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Moments That Matter: The Role of Emotional Stimuli at Event Boundaries in Memory

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Every edit is a lie.

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Abstract

The present study examined the impact of event segmentation and emotional arousal on long-term memory performance. Event segmentation is the cognitive process of automatically dividing experiences into smaller pieces for better consolidation and retrieval, resulting in the formation of event boundaries. Prior research has identified the crucial role of event segmentation in long-term memory and working memory. However, few studies have explored ways to enhance its effects. Emotional arousal refers to the physiological and psychological activation of the body and mind in response to an emotional stimulus. Previous research has indicated that heightened levels of arousal may enhance memory performance. The present study seeks to investigate whether this phenomenon may extend to the impact of event segmentation on memory.

In this 2 x 2 factorial study, 44 participants were exposed to a narrative TV episode containing emotionally arousing materials with varying arousal levels at different locations in the episode. The participants were subsequently tested to evaluate their ability to recognize, recall, and accurately recall the temporal order of the contents of the episode. The results indicated significant main effects of both break location and arousal level on memory, as well as a significant interaction between the two factors. The findings support the notion that event segmentation and emotionally arousing materials can enhance memory performance and suggest that high-arousal materials may amplify the effect of event segmentation on memory.

Event Segmentation

Imagine you are at a music concert. The stage is lit up with bright, flashing lights, and the atmosphere is buzzing with excitement. As you soak in the experience, the band takes the stage and begins to play. The sound of the music fills the air, and you feel your body swaying to the rhythm. You look around and see the crowd cheering and singing along. You take a deep breath and feel a rush of emotions, from excitement to happiness to pure joy.

All of these individual events and elements, from the music to the lighting to the audience, form separate episodic memories that combine to create the overall memory of the concert. Each memory is like a puzzle piece that helps you reconstruct the experience, even years later. It will be like you can almost hear the music and feel the excitement all over again just by thinking back to that amazing concert. These puzzle pieces of memory come from your segmented perception of the concert. Similarly, when people experience a day or a period of time, they experience it as multiple events instead of a single event representing the time period. Later when they recall past experiences, they are more likely to recall an event that occurred at a particular time and location. According to models of situated memory, individual event memories are considered to be the fundamental units that are stored in long-term memory. These event memories contain a variety of information about the various components of the event, such as the objects, people, actions, emotions, and spatial and temporal context (Tulving, 1972).

In order to decompose continuous external information into a number of meaningful and interrelated events to maximize memory, the human brain performs event segmentation, which allows individuals to automatically segment the information stream into chunks of information for processing (Zacks, Tversky, & Iyer, 2001). In other words, event segmentation refers to the cognitive process by which individuals perceive and organize continuous information in real-life situations. The event, as Zacks et al. defined it, is something observable that takes place at a specific location for a specific duration of time, with discernible starting and ending points for the observer. The temporal locations between the end of the previous event and the beginning of the next event are known as event boundaries. The beginning and end of Chopin's *Nocturnes Op. 9* in the concert, for instance, are event boundaries that mark the event of listening to this masterpiece.

In relevant psychological experiments, the event segmentation task is commonly utilized to investigate the processing and features of event segmentation. This task was originally proposed by Newtson (1973) and has since evolved into a mature research paradigm. The present study employed an adaptation of Newtson's event segmentation task. Such tasks typically require participants to view a short video of a daily activity event and make a key press response when they perceive a meaningful event ending and beginning of another event, thus dividing the video into meaningful activity units. Subsequently, similar experimental tasks have been introduced into text-based research, where participants were asked to mark the event boundaries between continuous events described in narrative texts (Li & He, 2009). Through the event segmentation task, researchers can understand participants' judgment of event boundaries, measure their structural perception of complex events, and explore the underlying regularities.

After determining event boundaries through the event segmentation task, researchers can further investigate how the appearance of event boundaries affects an individual's processing and cognitive performance by comparing the differences in brain activity, visual attention, memory, and other factors at locations near event boundaries versus locations without event boundaries.

Researchers also use changes in temporal and spatial dimensions contained in short films or text materials as event boundaries to investigate individual cognitive characteristics in these aspects. Some studies in this branch refer to the appearance of event boundaries as an “event shift.” In recent years, as VR technology has continuously advanced, researchers have aimed to replicate experimental procedures that require participant involvement. They have explored the impact of event transitions on individual memory by using spatial updates as event boundaries, which is a more realistic approach to real-life scenarios (Serrano et al., 2017; Carlos, 2018).

The concept of event segmentation was originally proposed to describe how individuals perceive real-life events. However, when researchers began to explore the process of event segmentation, they initially approached it from the perspective of text reading. As a result, theoretical models that had been developed to explain text-reading processes were used to understand the mechanism of event segmentation.

Models of Event Segmentation

Segmenting events and remembering them based on the segmentation is a crucial cognitive skill that enables individuals to comprehend and remember complex experiences effectively. In 1978, Kintsch and Van Dijk introduced the concept of a situation model to explain how readers create different mental pictures of the different situations described in narrative texts. Researchers have since used this idea to develop theoretical models for studying event segmentation. The most widely accepted model in the present days is the event segmentation theory, which proposes that people divide ongoing activities into smaller, more manageable units based on perceptual information and past experiences. While related, the situation model and event segmentation theory differ in their focus, with the former emphasizing mental representations of events and the latter on the division of ongoing experiences into distinct events.

