

Yamashita, A., Rothlein, D., Kucyi, A., Valera, E. M., Germine, L., Wilmer, J., DeGutis, J., & Esterman, M. (2021). Variable rather than extreme slow reaction times distinguish brain states during sustained attention. *Scientific Reports*, *11*(1), 14883. https://doi.org/10.1038/s41598-021-94161-0

Zacks, J. M., & Swallow, K. M. (2007). EVENT SEGMENTATION. *Current Directions in Psychological Science*, *16*(2), 80–84. https://doi.org/10.1111/j.1467-8721.2007.00480.x

Zacks, J. M., Tversky, B., & Iyer, G. (2001). Perceiving, remembering, and communicating structure in events. *Journal of Experimental Psychology: General*, *130*(1), 29–58. https://doi.org/10.1037/0096-3445.130.1.29

Zwaan, R. A., Langston, M. C., & Graesser, A. C. (1995). The Construction of Situation Models in Narrative Comprehension: An Event-Indexing Model. *Psychological Science*, *6*(5), 292–297. https://doi.org/10.1111/j.1467-9280.1995.tb00513.x

Zwaan, R. A., Radvansky, G. A., Hilliard, A. E., & Curiel, J. M. (1998). Constructing multidimensional situation models during reading. *Scientific Studies of Reading*, *2*(3), 199–220. https://doi.org/10.1207/s1532799xssr0203_2

Chapter 3: ConTemplate: Dynamic contexts promote memories of hierarchical events

Introduction

Although everyday life unfolds continuously, we remember the past as being more discrete and episode, broken down into individual memories, or events. But what creates these episodes and influences how they organized over time? Past work indicates that the temporal stability of context guides memory integration (DuBrow & Davachi, 2013, 2014, 2016; Ezzyat & Davachi, 2011), linking information together into cohesive and contextually-distinct episodes. This includes features in the environment, such as spatial (Radvansky & Copeland, 2006) and perceptual information (Sridharan et al., 2007; Swallow et al., 2011; Swallow, Zacks, & Abrams, 2009), as well as internal states such as arousal and valence (Clewett, Gasser, Davachi et al., 2020; McClay, Rouhani, & Clewett, 2024).

Event boundaries, or shifts in these contexts, promote memory separation into discrete episodes. For example, after studying lists of information, people are worse at remembering the order of item pairs that had spanned an event boundary (DuBrow & Davachi, 2013, 2014, 2016), remember item pairs as happening farther apart in time (Ezzyat & Davachi, 2014; Lositsky et al., 2016), and better at remembering the source information of boundary items (Heusser et al., 2018). Evidence suggests that information internal to a contextually defined event become integrated such that individuals' rate within-event item pairs are occurring closer in time compared to items that spanned a boundary (DuBrow & Davachi, 2013; 2014). These findings provide evidence to the idea that event boundaries serve as points in time where recently experienced information is processed into temporally discrete units of memory, to promote the associations within an event than across events.

In this way, event segmentation in memory is adaptive and enhances the memorability of events (Flores et al., 2017). Event Segmentation Theory (EST) suggests that ongoing experience is parsed into meaningful events by salient changes in mental context that signal the end of an event and the beginning of a new one (Kurby & Zacks, 2008; Zacks & Swallow, 2007). Given a current context, situation models are created using spatial, perceptual, goal, or other contextual features. This situation model for the event will be terminated if the parameters of the current model do not align with a new changed context, and a new model emerges (G. Radvansky et al., 2005; Zwaan et al., 1998).

While much of this work in the field has been done on the processes and memory effects of segmenting on going experience, to be truly adaptive, our memory systems must be capable of simultaneously integrating across and separating adjacent events (Griffiths & Fuentemilla, 2020). Further, boundary effects appear to be malleable: contextual information at retrieval can either impair or enhance temporal order judgements across event boundaries (Wen & Egner, 2022), and individuals are generally good at recalling the timeline of complex narratives such as stories or films (Baldassano et al., 2017; Zacks et al., 2001). It is also important to recall the relative order of events in temporal succession, and therefore processes of integration and separation must work in congress to support both the within event and across event representations of experience.

Recent work has showed that in the period directly after an event boundary, there is rapid neural replay of the previous event and the pattern similarity between replay and the activity during the event predicts more accurate binding of temporally adjacent events (Sols et al., 2017). This finding suggests that boundaries not only serve to demarcate context shifts and promote within-event associations, but also to promote the binding of higher-order representations of event structure.

Recall of within vs across boundaries rely on different retrieval strategies. For example, one study found that increased univariate BOLD activity in the hippocampus and left ventrolateral prefrontal cortex (vlPFC) was associated with recall of items that spanned a boundary, while within event recall was associated with increased functional connectivity between the hippocampus and ventromedial PFC (DuBrow & Davachi, 2016). Further, a lesion study found that damage to the lateral PFC corrupts temporal order memory when intentional, strategic recall was necessary (Mangels, 1997). In sum, these findings suggest that recall of temporal relations across event boundaries are supported by different retrieval strategies and neural processes.

The need for ongoing updating of complex event structures is evident in the case of narratives. For comprehension, it is critical to be able to bridge across related sub-events or contexts to form an over-arching grasp of a storyline. Knowledge of hierarchical structure of different levels of context within a narrative are important to the maintenance of on-going event comprehension. To demonstrate this, Chang and colleagues used a professional writer to design a narrative with two discrete storylines which were interleaved in segments and only in the last segment was it revealed that characters in the storylines had shared history (Chang et al., 2021). In this way, the researchers could investigate the neural signals associated with both the segmenting of events across the story, but also the integration of previous events at the end of the story. They found that neural reinstatement of higher-order contextual motifs in the first parts of the story was associated with better comprehension of the events across the narrative timeline. This suggests that tracking of higher order event representations, such as shared motifs within intersecting stories, is necessary for narrative comprehension.

Like in narratives, it makes sense to bridge event boundaries to maintain a subjective sense of continuity for ongoing personal experiences. Event structure in the world is hierarchical (Baldassano et al., 2017, 2018)), so there must be processes that allow us to construct event representations on both shorter and longer timescales. There are many types of contextual information, including space and perceptual features in the world. Increasing evidence suggests that the temporal stability of this information - or how it fluctuates or stabilizes across time - provides scaffolding for forming memories of discrete and meaningful events. This event segmentation process, however, is typically only studied with respect to one type of contextual information. In reality, layers of context exist at a given moment and they change at different rates over time.

In this study, we ask: one, if event separation and integration processes co-exist so as to promote a hierarchical organization of memory? And two, parallel processes simultaneously bridge events and separate events at event boundaries based on the stability of overlapping contexts?

Methods

Participants

Participants were recruited via UCLA's SONA Undergraduate Study Recruitment service. We were informed by the effect size derived from a similar event boundary experiment with moderate-to-large effect sizes (power=.05, alpha = .05; Yen & Enger, 2022; DuBrow & Davachi, 2013; Heusser et al., 2018), ranging from 28 to 56 participants. We increased our target sample size to 60 to account for noisier measures and potential failures in task performance.

Task

This study is a three-way mixed design. The critical manipulation is a 2 (Probe: preboundary, same-context) x 2 (Context Stability: stable, shift) x 2 (Shift Type: character, scene) mixed design. While Probe and Context stability were varied within each subject, subjects were assigned to one Shift Type condition for the entire experiment. All image stimuli were randomized across subjects during encoding. All image stimuli were randomized a second time during all memory tests.

The experiment was an event boundary type design, where participants study lists of images of everyday objects (e.g., Clewett et al., 2020; Dubrow and Davachi, 2013). To define context dynamics, all items in each list were surrounded by two context dimensions: a scene and a character. The critical manipulation was the stability, or rate of change, of the two types of contextual information. One context changed features after 4 items, while the other context was changed after 8 items within any given list. After encoding each list, subjects were tested on their cued serial recall for pairs of items in the list.

Cued serial recall (temporal order memory)

Participants were assessed by a cued free recall memory test where participants will view one image from a list they just viewed and be asked which item came next. They were instructed to press a button when they were ready to type their response and then type their responses into a text box. RT was taken from the time they the READY button. Participants will only be probed at key points from the list sequence: same-context, where the test items occurred in the same context, and across-context, where the test items spanned a context shift.

Source memory

Subjects were tested on source memory after all lists were presented. All items in subevent positions 1 and 3 were tested and participants chose among 4 colors and 4 shapes.

To test our key hypotheses that context dynamics influence the temporal structure of memory, we will perform linear regression analyses using the lme4 packages in R (http://cran.r-project.org/web/packages/lme4/). Linear mixed regression analysis was used to test the relationship between Probe Type (preboundary, same-context), Context Stability (stable, shift), and Shift Type (color, shift) on Temporal Order Memory and Temporal Source Memory. Slopes and intercepts for each participant will be specified as random effects, enabling us to account for individual differences in these variables.

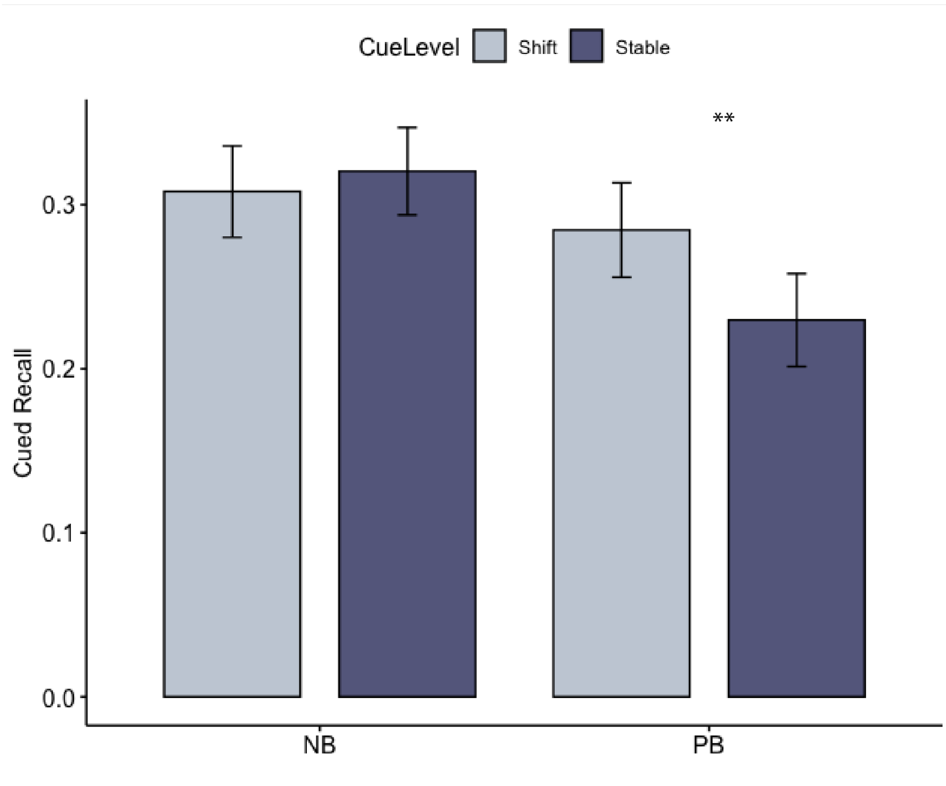
Participants were excluded based on performance criteria. Participants will be excluded if they: Fail to respond to more than 10% of encoding trials, correctly recall any stimuli on the cued serial memory test trials, perform at or below chance level on the source memory task (25% on 4AFC), or fail comprehension tests administered after practice and before the experimental trials begin. No participants were excluded in the following analyses. This study was pre-registered at asPredicted.com.

Results

Participants

Participants were recruited via the UCLA Online Subject Online for course credit. We collected 60 participants (42 female; Age M= 19.43, SD = 1.34, Range: 18 - 25). There were no differences between the conditions for age (Character Stable: M = 19.24, SD = 1.97, Scene Stable: M = 20.06, SD = 2.56).

Cued Memory Recall

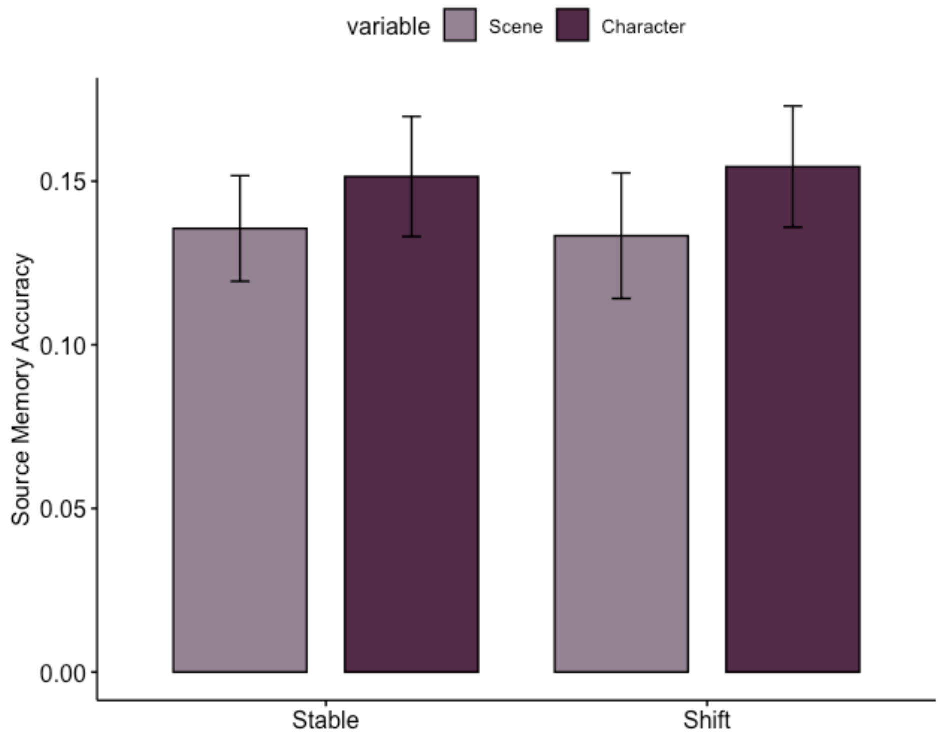


5 Figure 3.1. Bar plot depicting mean cued recall accuracy as a function of Cue Level (Shift vs. Stable) and Test Cue Type (NB = Non-Boundary, PB = Pre-Boundary). Error bars represent the standard error of the mean (SEM).

Overall cued memory recall was 39.34% (SD = 23.45%). There was no difference between conditions (Scene Stable: M = 27.8, SD = .448, Character Stable: M = 30.2%, ST = .46), t(58) = -.87, p = .384). Non-boundary items were recalled more accurately (M = .316, SD - .465) than pre-boundary items (M = .259, SD = .438), t(58) = 2.00, p = .045 CI = [.001 .111]. Finally, there was no overall difference between Shift (low level; M = .297, SD = .457) and Stable cue levels (high level; M = .282, SD = .451), T(58) = .516, p = .606.

In order to test the relationship between context hierarchies, we submitted the data to a linear mixed model with Probe Type (pre-boundary, non-boundary), Context Stability (stable, shift), and Shift Type (scene, character) as fixed effects to predict Temporal Order Memory accuracy, with Subject as a random factor to account for individual differences. Baseline accuracy was revealed by the intercept as 28.6%, β=0.286, SE=0.033, t(57.17)=8., p < .001. Neither Condition (β=−0.014 SE=0.033S, t(57.17)=−0. , p=.668p), nor Cue Level (β=0.0026, SE=0.013, t(1015)=0.202, p=.840) significantly contributed to predicting memory accuracy. However, Cue Type was significant (β=0.027, SE=0.013, t(1008)=2.118, p=.034), where in Pre Boundary memory accuracy was lower (M = 25.8%, SE = 3.56%, CI = [18.6& 32.9%]) than Non Boundary items (M = 31.4%, SE = 3.45%, CI = [24.4% 38.3%]. Further, there was a significant interaction between Cue Type and Condition (β=0.028, SE=0.013, t(1008)=2.151, p=.032), suggesting that Scene Shift Condition tended to have higher memory recall.

Due to the structure of our item presentation, there was one item at the 8^{th} position of the 16-item list which was a Pre-Boundary item at both a scene and character shift. This “super boundary” item accuracy was assessed in a separate model with a 3^{rd} type of Cue Type along with Pre-Boundary and Non Boundary. The same model was run as above including this variable, revealing an interaction between Cue Level and Cue Type (β=0.046, SE=0.003, t(1008)=2.281, p=.027). However, follow up pair-wise contrasts for Cue Level and Cue Type did not survive tests for multiple comparisons (t(1009) = .064, SE = .029, p = .074).



6 Figure 3.2 Mean source memory accuracy as a function of Cue Level (Stable vs. Shift) and Variable (Scene vs. Character). Error bars represent the standard error of the mean (SEM).

Source Memory Recall

Mean source memory recall was overall 14.4% (SD = .35) and was not different by Cue Level or Condition (all ps > .60). We ran a linear mixed effect model to examine the effects of Cue Level, Cue Type, and Condition on Source Memory accuracy. Neither Cue Level (β=0.011, SE=0.068, t(1495)=0.163t, p=.87), nor Cue Type (β=−0.006, SE=0.023, t(1492)=−0.252, p=.801), or their interaction predicted source memory accuracy. The lack of significant effects implies that neither the experimental manipulations nor their interactions had effects on the accuracy of source memory. This may be due to the challenging nature of the task – source memory tests occurred after all the recall tests were performed at the end of the experiment where time on task effects could have decreased accurate recall.

Discussion

The present study examined how dynamic temporal context shifts influence memory integration and separation in episodic memory. Participants performed a cued recall and source memory test where they encoded items within hierarchical contexts that were manipulated for stability (stable vs. shift) and subsequently tested for their order memory at specific time points (pre-boundary vs non-boundary). Consistent with prior research (DuBrow & Davachi, 2013, 2014), we found that non-boundary items were more accurately recalled than pre-boundary items, suggesting that memory integration is disrupted at event boundaries. We did not find that pre-boundary and stable context clues ameliorate this consistent finding, suggesting that pre-boundary memory decrements are robust. The significant interaction between cue type and condition further indicated that memory recall may depend on the type of contextual shift, with scene shifts associated with higher recall accuracy.

These findings are aligned with Event Segmentation Theory (EST), which hypothesizes that salient contextual changes disrupt memory integration and simultaneously facilitate event boundary segmentation (Zacks & Swallow, 2007). Therefore, regardless of context cue stability, event boundaries disrupt ongoing temporal order information and memory processes prioritize internal event information over and above pre-boundary information.

However, no significant differences were observed for source memory accuracy across conditions or cue levels. This null effect may reflect task difficulty or the timing of source memory tests, which were administered after list recall trials. Such time-on-task effects may have depleted cognitive resources, reducing participants' ability to retrieve specific source details. Future studies may address this limitation by reducing task length or alternating the order of source and recall memory tests. Interestingly, the interaction between cue level and cue type revealed nuanced effects on recall accuracy, particularly for "super boundary" items, which experienced simultaneous shifts in both scene and character contexts. Although follow-up pairwise contrasts did not survive corrections for multiple comparisons, this trend suggests that the convergence of multiple contextual shifts may amplify memory segmentation effects. Future research, with longer lists which may include multiple “super boundary” items may help elucidate this finding.

These findings help elucidate how we are able to retain information in dynamic contexts. In this study, we find that context stability aids in guiding episodic memory integration and separation. While stable contexts promote within-event associations, context shifts at boundaries enhance the formation of discrete event representations. This reciprocal relationship of integration and segmentation likely supports memory organization in adaptive ways, enabling people to recall both detailed internal event details, but also the broader temporal structure of experiences through segmentation. Future research may investigate how individual differences in cognitive strategies or task demands may influence these adaptive processes so as to further clarify the mechanisms underlying event segmentation and integration.