Situation Model

Kintsch and Van Dijk (1978) proposed the situation model to explain the text-reading process. This model posits that readers construct a representation of the situation described in the text and was divided into two models: the event model, which represents the single spatiotemporal structure of situations and the structural relationships among them, and the episode model, which represents the combination of a series of event states. Researchers have altered their perspective on the text-reading process over time, as the introduction of the situation model prompted a shift away from constructing and extracting cognitive representations of the discourse, towards constructing and extracting a discourse description of the context. In essence, readers extract pertinent details from the text in order to create a mental model of the situation depicted, which facilitates comprehension of the overall context and the connections between various pieces of information.

This perspective has been adopted in the study of event segmentation, and researchers have used it to develop theoretical models of the cognitive processes involved in the segmentation of events (Zacks et al., 2009; Magliano et al., 2014; Van Dijk, 2015). Specifically, they have focused on the cognitive representations that individuals construct of the events they perceive and how these representations are influenced by contextual information. The application of this approach has led to a better understanding of the mechanisms that underlie event segmentation and has enabled researchers to develop new experimental paradigms for studying this phenomenon. As event segmentation, the situation model requires constant updates as new information is acquired during text-reading for readers to apply the model to a current situation (Morrow, Bower, & Greenspan, 1989). The event-indexing model examined and explained the updating process of situation models by introducing dimensions of information (spatial, temporal, causal, role intention, and entity) for observers to track the updates. Researchers found that the updating of the situation model means that individuals decompose the big event into a series of smaller events based on dimensional changes during reading, where the perceived dimensional changes are the boundaries of the events described in the text (Zwaan, Langston, & Graesser, 1995).

Event Segmentation Theory

Later, researchers developed event segmentation theory (EST), which directly describes the process of event segmentation of continuous daily activities. This theory is predominant in literature in the field of event segmentation. According to the event segmentation theory, individuals divide ongoing activities into smaller and more manageable units called event models. This is done based on the multichannel perceptual information they receive, as well as the empirical schema that stores the characteristics of past events. These schemas can cover time scales ranging from seconds to tens of minutes, and it is possible for coarse and fine time scales to exist simultaneously across events (Radvansky & Zacks, 2011; Zacks et al., 2007).

An event model is a perceptual representation activated by an individual in working memory. It stores information about the current event in progress, which guides the perception of input information and helps the individual to predict future events. In most cases, the event model is stable, and the individual, as an observer, integrates the continuous input into an event. However, when the perceptual input is inconsistent with the individual's expectation and the prediction becomes more difficult, the individual's sensitivity to the input is temporarily increased in order to reestablish the event model. In other words, event segmentation happens when an individual's prediction error surpasses a certain threshold. Later when the prediction becomes stable, the event model also stabilizes again. During this time, the unpredictable course of change between events is namely the event boundary that the individual perceives.

Compared with the situation model, the EST is based on individuals' perceptions of real-life events, describes the process of constructing and extracting event representations in more detail, and provides an in-depth analysis of the mechanisms related to memory encoding and consolidation. EST suggests that event segmentation is a spontaneous process that does not require attentional involvement (Zacks, Braver, et al., 2001; Zacks & Tversky, 2001) and involves perceptual representations that integrate multiple channels of information input. In essence, this mechanism is a cognitive control process that works in conjunction with covert attention. It involves the cognitive system making decisions about whether to allocate additional attentional resources to the ongoing perceptual processing and update working memory in response to changes in information. Then, it completes the event segmentation process under the influence of sensory input and past knowledge.

Event segmentation is a crucial cognitive ability that can benefit individuals in multiple ways. Enhancing their event segmentation skills not only improves their memory but also helps them overcome specific cognitive deficits such as Alzheimer's disease and schizophrenia spectrum disorders (Richmond, Gold, & Zacks, 2017; Radvansky, 2017). A neuroimaging study conducted by Lee et al. (2013) revealed that an individual's event segmentation ability can be predicted by the volume of gray matter in the inferior frontal gyrus. This region has been found to be associated with aggressive behavior in schizophrenia spectrum disorders (Schoretsanitis et al., 2019).

To conclude, situation models and event segmentation theory are both cognitive frameworks that help us understand how people comprehend and remember complex events, but they differ in some functional ways. Situation models refer to mental representations of situations that are created and updated as people process information from text, discourse, or other sources. It is essentially a mental simulation of the events being described, including information about the physical environment, characters, actions, and goals. They allow people to form a coherent understanding of the events they are reading or experiencing and to make predictions about what might happen next or what could have happened if things had gone differently. For example, in the concert we mentioned, the audience could utilize the situation model to predict a round of applause based on the previous beautiful performance of the orchestra and stimulate mental representations based on their predictions. The event segmentation theory proposes that individuals parse continuous experiences into discrete events or chunks. This segmentation process relies on both perceptual cues, like visual or audio inputs, and conceptual cues, such as goals or intentions, to identify and extract meaningful units. For instance, as a result of the audience's knowledge of the Playlist and their personal experience, the audience may naturally segment a concert into different pieces and intermissions. This enables them to recall specific pieces of music when asked, instead of trying to remember the entire 3-hour performance at once. The process of event segmentation suggests that these resulting units are stored in memory as individual events, which can later be accessed to inform behavior or recollect past experiences.

In short, situation models are primarily concerned with how individuals form mental representations and predictions of events, while event segmentation theory is focused on how individuals parse ongoing experiences into distinct events. Despite the opposing directions of these two concepts, they are interconnected, as situation models are often constructed from the segmented events that individuals experience.

Processing of Event Segmentation

Top-down and bottom-up processing are two cognitive processes that play important roles in how individuals perceive and segment events. Bottom-up processing involves changes in sensory characteristics that serve as the basis for the individual perception of event boundaries. For example, during a concert, the audience may distinguish different sections based on the various sounds they hear, such as music, applause, or the accidental ringing of a phone. Top-down processing, on the other hand, allows individuals to perform event segmentation with specific goals or targets in mind, which can significantly impact the outcome of the segmentation process.

Newtson's (1973) seminal research on event perception has provided valuable insights into how individuals parse and segment continuous streams of information into discrete events. In his study, participants were shown brief films and were asked to identify event boundaries. Newtson discovered that people typically identified changes in motion as event boundaries, with the point in time when the character's movement changed most being perceived as the boundary between events. Moreover, Newtson's findings were consistent across all experimental conditions, suggesting that changes in motion information are closely related to the individual's decision to determine event boundaries. Further research has investigated the neurological underpinnings of event segmentation. It has been noted that the brain areas most activated at event boundaries are those involved in the visual processing of motion information. Using fMRI, Zacks (2004) and colleagues (Zacks et al., 2006) found that the activation of these areas increased not only with the speed of object motion but also at event boundaries. This suggests that the processing of motion information is important for perceiving event boundaries and that there are specialized brain regions that process motion and target features to recognize changes in these features and identify event boundaries.

In addition to motion information, other sensory cues, such as sound and visual features, are also important in event segmentation. Hard, Tversky, and Lang (2006) conducted a series of studies involving visual and auditory stimuli and discovered that individuals consistently segmented events at similar boundaries, regardless of various factors such as the direction of the clip, their familiarity with the content, or their perception of the actions in the clips as intentional or unintentional. These studies suggest that top-down processes play a critical role in event segmentation. While sensory information provides important cues for identifying event boundaries, cognitive processes such as memory, attention, and expectations also influence event segmentation.The consistent segmentation points observed in previous research provided the current study with the rationale to employ video material and investigate the memory effects utilizing event boundaries that were previously identified and studied by Boltz in 1992. In her study, participants watched a video clip and were asked to identify the event boundaries within it.

A study by Zacks et al. (2001) has demonstrated that event segmentations follow a hierarchical structure whereby larger event units can be further divided into smaller events. This finding implies that people rely on higher-level cognitive processes to comprehend events and their constituent parts. However, the level of familiarity with the event content can also impact event segmentation. When individuals are unfamiliar with the content, they tend to segment events into smaller units, as revealed in a study by Hard et al. (2006). In contrast, when individuals are familiar with the content, they make finer distinctions in their judgments and are more likely to rely on other sources of information to comprehend changes in perceptual features during the development of events. This highlights the important role of top-down processing in event segmentation and suggests that individuals' knowledge and experience play a critical role in shaping their perceptual experiences.

Studies in text reading support the importance of conceptual feature information that relies on top-down processing in event segmentation. For instance, a study using reading events in texts as an experimental task found that brain activation associated with event boundaries in text showed similar activation patterns in temporal and spatial dimensions to those seen when watching short clips of everyday life. The spatial dimensional features of the narrative text significantly influence the brain activation processes of individuals perceiving event boundaries (Speer, Zacks, & Reynolds, 2007).

Other virtual space studies have shown that updates of spatial locations cause event segmentations (Radvansky & Copeland, 2006; Radvansky et al., 2010; Radvansky et al., 2011; Radvansky et al., 2015). Changes in perceptual information about the surroundings are not treated as event boundaries per se and are less likely to result in event segmentation. Event segmentation only occurs when individuals make further judgments of categorical change based on changes in perceptual information (Pettijohn & Radvansky, 2016). Recent studies using video clips as experimental material have also supported the significant role of conceptual feature information. Gupta and Gurrin (2018) found that segmentation of first-view lifelogs, which is a personal record of one's daily life in a varying amount of detail, using data processing methods based on image classification and visual concepts provided more high-level semantic concepts reflecting differences in individual activities, leading to event segmentations more similar to those of real users. Additionally, segmentation results for the same event content are not particularly affected by the observation perspective, which suggests that segmentation can be partially separated from visual input (Swallow, Kemp, & Candan, 2018).

Further, observers' expectations of events can also influence event segmentation. Massad, Hubbard, and Newtson (1979) provided subjects with different background information before asking them to perform event segmentation tasks and found that participants who received different information showed different patterns in their segmentation results, suggesting that observers' prior knowledge affects the process of event segmentation. Bailey et al. (2017) asked subjects to segment a text into a series of events after reading it. They found that when changes in the dimension of characters or spatial locations in the text occurred, subjects tended to segment the text information according to the instruction to pay attention to the dimensional change they were directed to pay attention to. These studies indicate that top-down processing, guided by observers' perceptual goals, plays an important role in shaping the outcome of event segmentation, as individuals with clear goals tend to selectively attend to event information that is relevant to their goals.