References:

1. Baldassano, C., Hasson, U., & Norman, K. A. (2018). Representation of Real-World Event Schemas during Narrative Perception. *Journal of Neuroscience*, *38*(45), 9689–9699. https://doi.org/10.1523/JNEUROSCI.0251-18.2018
2. Bonnici, H. M., Cheke, L. G., Green, D. A. E., FitzGerald, T. H. M. B., & Simons, J. S. (2018). Specifying a Causal Role for Angular Gyrus in Autobiographical Memory. *Journal of Neuroscience*, *38*(49), 10438–10443. https://doi.org/10.1523/JNEUROSCI.1239-18.2018
3. Bonnici, H. M., & Maguire, E. A. (2018). Two years later – Revisiting autobiographical memory representations in vmPFC and hippocampus. *Neuropsychologia*, *110*, 159–169. https://doi.org/10.1016/j.neuropsychologia.2017.05.014

4. Chang, C. H. C., Lazaridi, C., Yeshurun, Y., Norman, K. A., & Hasson, U. (2021). Relating the Past with the Present: Information Integration and Segregation during Ongoing Narrative Processing. *Journal of Cognitive Neuroscience*, *33*(6), 1106–1128. https://doi.org/10.1162/jocn_a_01707
5. Clewett, D., Gasser, C., & Davachi, L. (2020). Pupil-linked arousal signals track the temporal organization of events in memory. *Nature Communications*, *11*(1), Article 1. https://doi.org/10.1038/s41467-020-17851-9
6. Doré, B. P., Rodrik, O., Boccagno, C., Hubbard, A., Weber, J., Stanley, B., Oquendo, M. A., Miller, J. M., Sublette, M. E., Mann, J. J., & Ochsner, K. N. (2018). Negative Autobiographical Memory in Depression Reflects Elevated Amygdala-Hippocampal Reactivity and Hippocampally Associated Emotion Regulation. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, *3*(4), 358–366. https://doi.org/10.1016/j.bpsc.2018.01.002
7. DuBrow, S., & Davachi, L. (2013). The influence of context boundaries on memory for the sequential order of events. *Journal of Experimental Psychology: General*, *142*, 1277–1286. https://doi.org/10.1037/a0034024
8. DuBrow, S., & Davachi, L. (2016a). Temporal binding within and across events. *Neurobiology of Learning and Memory*, *134 Pt A*(Pt A), 107–114. https://doi.org/10.1016/j.nlm.2016.07.011
9. DuBrow, S., & Davachi, L. (2016b). Temporal binding within and across events. *Neurobiology of Learning and Memory*, *134*, 107–114. https://doi.org/10.1016/j.nlm.2016.07.011
10. Ezzyat, Y., & Davachi, L. (2011). What constitutes an episode in episodic memory? *Psychological Science*, *22*(2), 243–252. https://doi.org/10.1177/0956797610393742
11. Ezzyat, Y., & Davachi, L. (2014). Similarity breeds proximity: Pattern similarity within and across contexts is related to later mnemonic judgments of temporal proximity. *Neuron*, *81*(5), 1179–1189. https://doi.org/10.1016/j.neuron.2014.01.042

12. Flores, S., Bailey, H. R., Eisenberg, M. L., & Zacks, J. M. (2017). Event Segmentation Improves Event Memory Up to One Month Later. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *43*(8), 1183–1202. https://doi.org/10.1037/xlm0000367
13. Griffiths, B. J., & Fuentemilla, L. (2020). Event conjunction: How the hippocampus integrates episodic memories across event boundaries. *Hippocampus*, *30*(2), 162–171. https://doi.org/10.1002/hipo.23161
14. Kurby, C. A., & Zacks, J. M. (2008). Segmentation in the perception and memory of events. *Trends in Cognitive Sciences*, *12*(2), 72–79. https://doi.org/10.1016/j.tics.2007.11.004
15. Liu, W., Shi, Y., Cousins, J. N., Kohn, N., & Fernández, G. (2022). Hippocampal-Medial Prefrontal Event Segmentation and Integration Contribute to Episodic Memory Formation. *Cerebral Cortex*, *32*(5), 949–969. https://doi.org/10.1093/cercor/bhab258
16. Mangels, J. A. (1997). Strategic processing and memory for temporal order in patients with frontal lobe lesions. *Neuropsychology*, *11*, 207–221. https://doi.org/10.1037/0894-4105.11.2.207
17. McClay, M., Sachs, M., & Clewett, D. (2022). *Dynamic music-induced emotions shape the episodic structure of memor*. https://doi.org/10.31234/osf.io/8hpwy
18. Nawa, N. E., & Ando, H. (2019). Effective connectivity within the ventromedial prefrontal cortex-hippocampus-amygdala network during the elaboration of emotional autobiographical memories. *NeuroImage*, *189*, 316–328. https://doi.org/10.1016/j.neuroimage.2019.01.042
19. Nawa, N. E., & Ando, H. (2020). Effective connectivity during autobiographical memory search. *Brain and Behavior*, *10*(8), e01719. https://doi.org/10.1002/brb3.1719
20. Radvansky, G. A., & Copeland, D. E. (2006). Walking through doorways causes forgetting: Situation models and experienced space. *Memory & Cognition*, *34*(5), 1150–1156. https://doi.org/10.3758/bf03193261

21. Radvansky, G. A., Zwaan, R. A., Federico, T., & Franklin, N. (1998). Retrieval from temporally organized situation models. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *24*(5), 1224–1237. https://doi.org/10.1037//0278-7393.24.5.1224
22. Sols, I., DuBrow, S., Davachi, L., & Fuentemilla, L. (2017). Event Boundaries Trigger Rapid Memory Reinstatement of the Prior Events to Promote Their Representation in Long-Term Memory. *Current Biology: CB*, *27*(22), 3499-3504.e4. https://doi.org/10.1016/j.cub.2017.09.057
23. Sridharan, D., Levitin, D. J., Chafe, C. H., Berger, J., & Menon, V. (2007). Neural dynamics of event segmentation in music: Converging evidence for dissociable ventral and dorsal networks. *Neuron*, *55*(3), 521–532. https://doi.org/10.1016/j.neuron.2007.07.003
24. Swallow, K. M., Zacks, J. M., & Abrams, R. A. (2011). “Event boundaries in perception affect memory encoding and updating”: Correction to Swallow et al. (2009). *Journal of Experimental Psychology: General*, *140*, 140–140. https://doi.org/10.1037/a0022160
25. Vodrahalli, K., Chen, P.-H., Liang, Y., Baldassano, C., Chen, J., Yong, E., Honey, C., Hasson, U., Ramadge, P., Norman, K. A., & Arora, S. (2018). Mapping between fMRI responses to movies and their natural language annotations. *NeuroImage*, *180*, 223–231. https://doi.org/10.1016/j.neuroimage.2017.06.042
26. Wen, T., & Egner, T. (2022). Retrieval context determines whether event boundaries impair or enhance temporal order memory. *Cognition*, *225*, 105145. https://doi.org/10.1016/j.cognition.2022.105145
27. Young, K. D., Siegle, G. J., Bodurka, J., & Drevets, W. C. (2016). Amygdala Activity During Autobiographical Memory Recall in Depressed and Vulnerable Individuals: Association With Symptom Severity and Autobiographical Overgenerality. *American Journal of Psychiatry*, *173*(1), 78–89. https://doi.org/10.1176/appi.ajp.2015.15010119

Chapter 4: Stuck in Reverse: Cognitive and Neural Perspectives on Overgeneral Memory in Depression via Ruminative Mind-wandering

Background

Autobiographical memories - memories of our personal experiences of past events - provide us with the ability for the rich re-experiencing of episodes in our lives. Through the reflection on our experiences, we gain insight into the causes, consequences, and meanings of events to weave a narrative of our personal identity. Theoretical perspectives on the function of autobiographical memories suggest that it is critical for maintaining social relationships, learning from past experiences, predicting the future (Buck et al., 2008; see Willams, 2003), and general well-being (Watkins, 2014).

Clinical depression is known to cause alterations in the way that individuals process information about themselves, including the reflection of one's past self as well as analysis of one's current self (Beck, 1979; Brewer, 1983). One such alteration is the decreased specificity of autobiographical memory, or overgeneral memory (OGM). When patients with depression are asked to recall memories of past events, they are more likely than non-depressed individuals to recall generalized summaries of habitual events, like "going to school" or "making mistakes" rather than rich, explicit memories of events specific to a time and place (Williams, 1996; Williams et al., 2007). This pathology is of particular concern because of the significance of autobiographical memory in social and cognitive function as well as in future thinking, decision making, and imaginative thought (Spreng, Hanna-Andrews, Kim, 2014; Schacter & Spreng, 2016).

Another common cognitive feature of depression is rumination: a thinking style marked by repeatedly and analytically focusing on symptoms of distress and on the possible causes and consequences of the symptoms (Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008). Despite not being a categorical symptom of depression per the DSM, rumination is a predictor of the onset of major depressive disorder, as well as of the severity and duration of episodes (Watkins, 2008). Likewise, it has been established by a body of literature that depression is associated with decreased executive function and regulation of emotion (Watkins & Brown, 2002). Rumination may serve to prolong negative mood states in patients by focusing on negative past events, their meanings, and consequences on self-identity.

Theories attempting to explain the link between sub-symptoms of depression and overgeneral memory posit dysfunctional executive control and emotional regulation as etiological factors of decreased specificity in memory. One prediction which has guided much of the empirical work on OGM in depression is made from the interaction of subsystems in these models: OGM is the consequence of inefficient retrieval strategies, either through executive control deficiencies or through rumination capturing attentional resources, which truncates the memory search at a general level to mitigate potential distressing reactions to details of events in their personal lives (Williams, 2006).

In lieu of this view, I will propose that a reconsideration of rumination as a form of aberrant mind wandering where patients become fixated on autobiographical information may affect memory specificity by acute effects through rumination’s effect on cognitive and neural state. In addition, spontaneous ruminations might alter the representation and organization of memory structures through persistent reactivations which decontextualize episodic autobiographical information and lead to generalization. Thus, without requiring executive dysfunction to drive the effect of memory specific reduction in depression, alterations in spontaneous thoughts and repetitive activations of self-relevant information could explain how the organization and retrievability of autobiographical memories is altered in depression.

Overgeneral memory in depression

It has been long known that depression is associated with a decrease in memory specificity for personal experiences, or what is known as autobiographical memory (Williams & Broadbent, 1986; Williams & Scott, 1988; Brittlebank et al., 1993; Williams, 1999). Rather than specific memories from a unique spatio-temporal environment, such as “going to the lunch hall on my first day of college and meeting my friend, Laura," overgeneral retrieval can present as categorical memories (e.g., "going to the store"), events over 24 hours in length (e.g., "spring break trip to Mexico"), or semantic associates or feeling states linked with a retrieval cue (e.g. "When I am feeling sad").

While there are small observed effects for semantic memory and short-term memory, investigation on memory in depression has demonstrated the largest effects on episodic memory (Zakzanis, Leach, And Kaplan, 1998; McDermott & Ebmeier, 2009). Further, the memory specificity deficit for individuals with depression appears to be unique to self-relevant, or autobiographical, information. Soderland and colleagues (2011) compared the memory specificity of individuals with and without depression for autobiographical details which were coded as either internal details such as the spatio-temporal environment, emotional, or physical features of the memory or external details such as semantic knowledge about the event. They found no global deficit in autobiographical memory retrieval but rather specific reduction for internal details in depressed patients, while the rate of external, semantic details recalled by depressed and non-depressed individuals were comparable.

Overgeneral memory is associated with a range of depressive symptoms, underscoring the influence that autobiographical memories have on a range of psychological processes. Overgeneral memory is associated with a concomitant decrease in social problem solving (Goddard et al., 1996), possibly as a cause of being unable to retrieve specific memories that may help remediate interpersonal concerns. Overgeneral memory is also associated with more general future thinking (Williams et al., 1996; Jing et al., 2016), a negative and generalized view of oneself and the world (Watkins et al., 2009), and with feelings of hopelessness (Raes et al., 2009).

Attempts to identify potential vulnerabilities of developing depression demonstrate that overgeneral memory is not only a consequence, but also a predictor of the onset of a depressive episode (Airaksinen et al., 2007; Van Daele et al., 2013). Kliem & Ehlers (2008) found that reduced specificity in autobiographical memory recollection predicted depression in response to a recent trauma. A recent meta-analysis found that across studies that used the AMT to assess overgeneral memory as a risk factor for depression, less specificity in memory predicted more severe symptoms of depression at follow ups (Halford et al., 2021).

There is substantial evidence that overgeneral memory is not simply a consequence of depressive pathology, but a factor in the maintenance of the disorder. Memory specificity inductions have been shown to reduce depressive symptoms and increase well-being among inpatients (Raes et al., 2009) and outpatients (Neshat-Doost et al., 2012). Overgeneral memory can be mitigated by specific cognitive strategies, such as altering attentional focus from self-relevant analytic style such as ruminating on the causes and consequences of events to distraction which focus on sensory features of a cue such as “how the Grand Canyon looks at sunset” (Watkins, Teasdale, & Williams, 2000).

Models of Overgeneral Memory in Depression

Much work has been done to identify the key features of depressive pathology that underlie overgeneral memory, and leading models consider overgeneral memory as the consequence of ineffective retrieval strategies. These models of overgeneral memory presume a hierarchical model of autobiographical memory (Conway and Pleydell-Pearce, 2000). In this model of autobiographical memory, the “self-memory system” is constructed from levels of memory representations with major levels increasing in specificity as one descends the hierarchy: lifetime periods, general events, single events, and event specific knowledge. Descending the hierarchy of memory representations into more specific knowledge parallels the range of autobiographical memory from semantic (thematic, less richly detailed memories) to episodic (generally includes sensory and emotional details). Retrieval of a memory begins with an intentional staged search that is guided by generative, top-down processes or from direct, bottom-up retrieval that allow one to access event-specific details.

The Autobiographical Memory Test has been the primary instrument used to measure specificity in memory retrieval (Williams & Broadbent, 1986). In this assessment, individuals are asked to provide specific memories to a set of cue words which are subsequently coded by a review process that codes the memory as general or specific. Memory specificity is then calculated as the proportion of memories that are retrieved in a general or specific style. In this way, memory specificity is operationally defined as proportionally more general responses and fewer specific responses.

The Car-Fa-X model (Williams, 2006) of overgeneral memory in depression posits that three key symptoms of depression contribute either in a direct or combinatorial manner: (1) capture and rumination (CaR), (2) functional avoidance (Fa), and (3) executive control dysfunction (X). This model has guided research in the nearly two decades since its publication and has been featured prominently in recent reviews of the literature on memory and depression (Barry et al., 2018; Sumner, 2012). In each of the following sections, I will review the evidence of each symptom's proposed influence on overgeneral memory in depression and at the end I will review proposed interactions between the systems.

Cognitive avoidance

Early conceptions of OGM drew primarily from models of cognitive avoidance (Williams, Stiles, & Shapiro, 1999) where it was thought that depressed individuals engaged in abbreviated memory searches to avoid potential distress of recalling specific details of a given event. Much of the literature that does exist on memory specificity and avoidance relies on studies that investigate how OGM might develop from childhood or adolescent trauma. However, the link between OGM and trauma experienced in early life is not clear: while some studies do report an association between memory specificity and trauma (Sinclair et al., 2007; Raemaekers et al., 2010), not all do (Johnson et al., 2005). Because these studies do not report whether cognitive avoidance is utilized by individuals within the study either by measurement of avoidance related cognitive processes (such as thought suppression or inhibition) or by self-report of engagement with avoidance, the link between avoidance and OGM remains unclear.

Despite its inclusion in theoretical accounts of OGM, the phenomena of cognitive avoidance have not historically factored greatly into empirical investigation. Although progress has been made in attempts to delineate the cognitive processes that underlie avoidance strategies in psychopathologies, there remains no functional model of cognitive avoidance in depression (but see Sibrava & Borovec, 2006 for review on avoidance in worry). Even without a parsimonious account of the mechanisms underlying depression related cognitive avoidance, candidate processes such as inhibition and cognitive control have been studied in depressed patients. If executive function processes contribute to cognitive avoidance, the expectation would be that individuals with depression would display the ability to inhibit negative information or deploy control strategies to suppress memory retrieval.

While there is evidence that individuals with depression and a history of trauma self-report engaging in cognitive avoidance strategies (Johnson et al., 2009; Crane et al., 2005), it is difficult to confirm how self-reported strategies might functionally contribute to OGM. Trait measures of depressive symptoms, such as rumination, are associated with self-reported tendencies to engage in thought suppression in individuals with PTSD and comorbid depression, however not in individuals with depression alone (Rosebrock et al., 2018). Further, a longitudinal diary study found that within the community, cognitive avoidance of daily struggles and worries were not associated with overgeneral memory, but rather, ruminations on those concerns and level of depressive symptoms was associated in less specific memory (Hallford et al., 2018). Thus, individuals with depression may attempt to engage in thought suppression strategies to attempt to avoid distressing memories, but these self-report measures alone do not demonstrate their effectiveness in actively inhibiting event specific details and promoting categoric recall of distressing events.

The most challenging feature of known depressive symptomatology that remains incongruous with cognitive avoidance accounts of OGM is that depressed patients are stereotypically worse at inhibiting negative information and memories. Depressed patients demonstrate preferential attendance to negative information, show delayed disengagement from negative content, interpret ambiguous information negatively, and recall more negative information (Everaert, Koster, Deraksahn, 2012). In studies where participants are given word lists to recall, individuals with depression are more likely to report depression related words in a free recall test compared to never depressed individuals (Bradley, Magg, & Williams, 1995). Instead of demonstrating an ability to inhibit negative memories, there is evidence that this bias pervades autobiographical memory: when individuals with depression retrieve personal memory, they report more negative memories compared to non-depressed controls (Whalley, Rugg, & Brewin, 2012) and report more intrusions of negative memories (Howell & Conway, 1992). In the attentional domain, difficulties in inhibition of negative material are more prevalent in MDD and associated with a tendency to ruminate (Joormann & Gotlib, 2009, Fawcett et al., 2015), suggesting to the authors that some of the perseverative qualities of rumination may be due to an inability to disengage from negative thoughts. In sum, if cognitive avoidance is playing a role in depression, there is limited evidence that it is functionally contributing to memory specificity deficits, but rather presents as a pathological coping strategy.

Executive function

Executive function involves a variety of processes, including, but not limited to, the inhibition functions discussed above. Another alteration in executive processing that has been identified in depression is a reduction in cognitive flexibility. Researchers have observed that depression impairs performance on tasks of executive function such as the Wisconsin Card Sorting Test and the Stroop Word Test (Merriam et al., 1999; Trichard et al., 1995). Depression is marked by patterns of decreased external focus as well as switching between internal and external orientation. Demeyer and colleagues (2012) used performance on the Internal Shift Task to show that cognitive inflexibility was associated with self-reported rumination scores in adults with depression. The Internal Shift Task asks the participant to switch attention between items in response to emotional and nonemotional expressions and requires both attending to internal emotional appraisals and external focus on task performance. Researchers found that decreased task performance, indicating lower control ability, was predictive of depressive symptoms a year later, and this relationship was mediated by rumination. This observed decrease in external focus and complementary increase in internal focus supports the idea that attentional bias to internal thoughts and feelings contribute to the cognitive rigidity in individuals with depression. While cognitive rigidity may be contributing uniquely to depressive symptomatology, it is also likely to be broadly related to the inability to disengage from internal mentation and is better thought of as contributing to rumination.

Rumination

Rumination is defined as repetitive, prolonged, and recurrent negative thinking about one's self, feeling, personal concerns, and upsetting experiences (Watkins, 2008). Rumination is a form of self-referential thinking (Watkins, 2008), and trait and state levels of rumination have been identified (LeMoult, Arditte, Scansato, & Joorman, 2013) in both healthy individuals and clinical conditions (Nolen-Hoeksema, 2008). Depressive rumination has specific symptomatology proposed to elongate and worsen symptoms of depression through focus on symptoms, their causes and consequences, and meanings and implications, of depressed mood and depression. Ruminators tend to dedicate cognitions to thematic questions such as "why are these things happening to me," rather than attend to the content or details of thoughts (Watkins & Teasdale, 2009).

Response Styles Theory (Nolen-Hoeksema, 1996) views rumination as a form of cognitive dysfunction with an emphasis on the connection between perseverative, negative self-referential thought and depressive symptomatology. It addresses rumination on a trait level, drawing from studies which demonstrate that rumination is a consistent style of responding to negative mood and appears to be a stable individual characteristic (Nolen Hoeksema et al., 1993). Because of the stability in the style of responding, the theory takes a developmental approach to understanding rumination as a habit learned in childhood, modeled by parents who had a passive coping style or because the child failed to learn a more active coping strategy for negative affect as a consequence of over critical and over-controlling parents.

However, rumination occurs not only in pathological conditions, but also in everyday circumstances and in non-clinical groups. For example, ruminating on the causes (i.e., forgetting) and consequences (i.e., upsetting a friend) about making a social faux pas, such as realizing that you forgot your friend’s birthday, may help an individual not commit the same mistakes again. Rumination has been demonstrated in healthy (Piguet et al., 2014) and clinical populations such as depression, anxiety, OCD, and PTSD (Nolen-Hoeksema et al., 2008). Its presentation in non-clinical responding to stressors suggests that it may hold some functional purpose, such as reflecting on previous events to understand the meaning and consequences of actions or events (Treynor et al., 2003). In concentrating on the causes and consequences of events and circumstances, healthy individuals can use rumination as a problem-solving strategy that allows individuals to reflect on self-relevant information to attain goals through focus on abstract features of events. In this way, the Goal-Progress Model of rumination regards rumination as a general self-regulation strategy where perseverative, reflective thoughts arise from discrepancies between goals and progress made towards their completion (Martin & Tesser, 2006). Like any other trait, the tendency to ruminate exists on a spectrum. It is likely that this thinking style predisposes individuals who tend to ruminate and then experience a life-stressor or trauma go on to develop depression by engaging with this pathological coping technique.