Memory

Structure of Memory

Events are experienced not only in the present but also in memory. Atkinson and Shiffrin (1968) proposed similar typical three-level models of processing memory information, consisting mainly of sensory memory, short-term memory, and long-term memory. Among them, long-term memory includes declarative memory (episodic memory) and non-declarative memory (implicit memory). Declarative memory can be further divided into situational memory and semantic memory. Notably, non-declarative memory involves emotional learning, priming effects, and non-associative learning, and some sensory memory content can directly enter long-term memory.

The concept of situational memory, originally introduced by Tulving and Donaldson (1972), can be extended to highlight how events are experienced both in the moment and in memory. This can be further developed by exploring how events are segmented and how these segmentations can affect memory and emotions. Thus, rather than solely focusing on the encoding and storage of time-specific situations or events and their temporal-spatial relationships, a more nuanced understanding can be achieved by considering the intricate interplay among situational memory, event segmentation, and emotions. Semantic memory is the memory necessary for the use of language, which includes a mental lexicon of words, their meanings and referents, connections between them, and organized knowledge about rules, formulas, and algorithms for manipulating these symbols, concepts, and relationships (Saumier & Chertkow, 2002). Thus, while situational memory is concerned with events that occurred at a particular time, semantic memory involves abstract things like words and concepts.

Emotional memory is distinct from other forms such as situational and semantic memory. It is responsible for the storage of information related to the emotional significance of past events. The encoding and consolidation of emotional memories involve the activation of different brain regions, such as the amygdala and hippocampus, which are responsible for processing and integrating emotional information into long-term memory (LaBar & Cabeza, 2006; Cahill et al., 1995). Research has demonstrated that emotional memory can have both positive and negative effects on an individual's well-being (Bradley, 2014; LeDoux, 2007). For instance, the experience of positive emotions such as happiness and joy can enhance the encoding and consolidation of positive memories, which can lead to greater life satisfaction and subjective well-being. In contrast, the experience of negative emotions such as fear and anxiety can lead to the encoding and consolidation initially introduced, which can result in the development of psychological disorders such as post-traumatic stress disorder (PTSD) (Durand et al., 2019). The storage and retrieval of emotional memories are influenced by various factors, such as the intensity and valence of the emotion, the timing of the emotional event, and the individual's cognitive and emotional state at the time of encoding and retrieval. For example, research has shown that memories associated with high levels of emotional arousal tend to be better remembered than memories associated with low levels of arousal (Costanzi et al., 2019). Additionally, Palombo et al. (2021) found that emotional memories tend to be better remembered when the emotional event occurs at the beginning or end of an experience rather than in the middle. This suggests that event segmentation may play a role in the encoding and retrieval of emotional memories, as the boundaries of emotional events may be more salient and distinct.

Semantic memory (SM) and episodic memory (EM) both belong to the category of declarative memory. Semantic memory is the basis for knowledge and concept learning and is necessary for the work of any cognitive system. Episodic memory stores personal experiences based on the importance of events aided by semantic memory, and it, in turn, also aids the work of semantic memory (Greenberg & Verfaellie, 2010; Horzyk et al., 2017; Mueller & Shiffrin, 2006). LeDoux (2007) also suggests that emotional arousal tends to enhance memory, particularly for EMs associated with emotional experiences, which is the memory type the current study is focusing on. Emotional memory (or affective memory) can be either implicit (unconscious) or episodic (conscious). In laboratory studies on animals, implicit emotional memory has been demonstrated through phenomena such as fear conditioning and "freezing behavior," which stands for animals' remaining motionless when encountering natural enemies (Yu et al., 2022).

Episodic emotional memory manifests itself as a re-experiencing of the original emotion produced by an individual in response to an event. Evidence from fMRI studies suggests that the encoding process of emotional memory is centered on the amygdala in the subcortical part of the limbic system, specifically on adrenergic and dopaminergic mechanisms. For instance, a person with a damaged amygdala may calmly recall the details of a traumatic event without displaying any related fears associated with that event (Damis, 2022). In contrast, the encoding of episodic emotional memory involves cortical areas of the limbic system, such as the hippocampus (Anderson & Floresco, 2022; Rolls, 2022).

Another important element when talking about emotional memory is priming. Priming was originally defined as a technique for studying the effects on test performance in test contexts, that is, testing the individual's effects on the manipulation of a subsequently presented target stimulus in the context of a first-presented priming stimulus (Schacter & Buckner, 1998; Kuzyakov et al., 2000). This paradigm is often referred to as the priming paradigm. The initiation paradigm was gradually applied to the study of emotions, and it developed into a classic emotion initiation study (Beatty et al., 2016). The affective priming effect has various meanings, one of which is that an individual's emotional state is seen as a priming state that can influence their cognitive activity. This effect is associated with the enhancement of memory storage and retrieval by emotional stimuli, forming the foundation for emotional memories.

Examining theories that combine emotion and memory can enhance our understanding of their relationship. For instance, Bower's (1981) joint-semantic network model originated from the conceptual network theory of memory, which refers to the fact that the brain typically stores memories in clusters called nodes and links them to other memories that are associated with them. In the network theory, nodes represent concepts or events. In Bower's model, he introduced emotional nodes which form propositions when they are interconnected. A proposition refers to a unit of meaning that links two or more nodes in the semantic network. It is a statement about the relationship between concepts or events. People's basic emotions, such as happiness or fear, are directly represented as nodes in memory. Other more complicated emotions, such as disappointment and contentment, result from the simultaneous activation of nodes for several basic emotions. For example, disappointment may be a mixture of sadness and surprise. In this model, there are different types of nodes for emotional states: nodes representing propositions that elicit emotions and nodes for the associated arousal and expressive behavior patterns, which are interconnected within the network. These emotional nodes, like other regular nodes, can release and receive activation and have varying strengths of connection with each other. When a certain aspect of an event is activated, the activation of a pattern of nodes can trigger the activation of a specific emotion. Similarly, the activation of emotions can activate relevant event nodes. Based on the network model, Bower proposed that different emotions trigger the retrieval of different event memories, and memory activation can activate emotions just like activating concepts. If the emotional state during recall matches the emotional state during encoding, recall becomes easier (Bower et al., 1978).

Bower’s theory can also explain mood-congruent experiences: when emotion is induced, it activates the corresponding emotion node, which strengthens the connection between other nodes and propositions representing this emotion and event, making it easier to extract information related to the emotion.

In summary, there are several types of memory, each with its unique characteristics and functions. Situational memory pertains to the storage and retrieval of information about specific events, while semantic memory is essential for language use, learning, and general knowledge. Emotional memory involves the retention of information about the emotional significance of past events, which can be either implicit or episodic. Autobiographical memory combines situational and semantic memory, representing a memory system that defines one's existence and purpose in the world. The recall of events is influenced by various factors, such as event segmentation and emotional arousal. By understanding these different types of memory, we can gain insight into how they may be influenced by different factors, leading to a better understanding of memory processing in general.

Memory Effects Related to Event Segmentation

Event boundaries play a crucial role in an individual's episodic memory of the overall event, as they can help people understand and recall the content of the event. The current study focuses on investigating the effects event boundary has on long-term memory (LTM), yet there are plenty of studies looking at its effect on working memory (Kurby & Zacks, 2008; Radvansky, 2017; Guerin-Dugue et al., 2018; Jafarpour et al., 2022).

Improvement

In terms of LTMs, in multiple studies, researchers have found that people have better memory for information at event boundaries, which are moments of transition between different segments of an event. For example, in a study by Newtson and Engquist (1976), participants were better able to recall event boundary information in short film materials. Recall analyses have also shown that people provide more detailed and richer descriptions of information at event boundaries than at non-event boundaries (Schwan & Garsoffky, 2004).

Another study by Swallow et al. (2011) asked participants to complete a test of item memory while watching a short video. They found that if an item appeared in the previous event, the subjects' performance on retrieval was poor; however, if the item was an item that appeared at the event boundary or in the current event, the subjects' recollection performance was better. Additionally, differentiating the test into sensory and conceptual recognition of test items, the study found that the acquisition of perceptual information depended on whether the test item was present in the center of the subject's gaze, whereas the recognition of conceptual information was not affected by gazing. Researchers have also found that people may increase their attention at event boundaries to adapt to new events, and that this modulation of attention is responsible for individuals' ability to acquire more information at event boundaries (during memory encoding) so that conceptual information at boundaries is more easily accessible than perceptual information (Swallow et al., 2009).

The event boundary plays an important role in long-term memory for the overall event. For example, a study by Pettijohn et al. (2016) examined the effects of event segmentation on memory using different types of materials and forms of event boundaries. The study found that the presence of event boundaries was associated with better recall performance than the absence of event boundaries and that the higher the number of event boundaries, the better the recall performance. Later, a study by Wahlheim and Zacks (2019) found that if participants watched two clips with similar content consecutively, they were unable to recall the details when comparing the differences in the details of the clips. However, if they watched the second clip after an interval, they had relatively less difficulty in recalling the details, marking the enhanced long-term memory after event segmentation. Further, a study by Schwan, Garsoffky, and Hesse (2000) found that for the same short film, removing some non-boundary content did not affect participants' recall scores of the content of the film, but removing some boundary content of the film's event led to a decrease in recall scores. Recent studies have also shown that infants exhibit better recognition scores for objects inserted at the event boundaries of animated films, and inserting blank segments at the event boundaries is more likely to cause interference with memory than at non-event boundaries (Sonne, Kingo, & Krøjgaard, 2016, 2017). This suggests that information at event boundaries promotes individual memory for target material and helps individuals encode and retrieve event content. As the increase of changes in dimensions such as time, place, and characters in video material, individuals' recognition scores for time points near the changes also improve (Huff, Meitz, & Papenmeier, 2014).

In conclusion, event boundaries have been found to play a crucial role in individuals' ability to understand and recall the content of an event. Multiple studies have shown that people have better memory for information at event boundaries, which are moments of transition between different segments of an event. The cognitive process of event segmentation helps to break up ongoing experiences into smaller units for better encoding and retrieval, making information at event boundaries more distinctive and easier to remember. This effect is linked to attention modulation, which plays an important role in this process. Moreover, information at event boundaries tends to be thematically coherent, which further facilitates memory retrieval. Other studies have demonstrated that event segmentation has implications for working memory and recognition performance, as well as the acquisition of perceptual and conceptual information.