Rumination's putative role in the prolongation of negative mood in depression has been demonstrated in work that explicates the temporal effects of rumination. Rumination affects mood states by exacerbating and prolonging negative emotional states such as sadness, anger, anxiety, and depression (Blagden & Craske, 1996; Bushman, 2002; Nolen Hoeksema et al 2011). Furthermore, tendency to ruminate is associated with increased negative emotional reactivity when a stressful event occurs (Watkins, Moberly, and Moulds, 2008). Studies have demonstrated that rumination extends negative mood states, but does not necessarily induce them, such that depressive symptoms are exacerbated only when a negative mood is already present when rumination begins (Lavender and Watkins, 2004, Lymbormirsky, Caldwell, & Nolen-Hoeksema, 1998). This dissociation between mood and rumination further suggests that rumination constitutes a perseverative thinking style that is altered in depression, and while ruminations tend to be on negative topics, rumination itself is distinct from transient mood states.

Critically, rumination has been shown to have acute effects of memory retrieval in individuals with depression. When depressed individuals are induced to ruminate before performing a memory task, relative to a neutral control cue to concentrate on neutral words, they subsequently recall fewer specific memories (Sutherland & Bryant, 2007; Lyumbrsky et al., 1996). This effect seems to be specific to self-focused (feelings and emotions) rumination as analytic focus towards concrete thinking (Watkins & Teasdale, 2001; Park, Goodyear, & Teasdale, 2004) or experiential focus on sensory details of an event (Watkins, Teasdale, & Williams, 2000) ameliorate overgeneral retrieval in depressed patients.

Along with acute effects of rumination, individuals' tendency to ruminate has also been associated with a more general memory retrieval style. Trait rumination is measured by Ruminative Response Scale (Nolen-Hoeksema and Morrow, 1991), which measures an individual's propensity to ruminate in response to life stressors. Mediation analyses have revealed that trait rumination mediates the relationship between depression and overgeneral memory (Liu et al., 2017). One more study here

A critical issue to determine rumination's precise influence on OGM depends on its specific effect in memory: whether it is the process (e.g., cyclical thinking) or content (e.g. personal information and experiences) that drives ruminations' effect on memory specificity. In one early study by Teasdale and Barnard (1993), participants were asked to generate information on the same theme and produced fewer specific memories to a standard set of cues after the self-related category only. This suggests that the effect of cyclical thinking on memory retrieval is influenced by cue self-relevance and further suggests that the overlap between the content of rumination and memory to be retrieved drives the OGM effect. While some studies use standardized cues for memory and rumination, other studies ask participants to produce cues and themes that are unique to their personal concerns. For example, when there is overlap between the cue words used in the AMT and a participant's long-term attitudes and concerns, their memory is more likely to be overgeneral (Spinhoven, Bockting, Kremers, Schene & Williams, 2005).

Rumination and executive dysfunction presentation in depression may reveal a common deficit between the processes as cognitive flexibility. For example, some researchers propose that rumination results in patients becoming preoccupied with abstract features of past events, which in turn reduces sensitivity and responsiveness to specific contextual cues and events in the world around them (Watkins, 2008). The challenges to flexible attention also extend to beliefs and concerns about themselves as they concern depressive symptomatology. Patients with depression who scored high on a trait rumination questionnaire demonstrate difficulties in updating positive beliefs about themselves (Takano, Van Grieken, & Raes, 2019). Rumination also has been shown to have acute effects on cognitive processing that diminishes executive functioning ability. Individuals who were induced to rumination showed reduced sensitivity to reward and punishment associations with changing probabilities (Whitmer, Frank, & Gotlib, 2012), and difficulties inhibiting previous information that is no longer relevant (Witmet & Banich, 2007) and perseverate on the Wisconsin Sorting Task (David & Nolen-Hoeksema, 2000).

Critical to a parsimonious account of mechanisms contributing to OGM in depression is to identify and pare down redundancies of the processes proposed to explain the link between depressive symptoms and OGM. Instead of rumination and executive dysfunction acting separately on memory retrieval, the evidence presented above aligns with the idea that these two phenomena are constitutive of deficits in cognitive flexibility and may act together to produce OGM in depression. As I argue here, evidence is sufficient to address executive dysfunction as a part of the same general dysfunction in rumination in an inability to disengage from internal thoughts.

Problems with the Car-Fa-X model

While the Car-Fa-X model has held a privileged position in the literature on overgeneral memory in depression, this model has trouble accounting for some phenomena noted in depression that may be contributing to memory disturbances.

For example, by the Car-Fa-X model, the subsymptoms of depression result in OGM in a primarily acute fashion. First, rumination is proposed to block the retrieval of rich, episodic memory details by allocating cognitive resources to abstract, negative thoughts and away from executive functioning resources for retrieval of autobiographical memory. When an individual is induced to ruminate and attempts to retrieve a memory, this framework predicts that they will be unable to access the event specific details due to decreased available executive resources. While this account provides a functional relationship for the time sensitive effects of rumination, it does not account for the instances when patients with depression retrieve overgeneral memories without a rumination induction (Raes et al., 2006; Gibbs & Rude, 2004; Hermans et al., 2008). Relatedly, while executive functioning is rescued when patients remiss from depression (Zu et al., 2021), overgeneral memory persists (Nandrino et al., 2003, Mackinger et al., 2000; Crane & Williams, 2007), suggesting that although the momentary inaccessibility may occur in response to rumination, there are additional long-term effects in memory representation or organization of representations such that the general representation is the most likely to be retrieved.

This account can be rescued by a second proposed avenue by which rumination may alter the accessibility of memory through a process of “mnemonic interlock,” where retrieval of an event arrested at the general level is proposed to activate associated events at the same level, leading to strengthening of connections within the network at the categorical level and stalling future retrieval attempts at this level (Williams, 2006). If mnemonic interlock is driving enduring general retrieval patterns, it relies on effortful or voluntary retrieval strategies being deployed. And if voluntary retrieval is propelling the effect, the frequency with which individuals are recalling memories effortfully will be the determining factor of the network of general memories strengthening. However, studies have shown that involuntarily retrieved memories outweigh voluntary ones (Bernsten, 1998) by as much as 3 times (Rasmussen & Bernsten, 2011). The frequency of recall of memory is thought to affect the associative structure of memory (Clark, 1992; Raaijmakers & Shiffrin, 1980). Therefore, it seems more probable by understanding of memory network building/structure that the involuntary retrieval would drive the effect.

By the analysis of the current consistencies and disparities between empirical findings and model predictions, a candidate process(es) that is causally contributing to the alterations in memory processes in depression would be one that is associated with executive dysfunction, affect memory recollection and/or organization structures, as well as one that would occur within reasonable frequencies that could produce the enduring changes in the organization of autobiographical memory. In what follows, I will argue that rumination is a process that captures these requirements.

Rumination as sticky mind wandering

Effective understanding of rumination's putative effect on memory processes in depression requires a reinterpretation of rumination as a type of altered spontaneous thought process or "sticky mind wandering" (DuPre & Spreng, 2018). Critical to this interpretation is the adopting of new perspectives on mind wandering which underscore its functional role in cognitive processing rather than its historical role as a nuisance distraction or attentional divergence. By instead framing mind wandering as an adaptive form of internally oriented attention that serves important functions such as consolidation of memories (Tambini & Davachi, 2018), prospection of the future (Baird et al., 2011), creativity (Baird et al., 2013), and problem solving (Tan et al., 2015), researchers can gain new insights into the mechanisms underlying depressive symptoms and how to remediate symptomatology. In this section, I will review the current perspectives and functions of mind wandering, emphasizing its putative role in the processing of self-relevant information. From this purview, I will then compare the phenomena of mind wandering and rumination, illustrating rumination as an aberrant form of spontaneous thought where the wandering mind becomes stuck in negative, perseverative thought cycles on concerns and past experiences.

Mind wandering as spontaneous self-relevant thoughts

When the mind drifts, it detaches from the present moment and its sensory input to simulate situations or concepts other than the here and now. This ability, or mind wandering, refers generally to spontaneous thinking that most often occurs when not immediately engaged in a goal-directed task. It can rely on self-generation of thought, or the ability to mentally decouple from the current perceptual surroundings and generate independent internal thoughts (Smallwood and Schooler, 2015), or arise from states of low task demands such as boring or repetitive tasks (Yanko & Spalek, 2013). Some estimates suggest that up to 30 - 50% of waking thoughts are some form of mind wandering (Killingsworth & Gilbert, 2010).

Though the mind wanders, evidence does not suggest that this meandering is aimless and is instead guided by thematic paths. It has been long suggested that the content of mind wandering is not random but focused on self-relevant information such as reflecting on past experiences, planning future actions, and musing on one's personal traits or social dynamics (Klinger, 2013; Singer, 1998). Experimental investigations of spontaneous thought have demonstrated that participants often judge that thoughts unrelated to task performance are personally relevant and important to their goals (Andrews-Hanna et al., 2010; Starwarckyz et al., 2011). When individuals were asked to describe their thoughts and experiences of mind wandering while performing a sustained-attention task designed to induce mind wandering, a majority of thoughts (66%) contained mentions of the individual's self (Starwarckyz et al., 2011). These self-relevant and task-irrelevant thoughts that were invoked during minimally demanding tasks included memories and future plans and were linked to the participants' current concerns.

Using experience sampling methods outside of the lab, the same themes of self-relevance have been revealed. A study employing daily experience sampling methods using a phone-based application showed that oneself and personal life were the primary themes of spontaneous thoughts throughout the day (Song & Wang, 2012). Other diary-based studies have shown that thoughts about the future and spontaneously retrieved autobiographical memories are common in daily life during mind wandering episodes (Berntsen, 1996; Berntsen et al., 2012). It is important to note here that although these thoughts are characterized as "spontaneous," the contents of mind wandering are not truly random but rather can arise to awareness in response to the contextual cues (Bernsten & Jacobsen, 2008). In sum, laboratory and experience sampling methods demonstrate that a preponderance of the content of mental life is directed towards autobiographical thinking, either towards the future and planning or reflection on past experiences.

Mind wandering in depression

Where does the depressed mind wander? Individuals with depression demonstrate themes and content during mind wandering periods that are biased towards the past. In samples collected from healthy individuals without histories of depression, the temporal orientation of mind wandering content is consistently found to be towards the future (Smallwood et al., 2009; Baird et al., 2011; Smallwood, Sakur & Singer, 2013), such as planning, problem solving, and episodic future thinking. This forward orientation is reversed in individuals with depression: clinically diagnosed individuals report higher frequency of past-oriented spontaneous thoughts (Hoffman et al., 2016). The same effect can be produced by inducing negative mood, where more negative mood was associated with increased past focus in mind wandering content (Smallwood & O'Connor, 2011) and related to the severity of depressive symptoms. To return to the question raised above, the depressed mind appears to wander down paths that are negative and past oriented, and this converges with reports of ruminative symptoms of analytical focus on past events.

The increase in past oriented thoughts converges with knowledge of other important, but underrepresented, depressive symptoms of increased intrusive memories. Patients with depression report intrusive memories at similar rates to other psychopathologies that are more commonly associated with intrusive memories, such as Post Traumatic Stress Disorder (PSTD) (Payne et al., 2019; Mihailova & Jobson, 2018). In a community sample of non-depressed individuals who did not receive any treatment for depression across a 6-month period, the frequency and qualities of intrusive memories, namely distressing reactions, predicted the onset of depression (Newby & Moulds, 2011). Other work has shown that the qualities of intrusive memories are not different between depressed and non-depressed samples, such as vividness or perspective (Watson et al., 2013), but that depressed patients are more likely to give negative appraisals of intrusive memories than controls (Williams and Moulds, 2008). Critically, self-focused abstract rumination has been associated with increased intrusions about the self-related information compared to experiential focus (Watkins, 2004). From these lines of work, a feature of spontaneous recollection of memories is that during mind wandering episodes may prompt elaboration in an abstract, analytical way during rumination in individuals with depression.

Depressive rumination is pathological mind wandering

Recent perspectives on rumination view that the shared cognitive and neural features between states of mind wandering and rumination suggest some rumination is a form of mind wandering that has become "stuck" on a particular theme (DuPre & Spreng, 2018). If rumination is a form of spontaneous thought that is corrupted, it should share common core features with mind wandering, such as similar themes and processes, both in cognitive and behavioral features and neural correlates.

The phenomena of mind wandering and rumination share similar cognitive features, such as internal mental orientation, significant focus on self-relevant content, and involvement of autobiographical memories. Mind wandering and rumination are both forms of thought oriented towards internal rather than external attention. Indeed, both cognitive phenomena are defined by their directed attention being aimed away from the immediate external environment. Second, the content of mind wandering and rumination share a common concentration on self-relevant information: while mind wandering encompasses a wide array of self-relevant thoughts, rumination is directed at negative appraisals of the self and identity. Importantly, both mind wandering and rumination involve the recollection of autobiographical information: spontaneous thoughts are often focused on future plans and past events, but rumination is associated with perseverative return to past events, and their causes and consequences (Burgess et al., 2002; Cooney et al., 2010).

Mind wandering and rumination share neural correlates

Spontaneous thought has been consistently linked with a core set of brain regions including the medial prefrontal cortex, medial temporal lobe, posterior cingulate cortex, and inferior parietal lobule (Andrews-Hanna, 2012, Andrews-Hanna, Smallwood, & Spreng, 2014), and lingual gyrus, anterior cingulate, temporopolar cortex, and insula (Fox, Spreng, Ellamil, Andrews-Hanna, Christoff, 2015). These regions overlap with an identified functional network of regions that activate during the generation of thoughts which are unrelated to the outside environment, referred to as the Default Mode Network (DMN) (Raichle, 2015; Grecius et al., 2009). Other functions that have been identified in the DMN include toggling between introspective state and exteroceptive state (Fransson, 2006); internal mentalizing (Andrews-Hanna, Smallwood, Spreng, 2014); processing of self-related information (Spreng & Grady, 2009); theory of mind and projections into the future (Spreng & Grady, 2009); autobiographical memory retrieval (Zhu et al., 2011).

The neural correlates of trait rumination overlap with those activated during periods of rest and mind wandering. First, trait rumination is associated with increased DMN activity during states of internal focus, dominance of the DMN during tasks, and inefficient ability to flexibly toggle between networks. Second, individual differences in the tendency to reflect on past experiences in times of rest are reflected in the neural correlates of individuals with depression, and this rigidity can predispose the recollection of autobiographical information with a focus on abstract qualities rather than specific episodes in an individual’s life.

A collection of studies has demonstrated that trait rumination is associated with increased univariate activations of regions within the DMN. In one study, researchers observed increased resting state functional magnetic resonance imaging (rsfMRI) between the subgenual prefrontal cortex, an area known to be involved in emotion regulation (Coryell et al., 2005) and DMN structures were associated with higher trait rumination score (Berman et al., 2011). Along with univariate activations within the DMN, researchers have observed that individuals with depression express increased connectivity within nodes of the DMN, potentially providing evidence for the cognitive biases that are associated with rumination, such as internal, self-directed focus (Kaiser et al., 2015).

A feature of mind wandering is its transient state: the mind may wander away from the present moment, but it also can return quickly to external awareness when stimuli in the environment prompt attention to return, as one “snaps back” to attention. In this way, cognitive flexibility allows individuals to pay attention to both internal and external information. Aligned with this, mental flexibility linked to trait mind wandering in non-clinical individuals is associated with efficient coupling and decoupling of the default mode and frontoparietal control networks (Andrews-Hanna, Smallwood, & Spreng, 2014). In contrast, rumination, which has been linked with cognitive rigidity, has been associated with greater coupling of the default and salience networks (Carew, Miline, Tatham, MacQueen, & Hall, 2013). Even when engaged in tasks, when the DMN should have decreased recruitment compared to task positive networks, depressed individuals demonstrate DMN dominance over salience and executive networks (Belleau, Taubitz, & Larson 2014).

One recent study has brought light to bear on understanding how individual differences in resting state connectivity in large scale brain networks are related to the characteristics of mind wandering content (Karapanagiotidis et al., 2020). Using machine learning techniques applied to rsfMRI data, the researchers identified two network level connectivity states which predicted the content of thoughts: one future oriented thinking with future problem solving and one with reports of unintentional thought about the past. This later state was associated with higher activity within the DMN and, critically, was associated with participant reports of depression, anxiety, and rumination. This suggests that the trait levels of negative affect are associated with stable and identifiable patterns of activity in brain networks and individual differences in the "default mode" of resting cognition and brain connectivity patterns may serve as a neural substrate for vulnerability to develop clinical depression.

Trait rumination is associated with resting states that promote less specific recall of memory. Structures of self-processing overlap with those of autobiographical memory recall within the DMN (Spreng & Grady, 2009), suggesting that the default mode provides both the source material (memory) and the information processing system (thinking style) in decreased specificity in autobiographical memory retrieval in depression. The DMN has been shown to have two major hubs involved in the retrieval and processing of self-related information. The anterior DMN includes structures such as the medial temporal lobe (MTL) and anterior cingulate cortex (ACC), including the subgenual cingulate cortex, which are involved in self-reflection, introspection, and emotional regulation (Spreng & Grady, 2008), while the posterior structures of the DMN, such as the posterior cingulate cortex (PCC) and precuneus, are involved in episodic memory retrieval and mental visualization (Sestieri et al., 2011). Less specific, more semantic memories are associated with the anterior DMN and tend to rely more on themes and statements about life events, while specific memories, associated with posterior DMN, encompass rich episodic details including sensory details about specific events (Phillippi et al., 2013). Indeed, epilepsy studies have shown that damage to regions in the DMN results in lower episodic memory capacity, due to decreased connectivity between anterior and posterior nodes (McCormick et al., 2014), suggesting that coherence between these nodes is important for successful episodic retrieval.

In contrast to healthy controls, connective functionality between the anterior and posterior hubs in depression is reduced. Researchers have observed that individuals with depression produced resting state fMRIs with patterns of increased anterior and decreased posterior functional connectivity and are associated with self-reports of rumination (Zhu et al., 2012). Also, resting state brain activity in individuals with depression is associated with increased connectivity in the anterior nodes of the DMN, particularly from subgenual cingulate cortex (sgCC) (Greicius et al., 2011), an area of the ACC that is particularly active in emotional appraisal (Maddock et al., 2013). Further, Greicius and colleagues also found that this degree of activity in the sgCC positively correlated with the length of current depressive episode. This indicates that increased connectivity in areas related to self-evaluation, when exacerbated and supported by structures related to emotion processing, could be a neural substrate of depressive rumination.

In the discussion above, I have illustrated how rumination and mind wandering share cognitive features and neural correlates. Here, rumination was characterized as a form of aberrant mind wandering where the tendency to maintain attention towards internal representations is elevated in depressed ruminators and activation patterns were found to be in anterior and midline regions of the DMN that have been associated with reflection on autobiographical information. Critically, these studies were limited to those when individuals rested in the scanner with no instruction to ruminate. The preferential engagement in areas associated with abstract representations of self-relevant information in the anterior and midline regions of the DMN without instruction suggests that individual differences in default brain states may predispose individuals in times of rest to spontaneously recall autobiographical information and, once captured by internal attention, ruminative processing may begin to perseverate on details of those personal events.

Rumination's effect on memory organization

In the previous section, mind wandering was characterized as a "default mode" of processing and associated with activations of the DMN, a brain network associated with times of rest when self-referential information processing occurs. Individuals with depression were shown to display differences in their brain activity patterns during times of rest compared to healthy controls, and this was argued to reflect a predisposition to spontaneously recollect and elaborate on negative, autobiographical information. In this final section, I will: first, review how neural patterns of activity during active states of rumination reflect the same general pattern of increased DMN activity and bias autobiographical memory recall to be less specific; second, along with providing evidence of the acute effects of rumination, consideration will be given to how enduring changes as a function of repetitive spontaneous recall of autobiographical information may result in a decontextualization of specific personal episodic memories through increased reactivations over time and situate this effect in terms of well-established models of memory organization and generalization of representations of episodic memories.

States of rumination are associated with increased DMN activity

Memory retrieval after a rumination induction is more general and less specific: even when given the instructions to recall a specific episode in their lives, individuals who have been induced to ruminate recall categorical representations of memories. Trait ruminators demonstrate altered content and flow of thoughts during states of mind wandering and rest, and this was associated with alterations in key nodes and dynamic connectivity patterns of the DMN which reflect the bias of the content of spontaneous thought to negatively affected, autobiographical information. While there have been several studies investigating the relationship between default brain states and trait levels of rumination, relatively fewer studies have illustrated the neural correlates of state rumination. However, what work has been done is aligned with the evidence discussed above of trait rumination, where state rumination is associated with increased activity within the DMN and, critically, with anterior regions which have been shown to reflect abstract or semantic qualities of events rather than specific episodes.

Since trait rumination is associated with increased DMN activity, a similar pattern of activity is expected to be reflected during acute ruminative states after induction. Indeed, Lemogne and colleagues (2009) found that rumination about personality traits increased functional connectivity areas of the DMN relating to abstract representations of the self (medial frontal gyrus and ACC) and cognitive control regions (dorsolateral PFC), suggesting that rumination is associated with increased focal attention of abstract personal attributes. A recent meta-analysis analyzed the fMRI data of experiments where individuals were induced to ruminate or to distract themselves from self-focus (Zhou et al., 2020) and found a key set of DMN regions that were activated in ruminative self-focus compared to concrete distraction that was not self-focused: left anterior cingulate, precuneus, left superior temporal gyrus, and left angular gyrus areas have been found to be activated when participants reflect on personal experiences and personal characteristics (Andrews-Hanna et al., 2010).