Impairment

Researchers have investigated the effects of event boundaries on memory using various methodologies and materials. However, there are mixed findings in the literature that suggest that the relationship between event boundaries and memory is complex and multifaceted.

It has been found that experiencing event boundaries may interfere with an individual's memory of the previous event. Radvansky et al. (2006, 2010, 2011, 2015) designed a series of studies using virtual reality technology to explore the effects of spatial place updating as an event transition on participants' working memory. Subjects were asked to control a character walking around a virtual space in front of a computer and picking up an item from one table to put it down at another table. The locations for the two tables were either updated or not. In the non-updated condition, the two tables were in the same room; in the updated condition, the two tables were set in two adjacent rooms, and the character had to walk through a door to reach the other room. When the subjects walked through the door or walked the same distance in the same room, they were asked to make judgments about the objects they were holding or had just put down, and the program recorded their correctness and reaction time.

The results of the studies showed that moving between two rooms was more likely to induce forgetting of information about the currently processed item or vocabulary than moving within the same room, confirming that updating spatial locations can cause event segmentation and thus affect individuals' short-term memory (Radvansky & Copeland, 2006; Radvansky et al., 2010). The researchers referred to this as the location-updating effect. Subsequently, Radvansky et al. (2011) conducted experiments using both a less immersive virtual environment and a realistic environment and found consistent spatial location-updating effects in both conditions. Individuals showed slower responses and lower accuracy when recalling objects from the previous spatial exposure, regardless of whether the door they walked through was virtual or real (Radvansky et al., 2011). This is consistent with Swallow et al.'s (2009) test of item memory in short videos, in which individuals showed poorer recall of information that appeared in the previous event compared to the current event or event boundary.

The presence of event boundaries may also weaken the association between preceding and following events. Ezzyat and Davachi (2011) asked subjects to memorize a piece of textual material and gave a sentence as a cue to recall the next sentence during the test, and found that if there was an event boundary between the two sentences, memory performance was worse than if the two sentences belonged to the same event. In a study by Thompson and Radvansky (2016), subjects were asked to read textual material in which two sentences referred to the same thing in succession. Similarly, if the subjects read textual material with an event transition, they took more time to respond when recalling the sentence before the transition (Pettijohn & Radvansky, 2016).

In another study, researchers asked subjects to take a memory test on the temporal order of items in each room after walking through a series of rooms in a virtual reality space and found that after being presented with an item, subjects were more likely to recall items that appeared adjacent to it in the same room, and showed difficulty recalling objects in the previous or next room (Horner et al., 2016). These findings suggest that event boundaries weaken memory for connections between adjacent events and may shape the affected structure of long-term memory. In addition, it has been further found that experiencing event boundaries causes individuals to remember more fearful emotional information while more conceptually relevant information is forgotten, suggesting that event boundaries may influence the selective integration of memory information (Dunsmoor et al., 2018).

In order to provide a comprehensive understanding of the mixed findings in empirical studies concerning event segmentation and memory performance, it is necessary to delve deeper into the specific methodologies utilized in each study. Several studies have employed visual media, such as videos or films, as stimuli (Speer et al., 2003; Zacks et al., 2009), while others have utilized virtual reality technology (Carlos et al., 2018). These studies have reported a reduction in the performance of short-term memory before event boundaries following event segmentation.

On the other hand, some studies have employed textual materials as stimuli, such as Li & He (2009) and Dubrow & Davachi (2016), and they have observed an increase in the effect of boundaries on event memory. These discrepancies in findings can be attributed to the varying methods employed in these studies. For instance, the differences in sensory modalities may have a significant impact on the perception of event boundaries and memory performance, with visual media being more effective at facilitating boundary segmentation compared to textual materials.

Additionally, other studies have used computer-based tasks as stimuli, similar to those utilizing video materials (Radvansky & Copeland, 2006; Radvansky et al., 2010; Radvansky et al., 2015), and they have also found memory impairment in locations prior to event boundaries. These findings suggest that event segmentation is a complex process, and different stimuli and task designs can have varying effects on the perception of event boundaries and memory performance. Further, some studies have manipulated event boundaries by inserting blank segments or removing non-boundary content (Kosie & Baldwin, 2019), while others have used more naturalistic event transitions to avoid the effect of attention (Zacks et al., 2001). Manipulations in stimuli and task designs can significantly impact the perception of event boundaries, as attention plays a crucial role in conscious event segmentation. Research has shown that attentional mechanisms are responsible for identifying and selecting relevant information from the sensory input to create meaningful perceptual experiences. Therefore, any changes in the stimuli or task design can alter the attentional focus of the participant, which can ultimately affect the perception of event boundaries. Moreover, attentional mechanisms are closely linked to memory processes, and it has been suggested that the ability to maintain attention and selectively process information can enhance memory performance. Hence, any alterations in attentional focus induced by the manipulations in stimuli or task designs can also have a downstream impact on memory performance.

Another factor that may contribute to the mixed findings is the theoretical inconsistencies regarding the mechanisms underlying the effects of event boundaries on memory. Some researchers have proposed that the attentional modulation at event boundaries may be responsible for the enhanced memory performance (Kosie & Baldwin, 2019), while others have suggested that the change in context and the organization of information at event boundaries and the update of event model may promote better memory consolidation (Zacks et al., 2001, 2006). These different theoretical perspectives may have different implications for the design and interpretation of experiments, which may contribute to the mixed findings in the studies.