However, an important question is whether resting state brain activity patterns in those who tend to ruminate, such as depressed patients, are different from brain activity patterns during active rumination. After being induced to ruminate, Berman and colleagues (2014) compared depressed patients and healthy controls during unconstrained test states and active rumination. They found that patients with depression demonstrated dissociable patterns of activity between resting and active rumination within midline regions of the DMN, while healthy controls displayed similar patterns of activity between the two conditions. So, while ruminators display differential brain activity patterns at rest, active rumination is associated with heightened activation of nodes of the DMN. Further, a study where depressed patients were induced into a negative rumination state found decreased functional connectivity between the posterior regions associated with specific and vivid episodic recall such as the posterior cingulate cortex and the precuneus and regions in the prefrontal cortex (PFC) associated with control of memory retrieval strategies (Rener et al., 2017). Rumination is associated with cognitive inflexibility, such that patients are unable to disengage from ruminative thinking. If rumination is prompted, and subnetworks of the DMN are preferentially engaged in abstract reflection on personal characteristics such as the anterior and midline regions, this could disrupt attempts to retrieve specific memory.

Ruminative mind wandering promotes reactivation and reorganization of memory

Ruminative thought is characterized by its repetition on similar themes where patients feel they are unable to disengage from focus on negative past events. Thus, the content variability of mind wandering is reduced in individuals who perseveratively ruminate. In contrast, the mind without depression or other pathology naturally wanders and produces highly variable content. The Default Variability Hypothesis posits that the natural tendency for the mind to wander serves an adaptive function to increase the variability of mental content and that this supports efficient memory organizational strategies that promote storage of distinct episodic memories but also the abstraction of semantic knowledge (Mills et al., 2018). From this line of thinking, depressive rumination could be expressed as a decrease in the variability in thought content through the perseverative return to the same negative events and themes. In the following section, I will provide an overview of perspectives of mind wandering that highlight the role of variability in mental content and the processes which are proposed to contribute to it, to contextualize how ruminative thought may contribute to alterations in memory organization that promote categoric, rather than specific, memory recall.

Reactivations of episodic event representations are thought to play a critical role in the maintenance and retrieval of episodic memory. Models attempting to explicate the underlying computational processes of episodic memory have suggested that forming and retrieving distinct memory representations relies on two complementary processes: pattern separation, the formation of distinct representations, and pattern completion, the generation of the original memory representations when presented with a partial cue or feature contained in the memory (O'Reilly & McClelland, 1994; Treves & Rolls, 1994). While the neural dynamics of pattern separation remain contentious (see Quiroga, 2020, but also Suthana et al., 2021), it remains relatively uncontroversial that the human memory system requires a process through which episodic memory patterns are stored as distinct codes to avoid interference from competing experiences. That is, an adaptive, but resource limited, memory system would need to strengthen the features of memories that are the most critical (i.e., most frequently retrieved) and weaken more peripheral (i.e., least frequently retrieved) features to optimize storage capacity. By this idea, Competitive Trace Theory (Yassa & Reagh, 2013) posits that critical episodic features are preserved in memory through reactivations of the memory representation over time. Since each spontaneous retrieval is re-encoded as a new memory trace each time a reactivation occurs, competition is generated among the non-overlapping features. However, some of the features will overlap and these coinciding features will be strengthened and will result in higher fidelity during retrieval attempts. Similarly, pattern completion is proposed to strengthen episodic representations through generation of a memory trace by partial cueing, following from the same logic that the most frequently retrieved features should be those prioritized for strengthening.

While there is need for distinct episodic memory representations, an adaptive memory system should also be able to extract common features of events that overlap in their spatial, temporal, emotional, or contextual features. Aligned with cognitive models of autobiographical memory (Conway & Pleydell-Pierce, 2000), where specific events are grouped into thematic categories and life periods, autobiographical memory should be subject to the same neural and/or computational rules of memory dynamics and storage optimization. As such, the creation of semantic knowledge out of episodic experiences is presumed to be a gradual process that occurs across multiple instances (McClelland, McNaughton, & O'Reilly, 1995) where similarities between event representations emerge as themes or categories. The experience of repeated events in various contexts should aid the organization of relationships between their typical elements (Avrahami & Kareev, 1994), and event features can become stored together and promote the creation of a semantic representation of a collection of events (Nadel et al., 2012).

As reviewed above, the wandering mind often travels down memory lane where the preponderance of thoughts during periods of rest are self-relevant and include autobiographical memories. The transient activations of self-relevant information during spontaneous thoughts, such as autobiographical memory retrieval, can support semantic abstraction by providing repeated opportunities to activate memories and their contextual associates. In standard models of episodic to semantic generalization, the similarity between events can provide the basis for the abstraction of general categories, and dissimilarities can aid in ensuring that a specific instance is not overgeneralized (McClelland et al., 1995). In these models of semantic representation formation, learning a general category from specific exemplars is proposed to be a function of the number of examples and the temporal frequency of retrievals, where a slower rate of retrievals or exposures to category exemplars is assumed to be optimal so that representations are not overlearned over short periods of time (White, 1989). The Default Variability Hypothesis posits that the variability in the content during mind wandering supports spaced reactivations of autobiographical content at rates that allow for the maintaining of specific episodic representation while also allowing for semantic abstraction (Mills et al., 2018).

However, in rumination, the variability in mental content is reduced by persevations on the past experiences and their meanings; one potential avenue to explain how ruminative states in depression contribute to overgeneral memory in individuals with depression is to consider how rumination in depression encourages the repeated reactivation of episodic events over time, leading to the generalization of memory features into more semantic or abstract representations of a collection of events. Rumination involves the elaboration of the causes and consequences of events, so it is likely that once a specific memory is spontaneously retrieved, semantically related events are also retrieved as a consequence. Over time the repetitive retrievals of autobiographical memories and the ruminative elaboration on the abstract features will result in the winnowing of event specific details and promote a more general representation to be retrieved. For example, rumination in response to a stressor in a depressed patient's life, such as recently failing a test, will increase recall of that event and elaboration on related events to promote a categorical representation such as "I always fail tests" or general time period "when I did poorly in school." In this way, intrusive autobiographical memories prompt rumination to decontextualize event specific details from their unique spatio-temporal lodging in hierarchical memory organization and expedite a categorical representation to be formed.

A prediction from this framework would be that alterations in the content and frequency of the internal contents of this "default mode" may impact memory maintenance and retrieval. This question remains empirically unanswered, and future research should focus on how the variability of content in spontaneous thought relates to the representation of episodic events in memory. For example, one avenue to investigate this would be to track the neural reinstatement of episodic representations in individuals with depression and controls during times of rest to investigate whether the frequency of reinstatement differs between patients and controls, and how this may be related to the modification of memory organization.

Interim Summary

A robust finding in the depression literature is the reduction of memory specificity in patients and a well demonstrated link between ruminative states and overgeneral memory retrieval. The predominant model of this link has emphasized the acute effects of rumination to reduce executive function resources available to initiate a strategic retrieval of event specific details and as a result attempts are truncated at a categorical representation of the event. However, while the time sensitive effects of rumination are well documented, an account positing an executive dysfunction process of memory failure doesn't account for the enduring general retrieval after depressive symptoms are alleviated or when depressed patients are not ruminating at the time of retrieval. These findings suggest that instead of overgeneral memory being the consequence of inefficient memory retrieval strategies, other processes may be altering the autobiographical memory organization such that the categorical or semantic representation of an event is the most likely to be retrieved when a memory search is initiated, either after rumination or during neutral mental context.

Mind wandering has gained attention in the last decade as an important feature of cognition: rather than mind wandering being characterized as a failure to attend to a task, considerations of how mind wandering serves adaptive purposes has been explored (Mills et al., 2018; Smallwood & Andrews-Hanna, 2013). Understanding the cognitive and neural dynamics of spontaneous thought and how it might be contributing to mental illness is a promising avenue to illuminate cognitive processes involved in disorder pathology. Here, I have argued that a comprehensive framework to consider rumination's effect on memory pathology is to consider rumination as a form of aberrant mind wandering. I have demonstrated that the cognitive and neural features of mind wandering are like those of rumination, but that ruminative states are associated with key alterations in brain network connectivity that support autobiographical recall and perseverative reflection on self-relevant information. Finally, through spontaneous reactivations of memories during times of rest and elaborations on the abstract features of events, rumination may produce the conditions necessary for expedited episodic to semantic generalization.

Depression is a leading cause of mental illness worldwide: a recent study assessing the global rates of disease and illness found that depression was a leading cause of nonfatal disease in 2019 (Vos et al., 2020). It is critical for clinicians who develop and provide treatments for mental disorders to have knowledge of the cognitive and neural mechanisms that contribute to the pathologies. Here, I have provided a critique of a leading model of a distressing symptom in depression, overgeneral memory, and provided an alternative avenue through theoretical perspectives and empirical findings for which overgeneral memory may be produced in depression. By considering not only the failures of executive function in the expression of depressive symptoms, and instead focus on the cognitive and neural dynamics of spontaneous thought during times of rest, but a clearer understanding of depressive pathology can also be revealed.

References

1. A randomized, controlled proof-of-concept trial evaluating durable effects of memory flexibility training (MemFlex) on autobiographical memory distortions and on relapse of recurrent major depressive disorder over 12 months. (2021). *Behaviour Research and Therapy*, *140*, 103835. https://doi.org/10.1016/j.brat.2021.103835
2. Aglan, A., Williams, J. M. G., Pickles, A., & Hill, J. (2010). Overgeneral autobiographical memory in women: Association with childhood abuse and history of depression in a community sample.

The British Journal of Clinical Psychology, *49*(Pt 3), 359–372. https://doi.org/10.1348/014466509X467413

3. Andrews-Hanna, J. R., Reidler, J. S., Huang, C., & Buckner, R. L. (2010). Evidence for the Default Network's Role in Spontaneous Cognition. *Journal of Neurophysiology*, *104*(1), 322–335. https://doi.org/10.1152/jn.00830.2009
4. Baird, B., Smallwood, J., & Schooler, J. W. (2011). Back to the future: Autobiographical planning and the functionality of mind wandering. *Consciousness and Cognition*, *20*(4), 1604–1611. https://doi.org/10.1016/j.concog.2011.08.007
5. Barry, T. J., Chiu, C. P. Y., Raes, F., Ricarte, J., & Lau, H. (2018). The Neurobiology of Reduced Autobiographical Memory Specificity. *Trends in Cognitive Sciences*, *22*(11), 1038–1049. https://doi.org/10.1016/j.tics.2018.09.001
6. Beck, A. T. (1979). *Cognitive Therapy of Depression*. Guilford Press.
7. Berman, M. G., Misic, B., Buschkuehl, M., Kross, E., Deldin, P. J., Peltier, S., Churchill, N. W., Jaeggi, S. M., Vakorin, V., McIntosh, A. R., & Jonides, J. (2014). Does resting-state connectivity reflect depressive rumination? A tale of two analyses. *NeuroImage*, *103*, 267–279. https://doi.org/10.1016/j.neuroimage.2014.09.027
8. Berman, M. G., Peltier, S., Nee, D. E., Kross, E., Deldin, P. J., & Jonides, J. (2011). Depression, rumination and the default network. *Social Cognitive and Affective Neuroscience*, *6*(5), 548–555. https://doi.org/10.1093/scan/nsq080
9. Berntsen, D. (1998). Voluntary and involuntary access to autobiographical memory. *Memory (Hove, England)*, *6*(2), 113–141. https://doi.org/10.1080/741942071
10. Bevan, A., Hitchcock, C., Mitchell, D., & Dalgleish, T. (2021). *Lateralised attentional disruption and resource conservation in persistent depression and anhedonia*. PsyArXiv. https://doi.org/10.31234/osf.io/p3n2v

11. Biringer, E., Lundervold, A., Stordal, K., Mykletun, A., Egeland, J., Bottlender, R., & Lund, A. (2005). Executive function improvement upon remissionof recurrent unipolar depression. *European Archives of Psychiatry and Clinical Neuroscience*, *255*(6), 373–380. https://doi.org/10.1007/s00406-005-0577-7

12. Blondé, P., Makowski, D., Sperduti, M., & Piolino, P. (2021). In Medio Stat Virtus: Intermediate levels of mind wandering improve episodic memory encoding in a virtual environment. *Psychological Research*, *85*(4), 1613–1625. https://doi.org/10.1007/s00426-020-01358-5

13. Brittlebank, A. D., Scott, J., Mark, J., Williams, G., & Ferrier, I. N. (1993). Autobiographical Memory in Depression: State or Trait Marker? *The British Journal of Psychiatry*, *162*(1), 118–121. https://doi.org/10.1192/bjp.162.1.118

14. Chiu, C. P. Y., Griffith, J. W., Lenaert, B., Raes, F., Hermans, D., & Barry, T. J. (2018a). Meta-analysis of the association between rumination and reduced autobiographical memory specificity. *Memory*, *26*(10), 1323–1334. https://doi.org/10.1080/09658211.2018.1474928

15. Chiu, C. P. Y., Griffith, J. W., Lenaert, B., Raes, F., Hermans, D., & Barry, T. J. (2018b). Meta-analysis of the association between rumination and reduced autobiographical memory specificity. *Memory*, *26*(10), 1323–1334. https://doi.org/10.1080/09658211.2018.1474928

16. Chou, Y., Sundman, M., Whitson, H. E., Gaur, P., Chu, M.-L., Weingarten, C. P., Madden, D. J., Wang, L., Kirste, I., Joliot, M., Diaz, M. T., Li, Y.-J., Song, A. W., & Chen, N. (2017). Maintenance and Representation of Mind Wandering during Resting-State fMRI. *Scientific Reports*, *7*(1), 40722. https://doi.org/10.1038/srep40722

17. Christoff, K., Gordon, A. M., Smallwood, J., Smith, R., & Schooler, J. W. (2009). Experience sampling during fMRI reveals default network and executive system contributions to mind wandering. *Proceedings of the National Academy of Sciences*, *106*(21), 8719–8724. https://doi.org/10.1073/pnas.0900234106

18. Clark, S. E. (1992). Word frequency effects in associative and item recognition. *Memory & Cognition*, *20*(3), 231–243. https://doi.org/10.3758/bf03199660

19. Comas, M., Valentino, K., Johnson, A. F., Gibson, B. S., & Taylor, C. (2018). Differential roles of resistance to proactive interference and suppression of prepotent responses in overgeneral memory. *Journal of Behavior Therapy and Experimental Psychiatry*, *61*, 45–50. https://doi.org/10.1016/j.jbtep.2018.06.003

20. Coryell, W., Nopoulos, P., Drevets, W., Wilson, T., & Andreasen, N. C. (2005). Subgenual Prefrontal Cortex Volumes in Major Depressive Disorder and Schizophrenia: Diagnostic Specificity and Prognostic Implications. *American Journal of Psychiatry*, *162*(9), 1706–1712. https://doi.org/10.1176/appi.ajp.162.9.1706

21. Crane, C., Barnhofer, T., Mark, J., & Williams, G. (2007). Cue self-relevance affects autobiographical memory specificity in individuals with a history of major depression. *Memory*. https://doi.org/10.1080/09658210701256530

22. Daele, T. V., Griffith, J. W., Bergh, O. V. den, & Hermans, D. (2014). Overgeneral autobiographical memory predicts changes in depression in a community sample. *Cognition and Emotion*. https://www.tandfonline.com/doi/abs/10.1080/02699931.2013.879052

23. Davis, R. N., & Nolen-Hoeksema, S. (2000). Cognitive inflexibility among ruminators and nonruminators. *Cognitive Therapy and Research*, *24*(6), 699–711. https://doi.org/10.1023/A:1005591412406

24. Debeer, E., Hermans, D., & Raes, F. (2009). Associations between components of rumination and autobiographical memory specificity as measured by a Minimal Instructions Autobiographical Memory Test. *Memory*, *17*(8), 892–903. https://doi.org/10.1080/09658210903376243

25. Debeer, E., Raes, F., Claes, S., Vrieze, E., Williams, J. M. G., & Hermans, D. (2012a). Relationship between cognitive avoidant coping and changes in overgeneral autobiographical memory

retrieval following an acute stressor. *Journal of Behavior Therapy and Experimental Psychiatry*, *43*, S37–S42. https://doi.org/10.1016/j.jbtep.2011.04.002

26. Debeer, E., Raes, F., Claes, S., Vrieze, E., Williams, J. M. G., & Hermans, D. (2012b). Relationship between cognitive avoidant coping and changes in overgeneral autobiographical memory retrieval following an acute stressor. *Journal of Behavior Therapy and Experimental Psychiatry*, *43*, S37–S42. https://doi.org/10.1016/j.jbtep.2011.04.002
27. del Palacio-Gonzalez, A., Berntsen, D., & Watson, L. A. (2017a). Emotional intensity and emotion regulation in response to autobiographical memories during dysphoria. *Cognitive Therapy and Research*, *41*(4), 530–542. https://doi.org/10.1007/s10608-017-9841-1
28. del Palacio-Gonzalez, A., Berntsen, D., & Watson, L. A. (2017b). Emotional Intensity and Emotion Regulation in Response to Autobiographical Memories During Dysphoria. *Cognitive Therapy and Research*, *41*(4), 530–542. https://doi.org/10.1007/s10608-017-9841-1
29. del Palacio-Gonzalez, A., Berntsen, D., & Watson, L. A. (2017c). Emotional Intensity and Emotion Regulation in Response to Autobiographical Memories During Dysphoria. *Cognitive Therapy and Research*, *41*(4), 530–542. https://doi.org/10.1007/s10608-017-9841-1
30. Delhaye, E., & Bastin, C. (2021). Semantic and perceptual encoding lead to decreased fine mnemonic discrimination following multiple presentations. *Memory*, *29*(1), 141–145. https://doi.org/10.1080/09658211.2020.1849309
31. Dietsche, B., Backes, H., Stratmann, M., Konrad, C., Kircher, T., & Krug, A. (2014). Altered neural function during episodic memory encoding and retrieval in major depression. *Human Brain Mapping*, *35*(9), 4293–4302. https://doi.org/10.1002/hbm.22475
32. Disner, S. G., Beevers, C. G., Haigh, E. A. P., & Beck, A. T. (2011). Neural mechanisms of the cognitive model of depression. *Nature Reviews Neuroscience*, *12*(8), 467–477. https://doi.org/10.1038/nrn3027

33. Drakeford, J. L., Srivastava, S., Calthorpe, W. R., Mukherjee, T., Clark-Carter, D., Oyebode, F., & Edelstyn, N. M. J. (2020). Major depressive disorder and schizophrenia are associated with a disturbed experience of temporal memory. *Journal of Affective Disorders Reports*, *2*, 100049. https://doi.org/10.1016/j.jadr.2020.100049

34. Droit-Volet, S. (2013). Time perception, emotions and mood disorders. *Journal of Physiology-Paris*, *107*(4), 255–264. https://doi.org/10.1016/j.jphysparis.2013.03.005

35. Everaert, J., Koster, E. H. W., & Derakshan, N. (2012). The combined cognitive bias hypothesis in depression. *Clinical Psychology Review*, *32*(5), 413–424. https://doi.org/10.1016/j.cpr.2012.04.003

36. Fawcett, J. M., Benoit, R. G., Gagnepain, P., Salman, A., Bartholdy, S., Bradley, C., Chan, D. K.-Y., Roche, A., Brewin, C. R., & Anderson, M. C. (2015). The origins of repetitive thought in rumination: Separating cognitive style from deficits in inhibitory control over memory. *Journal of Behavior Therapy and Experimental Psychiatry*, *47*, 1–8. https://doi.org/10.1016/j.jbtep.2014.10.009

37. Fox, K. C. R., Spreng, R. N., Ellamil, M., Andrews-Hanna, J. R., & Christoff, K. (2015a). The wandering brain: Meta-analysis of functional neuroimaging studies of mind wandering and related spontaneous thought processes. *NeuroImage*, *111*, 611–621. https://doi.org/10.1016/j.neuroimage.2015.02.039

38. Fox, K. C. R., Spreng, R. N., Ellamil, M., Andrews-Hanna, J. R., & Christoff, K. (2015b). The wandering brain: Meta-analysis of functional neuroimaging studies of mind wandering and related spontaneous thought processes. *NeuroImage*, *111*, 611–621. https://doi.org/10.1016/j.neuroimage.2015.02.039

39. Garlitch, S. M., & Wahlheim, C. N. (2020). The role of attentional fluctuation during study in recollecting episodic changes at test. *Memory & Cognition*, *48*(5), 800–814. https://doi.org/10.3758/s13421-020-01018-4

40. Gibbs, B. R., & Rude, S. S. (2004). Overgeneral Autobiographical Memory as Depression Vulnerability. *Cognitive Therapy and Research*, *28*(4), 511–526. https://doi.org/10.1023/B:COTR.0000045561.72997.7c

41. Gil, S., & Droit-Volet, S. (2009). Time perception, depression and sadness. *Behavioural Processes*, *80*(2), 169–176. https://doi.org/10.1016/j.beproc.2008.11.012

42. Godwin, C. A., Hunter, M. A., Bezdek, M. A., Lieberman, G., Elkin-Frankston, S., Romero, V. L., Witkiewitz, K., Clark, V. P., & Schumacher, E. H. (2017). Functional connectivity within and between intrinsic brain networks correlates with trait mind wandering. *Neuropsychologia*, *103*, 140–153. https://doi.org/10.1016/j.neuropsychologia.2017.07.006

43. Gonzalez-Castillo, J., Kam, J. W. Y., Hoy, C. W., & Bandettini, P. A. (2021). How to Interpret Resting-State fMRI: Ask Your Participants. *The Journal of Neuroscience*, *41*(6), 1130–1141. https://doi.org/10.1523/JNEUROSCI.1786-20.2020

44. Greicius, M. D., Supekar, K., Menon, V., & Dougherty, R. F. (2009). Resting-State Functional Connectivity Reflects Structural Connectivity in the Default Mode Network. *Cerebral Cortex*, *19*(1), 72–78. https://doi.org/10.1093/cercor/bhn059

45. Guesdon, A., Lejeune, F.-X., Rotgé, J.-Y., George, N., & Fossati, P. (2020). mind wandering Changes in Dysphoria. *Frontiers in Psychiatry*, *11*, 544999. https://doi.org/10.3389/fpsyt.2020.544999

46. Habermas, T., & Diel, V. (2013). The Episodicity of Verbal Reports of Personally Significant Autobiographical Memories: Vividness Correlates with Narrative Text Quality More than with

Detailedness or Memory Specificity. *Frontiers in Behavioral Neuroscience*, *7*. https://doi.org/10.3389/fnbeh.2013.00110

47. Habermas, T., Ott, L.-M., Schubert, M., Schneider, B., & Pate, A. (2008). Stuck in the past: Negative bias, explanatory style, temporal order, and evaluative perspectives in life narratives of clinically depressed individuals. *Depression and Anxiety*, *25*(11), E121–E132. https://doi.org/10.1002/da.20389
48. Hallford, D. J., Austin, D. W., Raes, F., & Takano, K. (2018a). A test of the functional avoidance hypothesis in the development of overgeneral autobiographical memory. *Memory & Cognition*, *46*(6), 895–908. https://doi.org/10.3758/s13421-018-0810-z
49. Hallford, D. J., Austin, D. W., Raes, F., & Takano, K. (2018b). A test of the functional avoidance hypothesis in the development of overgeneral autobiographical memory. *Memory & Cognition*, *46*(6), 895–908. https://doi.org/10.3758/s13421-018-0810-z
50. Hallford, D. J., Rusanov, D., Yeow, J. J. E., & Barry, T. J. (2021a). Overgeneral and specific autobiographical memory predict the course of depression: An updated meta-analysis. *Psychological Medicine*, *51*(6), 909–926. https://doi.org/10.1017/S0033291721001343
51. Hallford, D. J., Rusanov, D., Yeow, J. J. J., & Barry, T. (2021b). *Reduced Specificity and Increased Overgenerality of Autobiographical Memory Persist as Cognitive Vulnerabilities in Remitted Major Depression: A Meta-Analysis*. PsyArXiv. https://doi.org/10.31234/osf.io/6df42
52. Hitchcock, C., Mueller, V., Hammond, E., Rees, C., Werner-Seidler, A., & Dalgleish, T. (2016a). The effects of autobiographical memory flexibility (MemFlex) training: An uncontrolled trial in individuals in remission from depression. *Journal of Behavior Therapy and Experimental Psychiatry*, *52*, 92–98. https://doi.org/10.1016/j.jbtep.2016.03.012
53. Hitchcock, C., Mueller, V., Hammond, E., Rees, C., Werner-Seidler, A., & Dalgleish, T. (2016b). The effects of autobiographical memory flexibility (MemFlex) training: An uncontrolled trial in

individuals in remission from depression. *Journal of Behavior Therapy and Experimental Psychiatry*, *52*, 92–98. https://doi.org/10.1016/j.jbtep.2016.03.012

54. Hitchcock, C., Smith, A. J., Elliott, R., O'Leary, C., Gormley, S., Parker, J., Patel, S. D., Esteves, C. V., Rodrigues, E., Hammond, E., Watson, P., Werner-Seidler, A., & Dalgleish, T. (2021). A randomized, controlled proof-of-concept trial evaluating durable effects of memory flexibility training (MemFlex) on autobiographical memory distortions and on relapse of recurrent major depressive disorder over 12 months. *Behaviour Research and Therapy*, *140*, 103835. https://doi.org/10.1016/j.brat.2021.103835
55. Hoffmann, F., Banzhaf, C., Kanske, P., Bermpohl, F., & Singer, T. (2016). Where the depressed mind wanders: Self-generated thought patterns as assessed through experience sampling as a state marker of depression. *Journal of Affective Disorders*, *198*, 127–134. https://doi.org/10.1016/j.jad.2016.03.005
56. Howell, A., & Conway, M. (1992). Mood and the suppression of positive and negative self-referent thoughts. *Cognitive Therapy and Research*, *16*(5), 535–555. https://doi.org/10.1007/BF01175140
57. Ionescu, T. (2012). Exploring the nature of cognitive flexibility. *New Ideas in Psychology*, *30*(2), 190–200. https://doi.org/10.1016/j.newideapsych.2011.11.001
58. Johnson, R. J., Greenhoot, A. F., Glisky, E., & McCloskey, L. A. (2005a). The Relations Among Abuse, Depression, and Adolescents' Autobiographical Memory. *Journal of Clinical Child & Adolescent Psychology*, *34*(2), 235–247. https://doi.org/10.1207/s15374424jccp3402_3
59. Johnson, R. J., Greenhoot, A. F., Glisky, E., & McCloskey, L. A. (2005b). The relations among abuse, depression, and adolescents' autobiographical memory. *Journal of Clinical Child and Adolescent Psychology: The Official Journal for the Society of Clinical Child and Adolescent*

Psychology, American Psychological Association, Division 53, *34*(2), 235–247. https://doi.org/10.1207/s15374424jccp3402_3

60. Joormann, J., Dkane, M., & Gotlib, I. H. (2006). Adaptive and Maladaptive Components of Rumination? Diagnostic Specificity and Relation to Depressive Biases. *Behavior Therapy*, *37*(3), 269–280. https://doi.org/10.1016/j.beth.2006.01.002
61. Joormann, J., & Gotlib, I. H. (2010). Emotion regulation in depression: Relation to cognitive inhibition. *Cognition and Emotion*, *24*(2), 281–298. https://doi.org/10.1080/02699930903407948
62. Jordão, M., & St. Jacques, P. L. (2021). Episodic-semantic interactions in spontaneous thought. *Memory & Cognition*. https://doi.org/10.3758/s13421-021-01211-z
63. Karapanagiotidis, T., Vidaurre, D., Quinn, A. J., Vatansever, D., Poerio, G. L., Turnbull, A., Ho, N. S. P., Leech, R., Bernhardt, B. C., Jefferies, E., Margulies, D. S., Nichols, T. E., Woolrich, M. W., & Smallwood, J. (2020a). *The psychological correlates of distinct neural states occurring during wakeful rest* (p. 2019.12.21.885772). https://doi.org/10.1101/2019.12.21.885772
64. Karapanagiotidis, T., Vidaurre, D., Quinn, A. J., Vatansever, D., Poerio, G. L., Turnbull, A., Ho, N. S. P., Leech, R., Bernhardt, B. C., Jefferies, E., Margulies, D. S., Nichols, T. E., Woolrich, M. W., & Smallwood, J. (2020b). *The psychological correlates of distinct neural states occurring during wakeful rest* (p. 2019.12.21.885772). https://doi.org/10.1101/2019.12.21.885772
65. Karapanagiotidis, T., Vidaurre, D., Quinn, A. J., Vatansever, D., Poerio, G. L., Turnbull, A., Ho, N. S. P., Leech, R., Bernhardt, B. C., Jefferies, E., Margulies, D. S., Nichols, T. E., Woolrich, M. W., & Smallwood, J. (2020c). The psychological correlates of distinct neural states occurring during wakeful rest. *Scientific Reports*, *10*, 21121. https://doi.org/10.1038/s41598-020-77336-z
66. Karapanagiotidis, T., Vidaurre, D., Quinn, A. J., Vatansever, D., Poerio, G. L., Turnbull, A., Ho, N. S. P., Leech, R., Bernhardt, B. C., Jefferies, E., Margulies, D. S., Nichols, T. E., Woolrich, M. W., &

Smallwood, J. (2020d). The psychological correlates of distinct neural states occurring during wakeful rest. *Scientific Reports*, *10*(1), 21121. https://doi.org/10.1038/s41598-020-77336-z

67. Karapanagiotidis, T., Vidaurre, D., Quinn, A. J., Vatansever, D., Poerio, G. L., Turnbull, A., Ho, N. S. P., Leech, R., Bernhardt, B. C., Jefferies, E., Margulies, D. S., Nichols, T. E., Woolrich, M. W., & Smallwood, J. (2020e). The psychological correlates of distinct neural states occurring during wakeful rest. *Scientific Reports*, *10*(1), 21121. https://doi.org/10.1038/s41598-020-77336-z
68. Kleim, B., & Ehlers, A. (2008). Reduced autobiographical memory specificity predicts depression and posttraumatic stress disorder after recent trauma. *Journal of Consulting and Clinical Psychology*, *76*(2), 231–242. https://doi.org/10.1037/0022-006X.76.2.231
69. Konu, D., Turnbull, A., Karapanagiotidis, T., Wang, H.-T., Brown, L. R., Jefferies, E., & Smallwood, J. (2020). A role for the ventromedial prefrontal cortex in self-generated episodic social cognition. *NeuroImage*, *218*, 116977. https://doi.org/10.1016/j.neuroimage.2020.116977
70. Kucyi, A., Esterman, M., Riley, C. S., & Valera, E. M. (2016). Spontaneous default network activity reflects behavioral variability independent of mind wandering. *Proceedings of the National Academy of Sciences*, *113*(48), 13899–13904. https://doi.org/10.1073/pnas.1611743113
71. Lavender, A., & Watkins, E. (2004). Rumination and future thinking in depression. *British Journal of Clinical Psychology*, *43*(2), 129–142. https://doi.org/10.1348/014466504323088015
72. Lehtonen, A., Jakub, N., Craske, M., Doll, H., Harvey, A., & Stein, A. (2009). Effects of preoccupation on interpersonal recall: A pilot study. *Depression and Anxiety*, *26*(1), 1–6. https://doi.org/10.1002/da.20472
73. Liu, Y., Yu, X., Yang, B., Zhang, F., Zou, W., Na, A., Zhao, X., & Yin, G. (2017a). Rumination mediates the relationship between overgeneral autobiographical memory and depression in patients with major depressive disorder. *BMC Psychiatry*, *17*(1), 103. https://doi.org/10.1186/s12888-017-1264-8

74. Liu, Y., Yu, X., Yang, B., Zhang, F., Zou, W., Na, A., Zhao, X., & Yin, G. (2017b). Rumination mediates the relationship between overgeneral autobiographical memory and depression in patients with major depressive disorder. *BMC Psychiatry*, *17*(1), 103. https://doi.org/10.1186/s12888-017-1264-8

75. Lyubomirsky, S., Caldwell, N. D., & Nolen-Hoeksema, S. (1998). Effects of ruminative and distracting responses to depressed mood on retrieval of autobiographical memories. *Journal of Personality and Social Psychology*, *75*(1), 166–177. https://doi.org/10.1037//0022-3514.75.1.166

76. Mackinger, H. F., Pachinger, M. M., Leibetseder, M. M., & Fartacek, R. R. (2000). Autobiographical memories in women remitted from major depression. *Journal of Abnormal Psychology*, *109*(2), 331–334.

77. Matsumoto, N., Takahashi, Y., & Kawaguchi, J. (2020). Increased Direct Retrieval of Overgeneral Categoric Memory in Individuals with Dysphoria and a History of Major Depression. *Cognitive Therapy and Research*, *44*(3), 483–498. https://doi.org/10.1007/s10608-020-10079-3

78. Matt, G. E., Vázquez, C., & Campbell, W. K. (1992). Mood-congruent recall of affectively toned stimuli: A meta-analytic review. *Clinical Psychology Review*, *12*(2), 227–255. https://doi.org/10.1016/0272-7358(92)90116-P

79. McCormick, C., Rosenthal, C. R., Miller, T. D., & Maguire, E. A. (2018). mind wandering in People with Hippocampal Damage. *The Journal of Neuroscience*, *38*(11), 2745–2754. https://doi.org/10.1523/JNEUROSCI.1812-17.2018

80. McFarland, C. P., Primosch, M., Maxson, C. M., & Stewart, B. T. (2017). Enhancing memory and imagination improves problem solving among individuals with depression. *Memory & Cognition*, *45*(6), 932–939. https://doi.org/10.3758/s13421-017-0706-3

81. Mckeown, B., Strawson, W. H., Wang, H.-T., Karapanagiotidis, T., Vos de Wael, R., Benkarim, O., Turnbull, A., Margulies, D., Jefferies, E., McCall, C., Bernhardt, B., & Smallwood, J. (2020). The relationship between individual variation in macroscale functional gradients and distinct aspects of ongoing thought. *Neuroimage*, *220*, 117072. https://doi.org/10.1016/j.neuroimage.2020.117072

82. Mihailova, S., & Jobson, L. (2018). Association between intrusive negative autobiographical memories and depression: A meta-analytic investigation. *Clinical Psychology & Psychotherapy*, *25*(4), 509–524. https://doi.org/10.1002/cpp.2184

83. Mihailova, S., & Jobson, L. (2020). Cross-cultural exploration of the characteristics, content and themes of intrusive autobiographical memories recalled during depression. *Memory*, *28*(5), 701–711. https://doi.org/10.1080/09658211.2020.1767143

84. Mildner, J. N., & Tamir, D. I. (2021). The people around you are inside your head: Social context shapes spontaneous thought. *Journal of Experimental Psychology: General*, No Pagination Specified-No Pagination Specified. https://doi.org/10.1037/xge0001057

85. Mittner, M., Hawkins, G. E., Boekel, W., & Forstmann, B. U. (2016). A Neural Model of Mind Wandering. *Trends in Cognitive Sciences*, *20*(8), 570–578. https://doi.org/10.1016/j.tics.2016.06.004

86. Neshat-Doost, H. T., Dalgleish, T., Yule, W., Kalantari, M., Ahmadi, S. J., Dyregrov, A., & Jobson, L. (2013). Enhancing Autobiographical Memory Specificity Through Cognitive Training: An Intervention for Depression Translated From Basic Science. *Clinical Psychological Science*, *1*(1), 84–92. https://doi.org/10.1177/2167702612454613

87. Newby, J. M., & Moulds, M. L. (2011a). Characteristics of intrusive memories in a community sample of depressed, recovered depressed and never-depressed individuals. *Behaviour Research and Therapy*, *49*(4), 234–243. https://doi.org/10.1016/j.brat.2011.01.003

88. Newby, J. M., & Moulds, M. L. (2011b). Intrusive memories of negative events in depression: Is the centrality of the event important? *Journal of Behavior Therapy and Experimental Psychiatry*, *42*(3), 277–283. https://doi.org/10.1016/j.jbtep.2010.12.011

89. Nolen-Hoeksema, S. (2000). The role of rumination in depressive disorders and mixed anxiety/depressive symptoms. *Journal of Abnormal Psychology*, *109*(3), 504–511. https://doi.org/10.1037/0021-843X.109.3.504

90. O'Reilly, R. C., & McClelland, J. L. (1994). Hippocampal conjunctive encoding, storage, and recall: Avoiding a trade-off. *Hippocampus*, *4*(6), 661–682. https://doi.org/10.1002/hipo.450040605

91. Ottaviani, C., Shahabi, L., Tarvainen, M., Cook, I., Abrams, M., & Shapiro, D. (2015). Cognitive, behavioral, and autonomic correlates of mind wandering and perseverative cognition in major depression. *Frontiers in Neuroscience*, *8*. https://doi.org/10.3389/fnins.2014.00433

92. Ottaviani, C., Shapiro, D., & Couyoumdjian, A. (2013). Flexibility as the key for somatic health: From mind wandering to perseverative cognition. *Biological Psychology*, *94*(1), 38–43. https://doi.org/10.1016/j.biopsycho.2013.05.003

93. Payne, A., Kralj, A., Young, J., & Meiser-Stedman, R. (2019). The prevalence of intrusive memories in adult depression: A meta-analysis. *Journal of Affective Disorders*, *253*, 193–202. https://doi.org/10.1016/j.jad.2019.04.055

94. Poerio, G. L., Totterdell, P., & Miles, E. (2013). mind wandering and negative mood: Does one thing really lead to another? *Consciousness and Cognition*, *22*(4), 1412–1421. https://doi.org/10.1016/j.concog.2013.09.012

95. Raaijmakers, J. G. W., & Shiffrin, R. M. (1980). SAM: A Theory of Probabilistic Search of Associative Memory. In G. H. Bower (Ed.), *Psychology of Learning and Motivation* (Vol. 14, pp. 207–262). Academic Press. https://doi.org/10.1016/S0079-7421(08)60162-0

96. Raes, F., Hermans, D., Williams, J. M. G., Demyttenaere, K., Sabbe, B., Pieters, G., & Eelen, P. (2005). Reduced specificity of autobiographical memory: A mediator between rumination and ineffective social problem-solving in major depression? *Journal of Affective Disorders*, *87*(2), 331–335. https://doi.org/10.1016/j.jad.2005.05.004

97. Raes, F., Hermans, D., Williams, J. M. G., & Eelen, P. (2006). Reduced autobiographical memory specificity and affect regulation. *Cognition and Emotion*, *20*(3–4), 402–429. https://doi.org/10.1080/02699930500341003

98. Raes, F., Hermans, D., Williams, J. M. G., & Eelen, P. (2007). A sentence completion procedure as an alternative to the Autobiographical Memory Test for assessing overgeneral memory in non-clinical populations. *Memory*, *15*(5), 495–507. https://doi.org/10.1080/09658210701390982

99. Raes, F., Williams, J. M. G., & Hermans, D. (2009a). Reducing cognitive vulnerability to depression: A preliminary investigation of MEmory Specificity Training (MEST) in inpatients with depressive symptomatology. *Journal of Behavior Therapy and Experimental Psychiatry*, *40*(1), 24–38. https://doi.org/10.1016/j.jbtep.2008.03.001

100. Raes, F., Williams, J. M. G., & Hermans, D. (2009b). Reducing cognitive vulnerability to depression: A preliminary investigation of MEmory Specificity Training (MEST) in inpatients with depressive symptomatology. *Journal of Behavior Therapy and Experimental Psychiatry*, *40*(1), 24–38. https://doi.org/10.1016/j.jbtep.2008.03.001

101. Raichle, M. E. (2015). The Brain's Default Mode Network. *Annual Review of Neuroscience*, *38*(1), 433–447. https://doi.org/10.1146/annurev-neuro-071013-014030

102. Raymaekers, L., Smeets, T., Peters, M. J. V., & Merckelbach, H. (2010). Autobiographical memory specificity among people with recovered memories of childhood sexual abuse. *Journal of Behavior Therapy and Experimental Psychiatry*, *41*(4), 338–344. https://doi.org/10.1016/j.jbtep.2010.03.004

103. Renner, F., Siep, N., Arntz, A., van de Ven, V., Peeters, F. P. M. L., Quaedflieg, C. W. E. M., & Huibers, M. J. H. (2017). Negative mood-induction modulates default mode network resting-state functional connectivity in chronic depression. *Journal of Affective Disorders*, *208*, 590–596. https://doi.org/10.1016/j.jad.2016.10.022

104. Renoult, L., & Rugg, M. D. (2020). An historical perspective on Endel Tulving's episodic-semantic distinction. *Neuropsychologia*, *139*, 107366. https://doi.org/10.1016/j.neuropsychologia.2020.107366

105. Rimes, K. A., & Watkins, E. (2005). The effects of self-focused rumination on global negative self-judgements in depression. *Behaviour Research and Therapy*, *43*(12), 1673–1681. https://doi.org/10.1016/j.brat.2004.12.002

106. Roberts, H., Watkins, E. R., & Wills, A. J. (2017). Does Rumination Cause "Inhibitory" Deficits? *Psychopathology Review*, *a4*(3), 341–376. https://doi.org/10.5127/pr.036914

107. Rosebrock, L. E., Arditte Hall, K. A., Rando, A., Pineles, S. L., & Liverant, G. I. (2019). Rumination and Its Relationship with Thought Suppression in Unipolar Depression and Comorbid PTSD. *Cognitive Therapy and Research*, *43*(1), 226–235. https://doi.org/10.1007/s10608-018-9935-4