Despite the mixed findings, some consistent patterns have emerged from the literature. For example, studies have consistently found that people have better memory for information at event boundaries and that they provide more detailed and richer descriptions of information at event boundaries than at non-event boundaries (Newston, 1976; Zacks et al., 2009; Kosie & Baldwin, 2019). The complex relationship between event boundaries and memory highlights the importance of investigating this topic using various methodologies and materials and taking into account the different theoretical perspectives underlying the effects of event boundaries on different types of memory. By examining the underlying mechanisms and the boundary conditions that influence memory performance, researchers can gain a better understanding of the cognitive and neural processes of the perception and memory of events.

Emotion

Emotion is a multifaceted construct that has been studied by psychologists for decades. Despite the absence of a universally accepted definition of emotion, it is generally acknowledged as a psychological phenomenon that is characterized by subjective experiences, physiological responses, and behavioral expressions. According to Cabanac (2002), emotion is a complex mental state that results from a combination of these factors, and it is typically triggered by internal or external stimuli, which are subjectively experienced by the individual.

Emotions can be positive or negative, and they can vary in intensity and duration. Some examples of emotions include happiness, sadness, anger, fear, and disgust. For many years, researchers have focused on the categorical approach to emotion, which identifies distinct categories of emotions. However, in recent years, researchers have shifted their attention towards a dimensional view of emotion, which breaks down emotions into two separate dimensions: valence and arousal (Niemic, 2004). Valence refers to the positive or negative quality of an emotion, while arousal refers to the intensity or activation level of an emotion. Emotions can be plotted along these two dimensions to create a two-dimensional space, which can help to identify different emotional states. For example, emotions such as happiness and contentment can be high in valence and low in arousal, while emotions such as fear and anger are high in both valence and arousal. The dimensional view of emotion has been found to have important implications for our understanding of the relationship between emotion and memory.

Research has shown that both valence and arousal can have separate and distinct effects on memory. For example, studies have found that positive emotional states can enhance memory for information that is presented during that emotional state, whereas negative emotional states can impair memory (Kensinger & Corkin, 2003). Similarly, high arousal states have been found to enhance memory for emotionally arousing information, whereas low arousal states can impair memory for similar types of information (Hamann, 2001). The present study aims to investigate the influence of emotional arousal on event segmentation and memory. However, it is worth noting that there is a considerable body of literature exploring the impact of emotional valence on memory (Gomes et al., 2013; Choi et al., 2017; Bowen et al., 2018; Kim et al., 2020).

Memory Effects Related to Arousal Levels

During our discussion in earlier sections, we explored the various effects that event boundaries may have on memory. However, it is important to note that arousal levels have also been found to impact an individual's memory in some capacity.

Selective attention and preferential processing of emotional information are the main reasons that influence the process of memory encoding (Gazzaley & Nobre, 2012). Research has consistently demonstrated that emotional events are more effectively remembered than neutral ones. Moreover, a multitude of studies has highlighted that the presentation of emotionally arousing stimuli enhances the recall of central information but inhibits the recall of peripheral information, as compared to neutral stimuli. An instance of such an effect is the weapon focus effect, in which crime witnesses recall the weapon in detail but are unable to remember other crucial information, such as the offender's clothing or vehicle (Hope & Wright, 2007). Furthermore, research suggests that emotional information is processed more easily when attention is constrained (Monk et al., 2003, 2008).

Further to the discussed effects on the encoding stage, it is worth noting that emotional arousal has been observed to increase the probability of consolidating memories, primarily through the delayed effects of emotional arousal (LaBar & Cabeza, 2006; Marchewka et al., 2016). These studies highlight the critical role of emotional arousal in memory consolidation, where the process of strengthening newly formed memories in long-term storage can help to stabilize and integrate new information into existing knowledge structures in the brain, thereby enhancing the long-term memory of emotional events (McGaugh, 2018). Several studies have indicated that memories associated with neutral stimuli are more likely to fade over time in comparison to memories that involve arousing stimuli, which are likely to remain stable or even improve (Sharot & Phelps, 2004). Others have found that memory for emotional information is enhanced more strongly after longer delays than relatively short ones. This delay effect is consistent with the idea that emotionally evoked memories are more likely to be consolidated into relatively permanent traces. In contrast, memories of non-evoked events are more likely to be forgotten. Some studies have even found that emotionally evoked stimuli enhance memory only after a period of time (e.g., the memory of 3 electric shocks was enhanced after a 2-min experiment block in Mather & Sutherland, 2011). The explanation for the delayed effect of emotional arousal is mainly around the post-stimulus refinement hypothesis, and the process of such refinement processing can be either autobiographical or semantic (Cooper et al., 2003).

The main effect of emotion on the memory retrieval process is the context effect of emotion on memory (Riegel et al., 2016). The context effect refers to the similarity of the emotional dimension between the encoding and retrieval contexts of memory, which is manifested in two central similar but slightly different effects, namely, the emotional consistency effect and the emotional state-dependent retrieval. The emotional consistency effect refers to the ease of retrieval when the emotional content of memory information is the same as the current emotional state; the emotional state-dependent retrieval is a type of context-dependent memory in which the information is extracted more effectively when the emotional state at the time of retrieval is similar to the state at the time of encoding (Leon et al., 2010).