108. Ruby, F. J. M., Smallwood, J., Engen, H., & Singer, T. (2013). How Self-Generated Thought Shapes Mood—The Relation between mind wandering and Mood Depends on the Socio-Temporal Content of Thoughts. *PLOS ONE*, *8*(10), e77554. https://doi.org/10.1371/journal.pone.0077554

109. Seli, P., Ralph, B. C. W., Konishi, M., Smilek, D., & Schacter, D. L. (2017). What did you have in mind? Examining the content of intentional and unintentional types of mind wandering. *Consciousness and Cognition*, *51*, 149–156. https://doi.org/10.1016/j.concog.2017.03.007

110. Sievers, C., Bird, C. M., & Renoult, L. (2019). Predicting memory formation over multiple study episodes. *Learning & Memory*, *26*(12), 465–472. https://doi.org/10.1101/lm.049791.119

111. Sievers, C., Smith, F. W., Saada, J., Simons, J. S., & Renoult, L. (2019). *Encoding Variability: When Pattern Reactivation Does Not Benefit Context Memory* (p. 586446). https://doi.org/10.1101/586446

112. Sinclair, J. M. A., Crane, C., Hawton, K., & Williams, J. M. G. (2007). The role of autobiographical memory specificity in deliberate self-harm: Correlates and consequences. *Journal of Affective Disorders*, *102*(1–3), 11–18. https://doi.org/10.1016/j.jad.2006.12.006

113. Smallwood, J., Karapanagiotidis, T., Ruby, F., Medea, B., de Caso, I., Konishi, M., Wang, H.-T., Hallam, G., Margulies, D. S., & Jefferies, E. (2016a). Representing Representation: Integration between the Temporal Lobe and the Posterior Cingulate Influences the Content and Form of Spontaneous Thought. *PloS One*, *11*(4), e0152272. https://doi.org/10.1371/journal.pone.0152272

114. Smallwood, J., Karapanagiotidis, T., Ruby, F., Medea, B., de Caso, I., Konishi, M., Wang, H.-T., Hallam, G., Margulies, D. S., & Jefferies, E. (2016b). Representing Representation: Integration between the Temporal Lobe and the Posterior Cingulate Influences the Content and Form of Spontaneous Thought. *PLoS ONE*, *11*(4), e0152272. https://doi.org/10.1371/journal.pone.0152272

115. Smallwood, J., & O'Connor, R. C. (2011). Imprisoned by the past: Unhappy moods lead to a retrospective bias to mind wandering. *Cognition & Emotion*, *25*(8), 1481–1490. https://doi.org/10.1080/02699931.2010.545263

116. Spasojević, J., & Alloy, L. B. (2001). Rumination as a common mechanism relating depressive risk factors to depression. *Emotion*, *1*(1), 25–37. https://doi.org/10.1037/1528-3542.1.1.25

117. Spinhoven, P., Bockting, C. L. H., Kremers, I. P., Schene, A. H., Mark, J., & Williams, G. (2007). The endorsement of dysfunctional attitudes is associated with an impaired retrieval of specific autobiographical memories in response to matching cues. *Memory*. https://doi.org/10.1080/09658210701256555

118. Stanghellini, G., Ballerini, M., Presenza, S., Mancini, M., Northoff, G., & Cutting, J. (2017). Abnormal Time Experiences in Major Depression: An Empirical Qualitative Study. *Psychopathology*, *50*(2), 125–140. https://doi.org/10.1159/000452892

119. Sui, J., & Humphreys, G. W. (2015). The Integrative Self: How Self-Reference Integrates Perception and Memory. *Trends in Cognitive Sciences*, *19*(12), 719–728. https://doi.org/10.1016/j.tics.2015.08.015

120. Sumner, J. A. (2012). The mechanisms underlying overgeneral autobiographical memory: An evaluative review of evidence for the CaR-FA-X model. *Clinical Psychology Review*, *32*(1), 34–48. https://doi.org/10.1016/j.cpr.2011.10.003

121. Suthana, N., Ekstrom, A. D., Yassa, M. A., & Stark, C. (2021). Pattern Separation in the Human Hippocampus: Response to Quiroga. *Trends in Cognitive Sciences*, *25*(6), 423–424. https://doi.org/10.1016/j.tics.2021.02.005

122. Takano, K., Van Grieken, J., & Raes, F. (2019). Difficulty in updating positive beliefs about negative cognition is associated with increased depressed mood. *Journal of Behavior Therapy and Experimental Psychiatry*, *64*, 22–30. https://doi.org/10.1016/j.jbtep.2019.02.001

123. Tambini, A., & Davachi, L. (2013). Persistence of hippocampal multivoxel patterns into postencoding rest is related to memory. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(48), 19591–19596. https://doi.org/10.1073/pnas.1308499110

124. The characteristics of involuntary and voluntary autobiographical memories in depressed and never depressed individuals. (2012). *Consciousness and Cognition*, *21*(3), 1382–1392. https://doi.org/10.1016/j.concog.2012.06.016

125. Treves, A., & Rolls, E. T. (1994). Computational analysis of the role of the hippocampus in memory. *Hippocampus*, *4*(3), 374–391. https://doi.org/10.1002/hipo.450040319

126. van Vugt, M. K., van der Velde, M., & Investigators, E.-M. (2018). How Does Rumination Impact Cognition? A First Mechanistic Model. *Topics in Cognitive Science*, *10*(1), 175–191. https://doi.org/10.1111/tops.12318

127. Vanderveren, E., Bijttebier, P., & Hermans, D. (2019). Autobiographical memory coherence and specificity: Examining their reciprocal relation and their associations with internalizing symptoms and rumination. *Behaviour Research and Therapy*, *116*, 30–35. https://doi.org/10.1016/j.brat.2019.02.003

128. Vogel, D. H. V., Krämer, K., Schoofs, T., Kupke, C., & Vogeley, K. (2018). Disturbed Experience of Time in Depression—Evidence from Content Analysis. *Frontiers in Human Neuroscience*, *12*, 66. https://doi.org/10.3389/fnhum.2018.00066

129. Vos, T., Lim, S. S., Abbafati, C., Abbas, K. M., Abbasi, M., Abbasifard, M., Abbasi-Kangevari, M., Abbastabar, H., Abd-Allah, F., Abdelalim, A., Abdollahi, M., Abdollahpour, I., Abolhassani, H., Aboyans, V., Abrams, E. M., Abreu, L. G., Abrigo, M. R. M., Abu-Raddad, L. J., Abushouk, A. I., … Murray, C. J. L. (2020). Global burden of 369 diseases and injuries in 204 countries and territories, 1990–2019: A systematic analysis for the Global Burden of Disease Study 2019. *The Lancet*, *396*(10258), 1204–1222. https://doi.org/10.1016/S0140-6736(20)30925-9

130. Waters, T. E. A. (2014). Relations between the functions of autobiographical memory and psychological wellbeing. *Memory (Hove, England)*, *22*(3), 265–275. https://doi.org/10.1080/09658211.2013.778293

131. Watkins, E. (2004). Adaptive and maladaptive ruminative self-focus during emotional processing. *Behaviour Research and Therapy*, *42*(9), 1037–1052. https://doi.org/10.1016/j.brat.2004.01.009

132. Watkins, E., Moberly, N. J., & Moulds, M. L. (2008). Processing mode causally influences emotional reactivity: Distinct effects of abstract versus concrete construal on emotional response. *Emotion (Washington, D.C.)*, *8*(3), 364–378. https://doi.org/10.1037/1528-3542.8.3.364

133. Watkins, E. R., & Roberts, H. (2020). Reflecting on rumination: Consequences, causes, mechanisms and treatment of rumination. *Behaviour Research and Therapy*, *127*, 103573. https://doi.org/10.1016/j.brat.2020.103573

134. Watkins, E., & Teasdale, J. D. (2001). Rumination and overgeneral memory in depression: Effects of self-focus and analytic thinking. *Journal of Abnormal Psychology*, *110*(2), 353–357. https://doi.org/10.1037/0021-843X.110.2.333

135. Watkins, E., & Teasdale, J. D. (2004). Adaptive and maladaptive self-focus in depression. *Journal of Affective Disorders*, *82*(1), 1–8. https://doi.org/10.1016/j.jad.2003.10.006

136. Watkins, P. C., Mathews, A., Williamson, D. A., & Fuller, R. D. (1992). Mood-congruent memory in depression: Emotional priming or elaboration? *Journal of Abnormal Psychology*, *101*(3), 581–586. https://doi.org/10.1037/0021-843X.101.3.581

137. Watson, L. A., Berntsen, D., Kuyken, W., & Watkins, E. R. (2013). Involuntary and voluntary autobiographical memory specificity as a function of depression. *Journal of Behavior Therapy and Experimental Psychiatry*, *44*(1), 7–13. https://doi.org/10.1016/j.jbtep.2012.06.001

138. Whalley, M. G., Rugg, M. D., & Brewin, C. R. (2012). Autobiographical memory in depression: An fMRI study. *Psychiatry Research: Neuroimaging*, *201*(2), 98–106. https://doi.org/10.1016/j.pscychresns.2011.08.008

139. White, H. (1989). Learning in Artificial Neural Networks: A Statistical Perspective. *Neural Computation*, *1*(4), 425–464. https://doi.org/10.1162/neco.1989.1.4.425

140. Whitmer, A. J., & Banich, M. T. (2007a). Inhibition Versus Switching Deficits in Different Forms of Rumination. *Psychological Science*, *18*(6), 546–553. https://doi.org/10.1111/j.1467-9280.2007.01936.x

141. Whitmer, A. J., & Banich, M. T. (2007b). Inhibition Versus Switching Deficits in Different Forms of Rumination. *Psychological Science*, *18*(6), 546–553. https://doi.org/10.1111/j.1467-9280.2007.01936.x

142. Whitmer, A. J., Frank, M. J., & Gotlib, I. H. (2012). Sensitivity to reward and punishment in major depressive disorder: Effects of rumination and of single versus multiple experiences. *Cognition & Emotion*, *26*(8), 1475–1485. https://doi.org/10.1080/02699931.2012.682973

143. Whitmer, A. J., & Gotlib, I. H. (2013). An attentional scope model of rumination. *Psychological Bulletin*, *139*(5), 1036–1061. https://doi.org/10.1037/a0030923

144. Williams, A. D., & Moulds, M. L. (2008). Negative appraisals and cognitive avoidance of intrusive memories in depression: A replication and extension. *Depression and Anxiety*, *25*(7), E26–E33. https://doi.org/10.1002/da.20409

145. Williams, J. M., & Broadbent, K. (1986). Autobiographical memory in suicide attempters. *Journal of Abnormal Psychology*, *95*(2), 144–149. https://doi.org/10.1037/0021-843X.95.2.144

146. Williams, J. M. G. (2006). Capture and rumination, functional avoidance, and executive control (CaRFAX): Three processes that underlie overgeneral memory. *Cognition and Emotion*, *20*(3–4), 548–568. https://doi.org/10.1080/02699930500450465

147. Williams, J. M. G., & Scott, J. (1988). Autobiographical memory in depression. *Psychological Medicine*, *18*(3), 689–695. https://doi.org/10.1017/S0033291700008370

148. Williams, J. M. G., Stiles, W. B., & Shapiro, D. A. (1999). Cognitive mechanisms in the avoidance of painful and dangerous thoughts: Elaborating the assimilation model. *Cognitive Therapy and Research*, *23*(3), 285–306. https://doi.org/10.1023/A:1018743615228

149. Wilson, F. C. L., & Gregory, J. D. (2018). Overgeneral autobiographical memory and depression in older adults: A systematic review. *Aging & Mental Health*, *22*(5), 575–586. https://doi.org/10.1080/13607863.2017.1326461

150. Yanko, M. R., & Spalek, T. M. (2014). Driving With the Wandering Mind: The Effect That mind wandering Has on Driving Performance. *Human Factors*, *56*(2), 260–269. https://doi.org/10.1177/0018720813495280

151. Young, K. D., Bodurka, J., & Drevets, W. C. (2016). Differential neural correlates of autobiographical memory recall in bipolar and unipolar depression. *Bipolar Disorders*, *18*(7), 571–582. https://doi.org/10.1111/bdi.12441

152. Zhu, X., Wang, X., Xiao, J., Liao, J., Zhong, M., Wang, W., & Yao, S. (2012). Evidence of a Dissociation Pattern in Resting-State Default Mode Network Connectivity in First-Episode, Treatment-Naive Major Depression Patients. *Biological Psychiatry*, *71*(7), 611–617. https://doi.org/10.1016/j.biopsych.2011.10.035

153. Zu, S., Wang, D., Fang, J., Xiao, L., Zhu, X., Wu, W., Wang, G., & Hu, Y. (2021). Comparison of Residual Depressive Symptoms, Functioning, and Quality of Life Between Patients with Recurrent Depression and First Episode Depression After Acute Treatment in China. *Neuropsychiatric Disease and Treatment*, *17*, 3039–3 https://doi.org/10.2147/NDT.S317

Chapter 5: Exploring the Multidimensional Nature of Autobiographical Memories: A Representational Similarity Analysis Using Natural Language Processing

Abstract

Depression has been long linked to alterations in the way that individuals process personal information, and specifically autobiographical memories. While many studies have investigated the features of recall in individual memories, we sought to characterize the dynamics of memory networks and their associations in depression. Depressed and healthy control participants recalled 20 autobiographical memories across positive and negative valences and four thematic categories. Memories were transcribed and transformed into vector embeddings using NLP to assess semantic similarity, allowing for the construction and analysis of memory networks. Graph-theoretic metrics revealed emotional clustering wherein positive memories showed higher clustering than negative memories across groups but was weaker in depressed subjects. In addition, the depression group exhibited lower modularity and higher edge density, indicating less distinct clustering of memories into thematic or emotional communities suggesting weaker emotional segregation. These findings suggest that depression alters memory network organization, characterized by reduced partitioning and heightened connectivity of negative memories. These data highlight structural disruptions in autobiographical memory networks associated with depression, providing insights into how emotional and cognitive processes may influence memory organization.

Introduction

Clinical depression is associated with problems in recalling personal memories (Williams, 1996). Depressed individuals display problems in retrieving specific episodic, autobiographical memories (Watkins & Teasdale, 2002), tend to recall negative memories more often than positive or neutral (Williams, 1998), and more intrusive negative memories than individuals without depression (Brewin, Reynolds, and Tata, 1998).

Hierarchical models of autobiographical memory (Conway and Pleydell-Pearce, 2000), argue that the “self-memory system” is constructed from levels of memory representations with major levels increasing in specificity as one descends the hierarchy: lifetime periods, general events, single events, and event specific knowledge. Descending the hierarchy of memory representations into more specific knowledge parallels the range of autobiographical memory from semantic (thematic, less richly detailed memories) to episodic (generally includes sensory and emotional details). Retrieval of a memory begins with an intentional staged search that is guided by generative, top-down processes or from direct, bottom-up retrieval that allow one to access event-specific details. Individuals with depression are thought to be unable to access the rich episodic details at the lowest level of this hierarchy. Though some models of memory in depression have posited that this reduction in specificity is due to deficits in top-down control (Williams, 2006), I have outlined reasons above to be skeptical of this approach in Chapter 3. In lieu of this view, I propose that recalcitrant ruminations may serve as a more parsimonious account of how spontaneously recalled autobiographical information may become overgeneral in memory stores and result in weakened and less specific memory recall in individuals with depression. In this way, the strength of associations between sets of negative memories is altered through rumination, resulting in organizational changes and loss of episodic details. We will use this framework of autobiographical information to solve the first piece of this puzzle: namely, if autobiographical information is differently organized within individuals with depression compared to healthy controls.

Personal memories stores are built upon extensive and interconnected associations between various features and details, encompassing spatial, temporal, social, and thematic information. Autobiographical memories, in particular, are proposed to be organized into hierarchical associations that can be flexibly constructed across multiple themes or categories (Conway, 1999).

The Autobiographical Interview (AI) is a standardized and structured interview during which trained interviewers probe participants for details of specific, episodic, autobiographical memories (Levine et al., 2002). In the AI, interviewers allow for a period of free recall before specific probes are asked to ensure the quality of details for the memory. Participants speak aloud their memories into a recording device for later transcription. Along with healthy and aging populations, this paradigm has been used to study memory effects in depression (Soderlund et al., 2014; Lam et al., 2022; de Assis da Silva et al., 2021; see Lockrow et al., 2023 for review). The main finding in these studies is that individuals with depression tend to recall relatively more semantic details than episodic details, and overall fewer details in memory, leading to the hypothesis that depression is related to less specific or overgeneral memory recollection.

However, the AI paradigm addresses memory representations singularly – each memory is recalled in response to a prompt and individuals do not make relational assessments between these recalled events. To address this [hole] in the literature, Tomita et al. (2021) recently investigated which features of real-life memories are perceived to influence associations or similarities. In this study, individuals were asked to recall two personal memories and afterwards were asked to rate which features made these memories similar. They found that emotion and the "purpose" of the event predicted memory similarity over and above social, temporal, and spatial characteristics. Further, Rouhani et al., 2023 found that personal memories recalled over the course of a stressful period (e.g. the 2020 Covid Lock-Down) were clustered and had enhanced recall based emotion.

Based on these previous data, we seek to operationalize recalled memories and their associations as semantic networks, emphasizing the connections between individual memories based on shared features, characteristics, and semantic content. This network-based perspective allows us to examine the structural and organizational properties of memory representations at a detailed level [without the need for neural recordings]. In this way, memories are treated as nodes in a network, and their associations - based on features, themes, or semantic content - are represented as edges. This approach allows us to analyze the relational structure of memory networks in a mathematically rigorous manner.

Graph theory provides a powerful tool for understanding memory structures. By leveraging graph-theoretic metrics, we can quantify the organization and complexity of memory networks, offering new insights into the interplay between memory content and structure. In this study, memories are represented as vector embeddings derived from natural language processing (NLP) techniques. These embeddings are assumed to incorporate episodic details within their semantic representations. For instance, while the similarity between two memories may be described as "semantic," the embeddings are expected to capture episodic nuances, such as the distinction between a negative family memory and a positive school memory.

Our analyses demonstrate that experimental categories (e.g., emotional valence or thematic content) are reflected in the semantic similarity of participants' memories. If the embeddings failed to include episodic details, we would not observe significant differences in similarity between memories of differing valences or categories. However, as our results indicate, such differences do emerge, providing support for the inclusion of episodic information in the memory representations.

To quantify similarity between autobiographical memories across individuals and conditions, we applied an NLP approach—an advanced computational linguistic method used to measure semantic distances between text-based content (Kozwolski et al., 2018). This approach embeds words and phrases in a high-dimensional space based on local co-occurrences within large text corpora. The resulting semantic space allows us to infer relational structures between concepts based on their spatial proximity. Similar methods have been successfully employed in prior memory research (Perl et al., 2022).

Many empirical problems, including memory organization, can be represented as networks and analyzed using topological approaches to reveal their structural features. In this study, we use a range of network metrics to quantify the organization of memory networks. In particular, we focus on three key features: modularity, clustering, and edge density. Modularity measures the extent to which memories cluster into distinct communities. It is defined as the fraction of edges within communities minus the expected fraction if edges were distributed randomly (Newman, 2006). Positive modularity values indicate that nodes are more densely connected within communities than expected by chance. Networks with high modularity exhibit dense intra-community connections and sparse inter-community connections, reflecting a well-organized and compartmentalized structure. In a similar vein, a network's clustering coefficient assesses the local interconnectedness of nodes within the network, reflecting the degree to which memories within a specific community are grouped together. Higher clustering coefficients suggest stronger associations within groups of related memories, particularly by shared emotional or thematic content. Finally, edge density quantifies the overall connectivity of the network, representing the proportion of existing connections relative to the total possible connections. Higher edge density indicates more densely connected networks, while lower edge density reflects sparsity.

Through the application of these network metrics, we aim to uncover how memories are structured based on their semantic and episodic content, and how these structures differ across emotions (e.g., Positive vs. Negative) and between depression and control groups. These analyses provide insights into the cognitive and emotional mechanisms underlying autobiographical memory organization.

Based on empirical and theoretical understandings of autobiographical memory structure, combined with principles of network and graph theory, we hypothesize that the organization and structure of memory networks will differ between individuals with depression and control participants. Specifically, individuals with depression will exhibit higher clustering within emotional memories, reflecting stronger intra-emotional grouping, alongside lower modularity, indicative of less distinct community separation in memory organization. Additionally, depression will be associated with reduced edge density, suggesting sparser overall connectivity within the memory network. Differences in linguistic attributes of memory descriptions are also anticipated, with individuals with depression expected to use fewer words and display a greater tendency toward negative word use, reflecting a more negative linguistic tone. Finally, we predict that features of recalled memories will differ between groups, with individuals with depression recalling memories that are rated as more negative, more frequently recalled, and less vividly. These hypotheses align with prior findings on autobiographical memory in depression and aim to advance understanding of how emotional and cognitive processes influence the organization and characteristics of behaviorally reported memory representations.

Methods

Participants

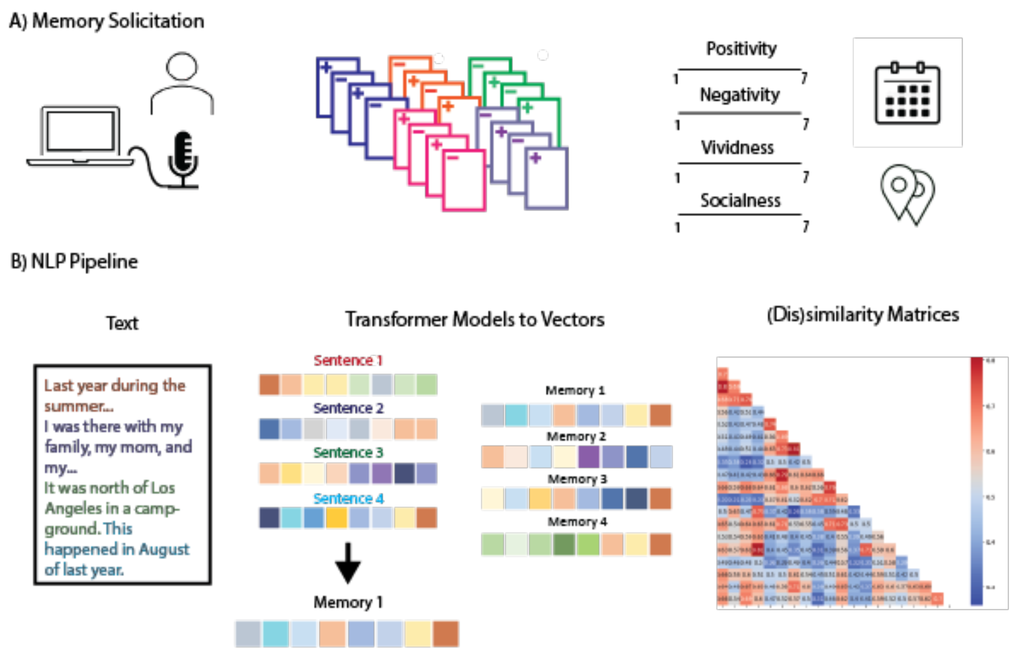
Participants were recruited via the UCLA Online Subject Online for course credit. We posted two advertisements for each group: the depression group were required to report that they have an ongoing mental health issue and further specify that it is depression. We additionally confirmed this after the memory task was complete with the Beck Depression Inventory (Beck, Steer, & Brown, 1996), excluding the suicidal ideation question (see Survey section below). For the healthy group, participants were required to not have any current or history with depression. We collected 70 participants (46 female; Age M= 20.03, SD = 1.78, Range: 18 - 30). There were no differences between the groups for age (Depression: M = 20.00, SD = 1.78, Control: M = 20.06, SD = 2.21).

Task.

To probe autobiographical memories from participants, we used a modified version of the Autobiographical Interview (AI) (Levine et al., 2002). The Autobiographical Interview is a standardized and structured interview during which trained interviewers probe participants for details of specific, episodic, autobiographical memories. In the original version, trained interviewers allow for a period of free recall before specific probes are asked to ensure the quality of details for the memory. We adapted a version of this task that will be modified for self-guided assessment via a laptop.

Participants were instructed to recall temporally and spatially specific, personally experienced memories. A prompt appeared on the screen indicating the category and valence to be recalled, and participants were instructed to speak out loud for up to 3 minutes with all details that they could recall from the memory. If they finished before the 3 minutes elapsed and they were instructed to wait until the timer was finished. Each participant was alone for the entirety of the task to preserve anonymity. Participants' voices were recorded and automatically transcribed using Otter.ai (source). After each participant was finished, the voice recordings were phonically altered, and all data was stored as the transcript text.

To aid in the recall of memories within these categories, we developed the "Autobiographical Memory Worksheet" which provides participants with examples across our categories of interest: social, school, travel, and family experiences. Further, they were asked to retrieve 2 positive and 2 negative memories from each category, with examples provided on the worksheet. Each memory was followed by a series of subjective ratings querying details of qualities of the memory including, vividness, self-relevance, emotionality, socialness, and perspective of the memory. Additionally, they were asked to report the perceived valence of the memory on both positivity and negativity, for both emotional conditions. Participants were also asked to report the approximate spatial location and when the memory occurred, as well as the approximate temporal remoteness as Month and Year.



7 Figure 5.1. Participants provided autobiographical memory descriptions, which were categorized by emotional valence (e.g., Positive, Negative) and thematic content. NLP tools to generate vector embeddings, representing each memory in high-dimensional semantic space. Pairwise cosine similarity matrices were constructed to quantify representational similarity across memories.

Questionnaires

The Beck Depression Inventory is a 21-item, self-report scale that measures attitudes and symptoms of depression. We used the short form which does not include questions of suicidal ideation. The Survey of Autobiographical Memory (Palombo, Williams, Abdi, & Levine, 2013) is a self-report scale which assess trait mnemonics, such as self-reported episodic autobiographical, semantic, and spatial memory. Finally, Rumination Response Scale is a self-report scale that assesses trait tendencies to ruminate, a process of “compulsively focused attention on the symptoms of one’s distress, and on its possible causes and consequences, as opposed to solutions” (Nolen-Hoeksema, 1998). Higher scores indicate more trait rumination.

Memory Text Processing

Once participants provided their autobiographical event memories, the audio was transcribed to text to be preprocessed using a natural language processing tool, BERT. BERT (Bidirectional Encoder Representations from Transformers) is a type of machine learning model that is used for natural language processing (NLP). RoBERTA a sentence transformers model which maps sentences and paragraphs onto a 384-dimensional dense vector space and can be used to address questions such as semantic clustering or search (Liu et al., 2019). At a high level, RoBERTA is a neural network that is trained on a large amount of text data to learn the relationships between words and sentences. It uses a technique called "self-attention" to analyze the context of words within a sentence and the relationships between different sentences in a document. One of the main benefits of RoBERTA is that it is a pre-trained model, meaning that it has already been trained on a large corpus of text data and can be fine-tuned for specific NLP tasks like sentiment analysis and similarity,

As opposed to directional models, which read the text input sequentially (left-to-right or right-to-left), the Transformer encoder reads the entire sequence of words at once. Therefore, it is considered bidirectional, though it would be more accurate to say that it's non-directional. This characteristic allows the model to learn the context of a word based on all its surroundings (left and right of the word). The input is a sequence of tokens, which are first embedded into vectors and then processed in the neural network. The output is a sequence of vectors of size H, in which each vector corresponds to an input token with the same index. During preprocessing of the semantic input, punctuation marks were erased, texts were transformed to be lower-case and tokenized.

Statistical Analyses

The preprocessed text data was then analyzed using graph theory to construct a graph of memories that are similar in content and structure. Each memory was treated as a node in the graph, and edges were created between nodes that are similar based on the specific attributes rated by participants. The resulting graph will represent the similarity structure of each participant's set of memories. The graphs were analyzed using community detection algorithms to identify clusters of memories that are densely connected within the graph. Each cluster will represent a group of memories that are similar in content and structure and are frequently recalled together by participants.

Results

Participants

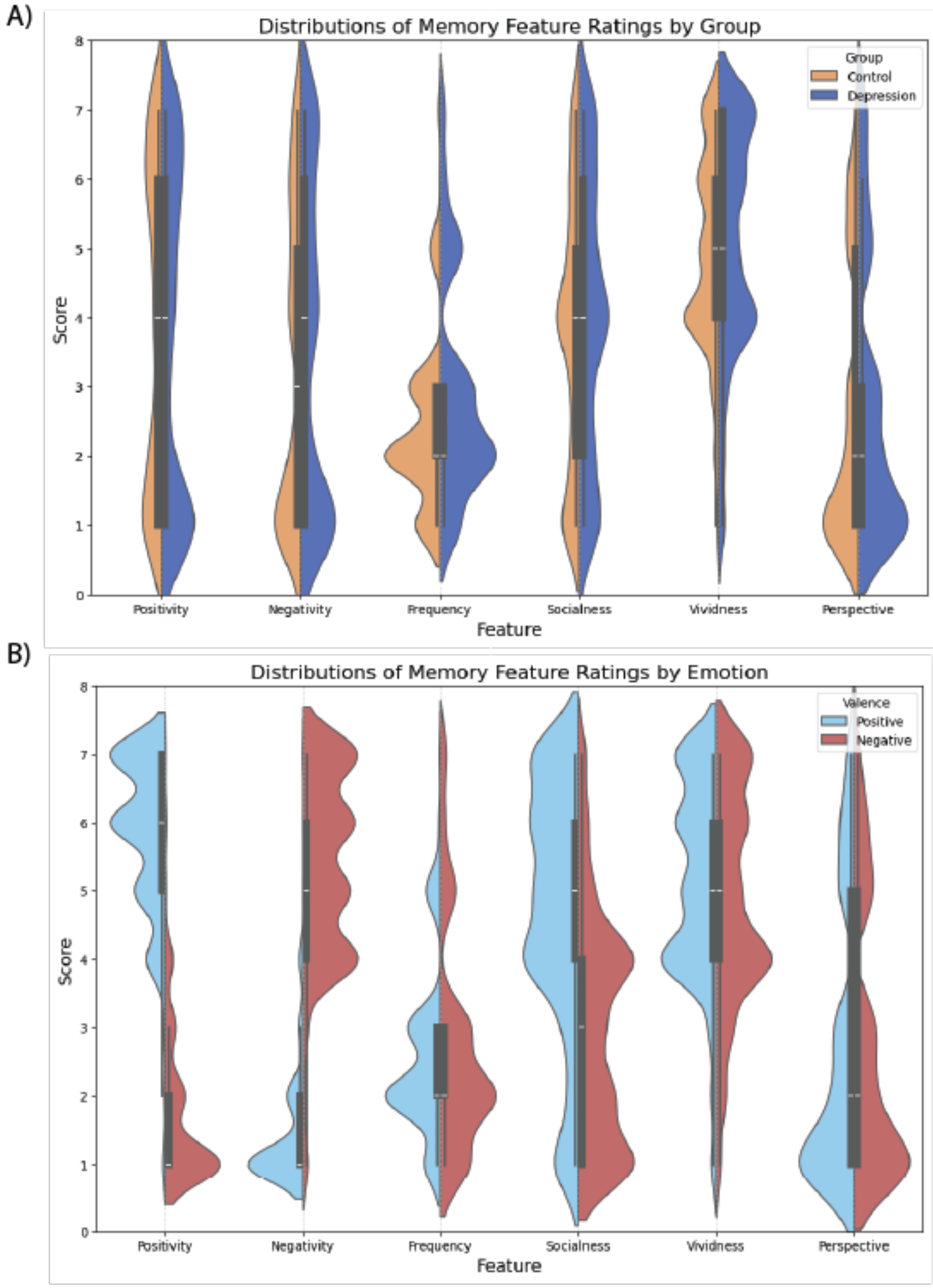
The average age for the sample was 20.03 (SD = 1.78, Range: 18 - 30). There were no differences between the conditions (Depression: M = 20.00, SD = 1.78, Control: M = 20.06, SD = 2.21).

We examined each group to confirm clinical group differences. The depression group had an average higher score on the BDI (M = 22.89, SD = 9.27, range 5-43), than the control group (M = 12.36, SD = 6.60, range, 2 28). A Levene test for equal variances revealed similar variance (F(1, 73) = 2.62, p = .11, d =), and an independent sample t-test revealed significant differences (t(73) = 5.01, p < .001). However, we found a substantial number of individuals in the self-selected depression group reported sub-clinical depression, we ran the analyses that follow with groups split at the clinical cut off of 20, regardless of which advertisement they responded to.

Further, we investigated whether there were differences in the Rumination Response Scale between the two groups. We found that the depression group was higher in the RRS (M = 58.39, SD = 13.11, Range = 24 - 80) compared to the control group (M = 44.18, SD = 23.43, Range = 26 - 70). A Levene test for equal variances revealed similar variances among the groups (F(1,68) = .02, p = .89), and an independent samples t-test showed that the groups were significantly different (t(68) = 4.58, p < .001, d = 1.14). Further, we found a significant relationship between RRS and BDI severity, assessed by a Pearson correlation (r(68) = .78, p < .001).

Next, we assessed the qualities for each of the reported qualities of each memory. First, we examined valence (Positivity vs Negativity). For this analysis, we calculated the mean scores across all categories within each emotion prompt (Positive and Negative) for each participant. Therefore, this analysis assesses how subjects tended to rate their prompted positive and negative memories. We examined the mean positivity and negativity ratings for positive memories and confirmed that when cued to recall positive memories, participants rated them as more positive ($M = 5.95$, $SD = .64$, Range: 1 - 3.8) than negative ($M = 1.44$, $SD = .55$, Range = 1 - 3.8), $t(73) = 36.52$, $p < .001$, $d = 7.58$). Similarly, we confirmed that when participants were prompted to recall negative memories, they rated their memories as more negative ($M = 5.43$, $SD = .39$, Range = 3.8 – 7) than positive (1.71, $SD = .68$, Range: 1 – 3.8), $t(68) = 27.37$, $p < .001$, $d = -5.40$. There was no difference between depressed and healthy subjects, STATS.

The depression group ($M = 2.91$, $SD = .77$) reported recalling memories more frequently than controls ($M = 2.41$, $SD = .66$), $T(1,73) = 2.565$, $p = .001$. Overall, frequency was not different across positive ($M = 2.61$, $SD = .69$) or negative ($M = 2.67$, $SD = .99$) across all participants, $T(1,73) = -.401$, $p = 6.89$). We then ran a repeated measures 2-way ANOVA predicting Frequency by Emotion x Group and found a significant main effect of Group ($B = .67$, $SD = .205$, $z = 3.284$, $p = .001$), but not emotion ($B = .072$, $SD = .07$, $Z = 1.013$, $p = .311$. There was a significant interaction for Emotion x Group on Frequency ($B = -0.327$. $SE = .106$, $z = -3.077$, $p = .002$), suggesting that Depression group recalls negative memories and positive memories more frequently and the negative memories more than positive. Neither socialness, vividness, nor perspective ratings differed between groups (all ps > .387).



8 Figure 5.2. Distributions of feature ratings (positivity, negativity, frequency, socialness, vividness, and perspective) for participants in the A) Control (orange) and Depression (blue) groups and B) across positive (blue) and negative (red) memories. The width of each violin represents the density of responses for each feature, with central boxplots showing the mean and interquartile range. Error bars represent variability across individual ratings.

Within Subject Representational Similarity Analyses

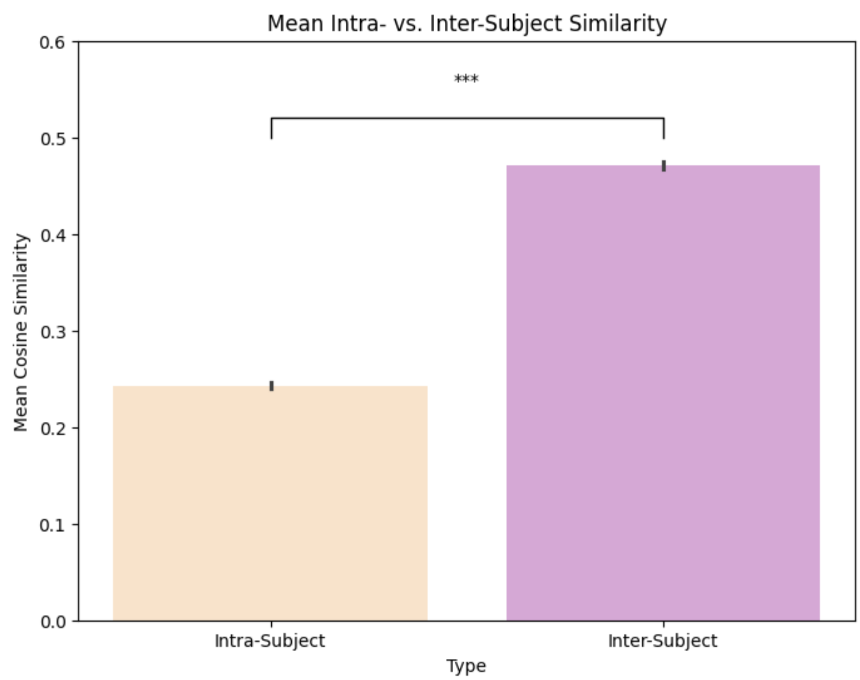
To assess the representational similarity of individual sets of participants' memories, we first compared how memory representations are organized within and across semantic or thematic categories. We utilized a representational similarity analysis (RSA) to compare the within-category similarity of memory embeddings to the across-category similarity for each subject. This approach assesses the extent to which memories from the same category exhibit higher similarity than those from different categories, providing insights into the structure and organization of memory networks. Cosine similarity was calculated for each pair of memory embeddings, and these similarity scores were categorized as either within-category or across-category based on the thematic labels assigned to the memories. Across all subjects, the mean within category score was higher ($M = .574$, $SD = .123$) than across category ($M = .453$, $SD = .103$), $T(1, 73) = 7.33$, $p < .001$.

To address differences between depression and control groups, we ran a linear mixed model predicting mean cosine similarity by Similarity Type and Group as fixed factors and Subjects as a random factor. The main effect of similarity type was significant ($\beta = 0.103$, $SE = 0.008$, $z = 13.74$, $p < .001$), but not group ($\beta = 0.015$, $SE = 0.017$, $z = 0.91$, $p = .363$). The interaction between similarity type and group was significant, $\beta = -0.030$, $SE = 0.010$, $z = -2.87$, $p = .004$, indicating that the difference between within-category and across-category similarity scores was smaller for the Depression group compared to the Control group. The results indicate that similarity type significantly influences mean similarity scores, with within-category similarity being significantly higher than across-category similarity. However, the significant interaction between similarity type and group indicates that the difference between within-category and across-category similarity is smaller for the Depression group compared to the Control group. This suggests that thematic clustering (as reflected by within-category similarity) may be less distinct in the Depression group, see clustering analyses below.

In a similar approach, we assessed the representational similarity of within-valence similarity of memory embeddings to the across-valence similarity for each subject. We submitted a linear mixed model predicting mean cosine similarity by Similarity Type and Group as fixed factors and Subjects as a random factor. The main effect of similarity type (Within-Emotion vs. Across-Emotion Similarity) was significant, $\beta = 0.062$, $SE = 0.004$, $z = 14.27$, $p < .001$, indicating that within-emotion similarity scores were significantly higher than across-emotion similarity scores across groups. The main effect of group (Depression vs. Control) was not significant, $\beta = -0.017$, SE=0.016S, $z = -1.05$, $p = .296$, suggesting no significant difference in overall similarity scores between the Depression and Control groups. The interaction between similarity type and group was significant, $\beta = 0.015$, $SE = 0.006$, $z = 2.36$, $p = .018$, indicating that the difference between within-emotion and across-emotion similarity was larger in the Depression group compared to the Control group. suggests that the Depression group exhibits a larger difference between within-emotion and across-emotion similarity compared to the Control group.

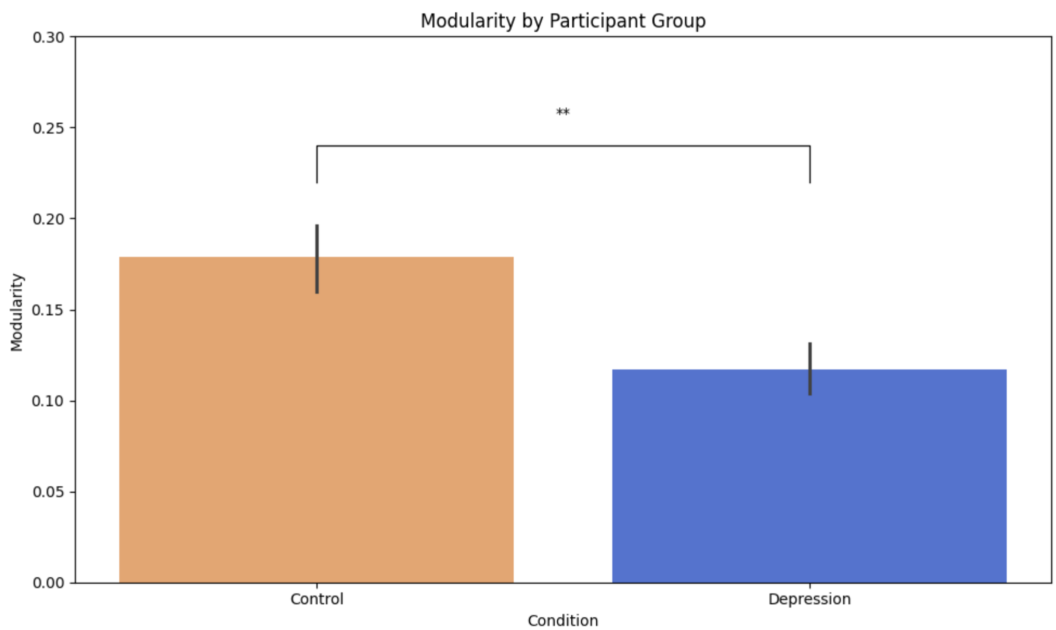
Having investigated the within-subject similarity, we now turn to examining the representational similarity both within individuals and across individuals to provide an assessment of the idiosyncratic features of memory across participants. Something here about how categories are ground truth, therefore perturbations or differences indicate uniqueness or distinctiveness of memory representations. We calculated the cosine similarity of each participant's set of memory embeddings. For intra-subject similarity, the mean cosine similarity of all pairwise comparisons within a participant's memory set were computed. For inter-subject similarity, the mean cosine similarity of a participants' memory embeddings was compared with the embeddings of all other participants.

First, we assessed the overall inter- and intra- subject similarity. Inter-subject similarity was significantly higher ($M = .471$, $SD = .031$), than intra-subject similarity ($M = .242$, $SD = .028$), $T(1,74) = 40.235$, $p < .001$). Next, we assessed the difference across groups (Control vs Depressed). We used a linear mixed model with Group and Similarity Type (Inter and Intra) as fixed effects and Subject as random effects. The main effect of condition (Depression vs. Control) was not significant, β =−0.008, SE=0.008, z=−1.04, p=.298, suggesting no significant difference in similarity scores between groups overall. However, the main effect of similarity type (Intra-Subject vs. Inter-Subject) was significant, β =−0.229, SE=0.003, z=−79.94, p<.001, where intra-subject similarity scores were significantly lower than inter-subject similarity scores across conditions. Finally, the interaction between condition and similarity type was not significant, β =0.003, SE=0.004, z=0.65, p=.515.



9 Figure 5.3. Mean cosine similarity for intra-subject (light orange) and inter-subject (light purple) comparisons. Error bars represent SEM.

A linear mixed model (LMM) was conducted to examine the effects of similarity type (Intra-Similarity vs. Inter-Similarity) and emotion (Positive vs. Negative) on similarity score, with random intercepts for participants to account for repeated measures. The intercept, representing the mean inter-similarity score for negative emotions, was significant (β=0.492, SE=0.004, z=116.91, p<.001), indicating a baseline similarity score of 0.492. The main effect of similarity type (Intra-Similarity vs. Inter-Similarity) was significant (β=−0.255, SE=0.002, z=−107.29, p<.001), indicating that intra-similarity scores were significantly lower than inter-similarity scores across emotions. The main effect of emotion (Positive vs. Negative) was not significant (β=0.004, SE=0.002, z=1.62, p=.105), suggesting no difference in similarity scores between positive and negative emotions. The results indicate that similarity type significantly influences similarity scores, with intra-similarity being significantly lower than inter-similarity, however they do not differ significantly between positive and negative memories.

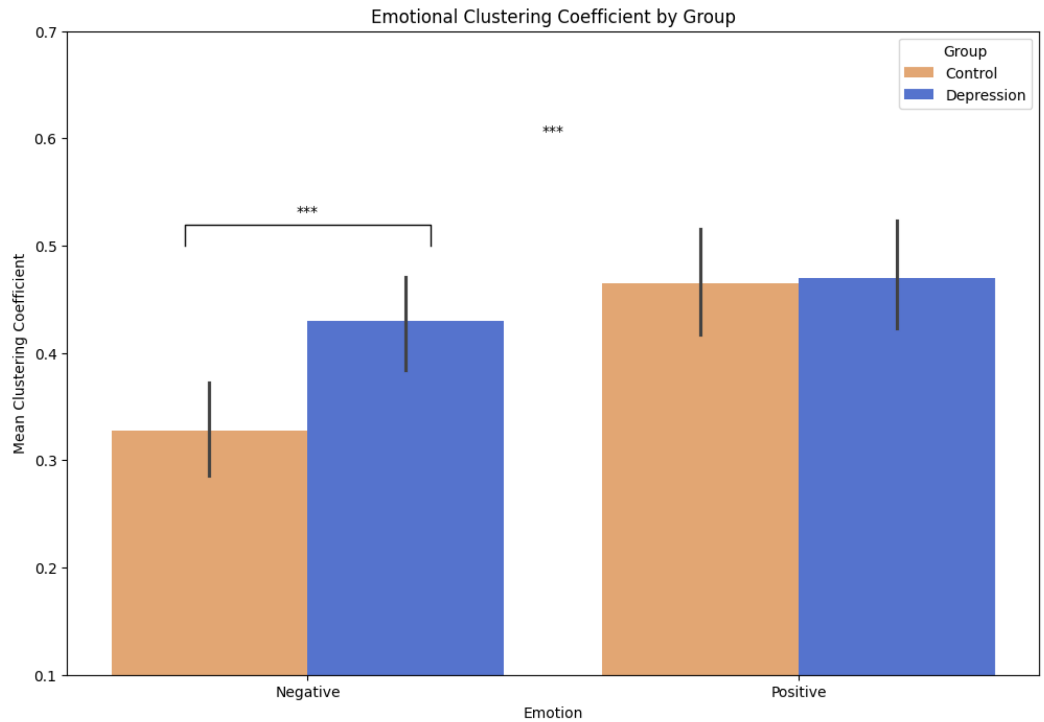


1 0 Figure 5.4 Mean modularity between control (orange) and depressed subjects (blue). Error bars represent SEM.

To further investigate the structure and organization of memory representations, network metrics were applied to memory embeddings derived from natural language processing (NLP). These metrics provide insights into how memory networks are organized based on emotional content and how these patterns differ between individuals with depression and control participants. By focusing on emotion-based and condition-based differences, we sought to determine whether individuals with depression exhibit less distinct clustering or altered connectivity in their memory networks, potentially reflecting impaired emotional differentiation or disrupted organization.

First, we examined modularity across groups. Modularity is a measure of the extent to which memories cluster into distinct communities, reflecting the degree of emotional or thematic compartmentalization in memory networks. Pairwise cosine similarity matrices were computed for memory embeddings for each participant. These matrices quantified the similarity between every pair of memories. To construct memory networks, a threshold of .6 was applied to the similarity matrices and weaker connections were set to zero. The resulting sparse networks were then represented as undirected graphs, where nodes corresponded to individual memories and edges represented connections between them. To identify clusters of memories within the networks, the Louvain method for community detection was applied. The modularity score for each participant's memory network was then calculated, reflecting the degree to which memories clustered into distinct communities.

Depressed participants exhibited lower modularity (M = .112, SD = .063) than control participants (M = .178, SD = .048), T(1,73) = 2.486, p = .001. To further investigate the changes in emotional memory communities, we analyzed the clustering coefficient for valanced memories across the groups. The main effect of emotion (Positive vs. Negative) was significant, β =0.137, SE=0.051, z=2.68, p=.007, suggesting that positive emotions were associated with higher clustering coefficients compared to negative emotions across groups. However, the main effect of group (Depression vs. Control) was not significant, β =0.102, SE=0.068S, z=1.50 p=.133, indicating no significant overall difference in clustering coefficient between the Depression and Control groups. Critically, the interaction between group and emotion was significant, β =−0.097, SE=0.07, z=−1.39, p=.164.



1 1 Figure 5.5 Mean clustering coefficient between control (orange) and depressed subjects (blue) for positive and negative memories. Error bars represent SEM.

We then examined at edge density. The main effect of emotion (Positive vs. Negative) was significant, β =0.100, SE=0.032, z=3.17, p=.002, suggesting that positive emotions were associated with higher edge density compared to negative emotions across groups. The main effect of group (Depression vs. Control) was also significant, β =0.106, SE=0.051, z=2.08, p=.038, indicating that the Depression group exhibited higher edge density compared to the Control group overall. Critically, the interaction between group and emotion was significant, β =−0.103, SE=0.043SE = 0.043, z=−2.40, p=.017, suggesting that the effect of emotion on edge density differed by condition. Specifically, the relative increase in edge density for positive emotions to negative emotions was smaller in the Depression group compared to the Control group. Positive emotions are associated with higher edge density compared to negative emotions across conditions. The Depression group exhibits higher overall edge density compared to the Control group. The significant interaction between condition and emotion indicates that the effect of emotion on edge density differs between groups. Specifically, while the Control group shows a larger increase in edge density for positive emotions relative to negative emotions, this effect is attenuated in the Depression group, suggesting weaker emotion-based clustering and reduced differentiation in edge density by emotion compared to the Control group.

Discussion

In this study, we examined the organization and structure of autobiographical memory representations in individuals with depression compared to control participants. We leveraged both self-reported measures and network analyses of memory embeddings derived from natural language processing (NLP). These data provide novel insights into how mood-disorders such as depression affect the semantic and structural organization of personal memory networks, as well as emotional composition within these networks.

Building upon previous literature, we confirmed that self-reported measures of memory recall were altered in our depression group. Participants in the depression group reported higher scores on the Beck Depression Inventory (BDI) and Rumination Response Scale (RRS), consistent with heightened depressive symptoms and tendencies to ruminate. In line with theoretical models (Williams, Carfax), depressed participants reported recalling memories more frequently than controls, particularly negative memories, suggesting that negative autobiographical memories may be more salient or accessible in depression. However, the data revealed no significant differences between groups in terms of vividness, socialness, or perspective ratings, suggesting that depression may primarily affect the emotional aspects of memory rather than more general features of memory recall.

Representational similarity analysis (RSA) of semantic embeddings of the memories revealed distinct patterns in how memories for events are organized by emotional and thematic categories. Across all participants, we confirmed our approach by showing that memories within the same category exhibited higher similarity than those across categories, indicating coherent clustering by themes. While this pattern was observed in both groups, depressed participants exhibited a reduced difference between within-category and across-category similarity scores, suggesting weaker thematic clustering. In a similar vein, an analysis of emotion-based similarity revealed that memories within the same emotional valence (e.g., positive or negative) were more similar than those across valence. However, the depression group exhibited a larger difference between within-valence and across-valence similarity, suggesting heightened emotional segmentation. These findings suggest that depression is associated with altered emotional memory organization, characterized by both reduced thematic clustering but also heightened emotional segmentation.

To further examine the structural properties of memory networks, we applied network metrics to the similarity matrices of participants' memory embeddings. Consistent with our predictions, the depression group exhibited lower modularity than controls, which indicates that these individuals may have less distinct community structures within their memory networks. This reduced modularity reflects diminished segmentation of memory networks as expected from our imposed category prompts, possibly reflecting weakened associations across large scale memory organization of autobiographical memory for individuals with depression.

Clustering coefficients revealed additional insights into emotion-based memory organization. Across all participants, positive memories exhibited higher clustering coefficients than negative memories across groups, reflecting stronger within-community cohesion for positive emotional memories. However, the depression group showed attenuated clustering of positive memories compared to controls, suggesting that emotional clustering is less robust in depression. This pattern aligns with previous findings that depression is associated with reduced positivity bias in memory recall (Everaert, Koster, & Deraksahn, 2012; Marsh et al., 2018).

Finally, edge density analyses showed that positive memories were associated with higher connectivity than negative memories across groups. However, the depression group exhibited higher overall edge density compared to controls, potentially reflecting more globally interconnected memory networks. However, the interaction between group and emotion revealed that the relative increase in edge density for positive memories compared to negative memories was smaller in the depression group. This suggests that while the depression group demonstrates globally higher connectivity, they exhibit weaker emotion-based differentiation within their memory networks.

While there is empirical basis to consider semantic similarity as a proxy for neural similarity (Lee & Chen, 2022), the current study relies on behaviorally reported text data to infer relationships between memories. In Lee and Chen, narrative networks were constructed and compared to fMRI recordings during the viewing of short video narratives. Still other work has investigated the concordance between representational similarity in neural representations and emotional memory texts in mood disorders such as PTSD (Perl et al., 2023). Given these findings, we may speculate that depression may show similar network alterations in neural representations (see Chapter 4 for discussion). In particular, we might see greater neural similarity between negative memories and overall less dissimilarity across memory associated neural activation patterns. It is, to our knowledge, the first study of its kind to investigate behaviorally derived high-dimensional representations of autobiographical memory in individuals with and without depression. Future studies are needed to provide and extend insights into the structure and organization of personal memory in neural-based measures.

Future research should investigate how these network properties relate to functional outcomes, such as problem-solving ability and emotional regulation, in depression. Additionally, integrating neuroimaging data with NLP-based network analyses could elucidate the neural mechanisms underlying these observed differences in memory organization. Longitudinal studies could also explore whether changes in memory network organization predict clinical outcomes, such as remission or relapse, providing a potential target for therapeutic intervention.

These findings advance our understanding of how depression affects the organization of autobiographical memory. The reduced modularity and attenuated emotional clustering observed in the depression group highlight disruptions in the thematic and emotional segmentation of memories in depression. These disruptions may contribute to the pervasive negative cognitive biases and ruminative thought patterns observed in depression, as less distinct memory networks could make it challenging to divert attention away from negative memories or traverse memory networks to positive ones.

References:

1. Beck, A. T., Steer, R. A., & Brown, G. (1996). *Beck Depression Inventory–II*. https://doi.org/10.1037/t00742-000
2. Brewin, C. R., Reynolds, M., & Tata, P. (1999). Autobiographical memory processes and the course of depression. *Journal of Abnormal Psychology*, *108*(3), 511–517. https://doi.org/10.1037//0021-843x.108.3.511
3. Conway, M. A., & Pleydell-Pearce, C. W. (2000). The construction of autobiographical memories in the self-memory system. *Psychological Review*, *107*(2), 261–288. https://doi.org/10.1037/0033-295x.107.2.261
4. Everaert, J., Duyck, W., & Koster, E. H. W. (2014). Attention, interpretation, and memory biases in subclinical depression: A proof-of-principle test of the combined cognitive biases hypothesis. *Emotion*, *14*(2), 331–340. https://doi.org/10.1037/a0035250
5. Lam, K., Barry, T. J., Hallford, D. J., Jimeno, M. V., Pinto, N. S., & Ricarte, J. J. (2022). Autobiographical Memory Specificity and Detailedness and Their Association with Depression in Early Adolescence. *Journal of Cognition and Development*. https://www.tandfonline.com/doi/abs/10.1080/15248372.2022.2083138

6. Lee, H., & Chen, J. (2022). Predicting memory from the network structure of naturalistic events. *Nature Communications*, *13*(1), 4235. https://doi.org/10.1038/s41467-022-31965-2
7. Levine, B., Svoboda, E., Hay, J. F., Winocur, G., & Moscovitch, M. (2002). Aging and autobiographical memory: Dissociating episodic from semantic retrieval. *Psychology and Aging*, *17*(4), 677–689.
8. Lockrow, A. W., Setton, R., Spreng, K. A. P., Sheldon, S., Turner, G. R., & Spreng, R. N. (2024). Taking stock of the past: A psychometric evaluation of the Autobiographical Interview. *Behavior Research Methods*, *56*(2), 1002–1038. https://doi.org/10.3758/s13428-023-02080-x
9. Marsh, L., Edginton, T., Conway, M., & Loveday, C. (2019). Positivity bias in past and future episodic thinking: Relationship with anxiety, depression, and retrieval-induced forgetting. *Quarterly Journal of Experimental Psychology*, *72*(3), 508–522. https://doi.org/10.1177/1747021818758620
10. Perl, O., Duek, O., Kulkarni, K. R., Gordon, C., Krystal, J. H., Levy, I., Harpaz-Rotem, I., & Schiller, D. (2023). Neural patterns differentiate traumatic from sad autobiographical memories in PTSD. *Nature Neuroscience*, *26*(12), 2226–2236. https://doi.org/10.1038/s41593-023-01483-5
11. Silva, R. de A. da, Tancini, M. B., Lage, R., Nascimento, R. L., Santana, C. M. T., Landeira-Fernandez, J., Nardi, A. E., Cheniaux, E., & Mograbi, D. C. (2021). Autobiographical Memory and Episodic Specificity Across Different Affective States in Bipolar Disorder. *Frontiers in Psychiatry*, *12*. https://doi.org/10.3389/fpsyt.2021.641221
12. Söderlund, H., Moscovitch, M., Kumar, N., Daskalakis, Z. J., Flint, A., Herrmann, N., & Levine, B. (2014). Autobiographical episodic memory in major depressive disorder. *Journal of Abnormal Psychology*, *123*(1), 51–60. https://doi.org/10.1037/a0035610

13. Tomita, T. M., Barense, M. D., & Honey, C. J. (2021). *The Similarity Structure of Real-World Memories* (p. 2021.01.28.428278). bioRxiv. https://doi.org/10.1101/2021.01.28.428278

14. Watkins, E., & Teasdale, J. D. (2001). Rumination and overgeneral memory in depression: Effects of self-focus and analytic thinking. *Journal of Abnormal Psychology*, *110*(2), 353–357. https://doi.org/10.1037/0021-843x.110.2.333

15. Williams, J. M. G., Barnhofer, T., Crane, C., Herman, D., Raes, F., Watkins, E., & Dalgleish, T. (2007). Autobiographical memory specificity and emotional disorder. *Psychological Bulletin*, *133*(1), 122–148. https://doi.org/10.1037/0033-2909.133.1.122

Chapter 6: Conclusion

This dissertation thesis investigated the mechanisms supporting the segmentation, differentiation, and representation of episodic memory. Within this framework, this thesis has interrogated questions of how the dynamics of on-going thought, such as in mind wandering, affects the encoding, retrieval, and structure of memory representations for events. Rather than addressing mind wandering as deficient attention, my line of research explores how the content of on-going thought interacts with other cognitive processes, such as memory and self-representation.

Chapter 2 attempted to tackle these questions by asking: first, how mind wandering in the moment influences the later recollection of the temporal structure of ongoing events. To do this, we sought to characterize consequences of attentional fluctuations on the formation and later recall of temporal dynamics of events. Because no such extant paradigm exists to address this question, we adapted the Sustained Attention to Response Task (SART) paradigm to give it episodic structure (e.g. the "EpiSART"). Across four experiments, we found a significant change in the slope of the response time variance time course (VTC) before versus after an event boundary. Critically, the degree to which participants redirected their focus, indexed by a reduction in the VTC, at critical time points such as event boundary (Experiment 1 and 2) or errors (Experiment 3) predicted subsequent memory for the temporal order of events.

Our findings demonstrate how mind-wandering affects our ability to remember the order of events. Salient changes in our environment (event boundaries) or noticing our mistakes (errors) can snap us out of mind-wandering and help us better attend to what comes next. These moments may act like mental bookmarks, making it easier to later recall sequences of events. Thus, by creating shifts or breaks in our activities, we could diminish mind-wandering and enhance our memory for the temporal order of events. This importance of event boundaries to "bookmark" ongoing temporal experience into segments was underscored in Chapter 3, where it was demonstrated that event boundaries disrupted temporal order memory, even when stable contexts were present. Thus, fluctuations in attention are present throughout every-day experiences and these studies sought to understand how it is attention and memory processes adapt dynamically to retain salient information that we encounter.

While this work has laid groundwork to understand the complexities of adaptive segmentation processes, they are not without limitations. In both studies, we infer the locus of attention during on-going task performance. In Chapter 2, due to concerns of interruptions of the task, we did not perform any in-task probes to identify when each subject perceived themselves to be mind-wandering. Nor in Chapter 3 were we able to confirm that attention was evenly allotted to both levels of hierarchical cues. However, the confluence of these findings suggest that event boundaries are indeed salient contextual changes that act as signals that are utilized adaptively to segment on-going experience into meaningful units.

With this base of empirical work in mind, Chapter 4 addresses a theoretical concern of attention and memory in clinical disorders. In so doing, it was a critical evaluation of evidence for the link between rumination and overgeneral memory in depression, considering the validity of the predominant model's predictions of how cognitive dysfunctions of executive control produce memory specificity deficits. In lieu of this view, I argued that a reconsideration of rumination as a form of aberrant mind wandering wherein patients become fixated on autobiographical information may affect memory specificity by acute effects through rumination's effect on cognitive and neural state to become biased towards abstract self-relevant information processing. I then address how spontaneous ruminations might alter the representation and/or organization of memory structures through persistent reactivations which decontextualize episodic autobiographical information and lead to the generalization of the memory representations.

Finally, Chapter 5 sought to investigate the organization and structure of autobiographical memory representations in individuals with depression compared to health controls. Leveraging behavioral and textual data, we were able to construct and investigate memory networks to examine how thematic and emotional memories differ between our participant groups. Individuals with depression demonstrated reduced representational similarity across semantic categories, but greater emotional clustering, suggesting that valence influences depressed memory organization above categorical or thematic organization. These results suggest that depression is associated with alterations in the semantic and emotional associative structures of personal memories. It is important to note that while NLP-based embeddings were used as proxies for neural representations, future work is needed to confirm the alignment between semantic and neural network representations..

In sum, these findings hopefully advance our understanding of how attentional dynamics, mind wandering, emotion, and mood disorders influence memory segmentation and organization. This dissertation provides a foundation for future research into how memory network and representations adapt to and with dynamics of attention, context, and emotion states.