The effect of emotional arousal is mostly found to be related to long-term memory. In the study by Kensinger and Corkin (2003), the researchers specifically investigated the effect of negative emotional content on memory. They found that negative emotional content had a selective effect on long-term memory by only enhancing memory for negative stimuli. However, there was no effect of emotional content found on working memory, which involves the temporary storage and manipulation of information.These findings suggest that the impact of emotional arousal on memory may be selective, depending on the type of memory being examined. The study also found that the effect of emotional content on memory was stronger for women than for men, suggesting that gender may play a role in the processing of emotional information. The results suggest that negative emotional content may have a particularly strong impact on long-term memory, which may have implications for the study of emotional disorders, trauma, and other aspects of emotional processing. Although working memory may not be directly related to emotional memory's encoding and retrieval, it may be affected by emotionally arousing materials due to their attention-grabbing natures and affect the binding between emotions and information within episodic memory (Phelps & Sharot, 2008). In the framework of binding between emotion and memory, studies have provided evidence supporting the idea that emotionally arousing objects draw attention and strengthen the binding of their individual features. Mather and Nesmith (2007) conducted a four-experiment study to investigate the effect of emotional arousal on location memory for pictures. Their results showed that participants were more likely to remember the locations of positive and negative arousing pictures compared to non-arousing pictures, suggesting better binding of the location to the picture. The arousal-enhanced binding effect did not have a negative impact on the binding of adjacent pictures to their locations. According to the study, emotional arousal can enhance the connection between the content of an arousing picture and its location without disrupting the link between nearby pictures and their respective locations. Moreover, the positive effect of arousal on the binding of picture-location memory is not solely attributed to improved memory for the picture, as this phenomenon persists regardless of the quality of recognition memory.

Neurobiological Underpinning of Memory Effects Related To Arousal Levels

Neurobiological investigations concerning the interplay between emotions and memory mechanisms in the brain are primarily centered on two memory systems located in the medial temporal lobe: the amygdala and the hippocampus. Of the two, the amygdala is the most crucial brain structure for emotional memory and is considered the core component of the entire emotional memory neural network. Conventionally, the amygdala's role in emotional memory has been limited to the encoding and consolidation stages. During the encoding stage, the amygdala generates the initial memory representation when an individual experiences an emotional event. Following the event's conclusion, the consolidation stage continues to influence the memory representation, and the impact of emotion on memory continues to intensify with time until the end of the consolidation stage (Hamann, 2001).

The enhancement of memory due to high arousal levels can be attributed to the fact that it triggers the release of stress hormones such as adrenaline, which can enhance memory consolidation (Pare, 2003). In 2017, Li et al. delved into the intricate neurobiological processes underlying the influence of emotional arousal on memory consolidation. The consolidation of memories refers to the process by which information is transferred from short-term to long-term memory, a critical component of learning and the formation of new memories. To better understand the neurobiological mechanisms underlying this phenomenon, Li et al. examined the role of the amygdala, which is responsible for detecting and responding to emotional stimuli, triggering a cascade of neurochemical changes that can influence various aspects of memory consolidation.

One mechanism by which emotional arousal enhances memory consolidation is through the release of adrenal stress hormones, such as cortisol and adrenaline. These hormones are released in response to stress, activating the amygdala and facilitating the consolidation of long-term memories. This process has been shown to be particularly effective for emotional memories, as the activation of the amygdala enhances the consolidation of memories associated with intense emotional experiences. Li et al. also found the release of Norepinephrine (NE) within the amygdala played a critical role in the consolidation of emotional memories. NE is a neurotransmitter that has been linked to a wide range of cognitive and emotional processes, including attention, motivation, and arousal (Marty et al., 2015). The activation of NE in the amygdala has been shown to enhance the consolidation of emotionally-charged memories while also modulating the strength and quality of these memories.

In addition to its direct influence on memory consolidation, the amygdala also projects to other brain regions, including the hippocampus and cortex, which are involved in the encoding and retrieval of different types of memories as well as event segmentation. Through these projections, the amygdala can influence the way in which emotional memories are encoded, consolidated, and retrieved, ultimately shaping the way in which we remember and respond to emotional experiences (Roozendaal et al., 2009). The role of NE in the amygdala in stress-induced memory consolidation has been the subject of much research, with studies indicating that the activation of NE in this region plays a critical role in the process (Morilak et al., 2005; Flak et al., 2014). Specifically, NE release in the amygdala has been shown to enhance the consolidation of memories associated with stressful or emotionally-arousing experiences, highlighting the important role that the amygdala and NE play in the intersection of emotion and memory.

The amygdala's impact on the encoding of emotional memory is based through enhanced attention to emotional stimuli, as increased attentional resources allow emotional stimuli to better acquire memory representations. FMRI studies have shown that when processing emotional facial expressions, particularly those with fearful expressions, the amygdala is significantly activated, which is thought to be related to the attentional enhancement of emotional stimuli (Müller et al., 2018). Amaral et al. (2003) found a corresponding relationship between the amygdala and sensory cortex. When reacting to fearful faces, the activity in the amygdala is very similar to that in the visual cortex, providing solid evidence for the amygdala's impact on attention. The amygdala can automatically process rapidly changing emotional stimuli in the environment, obtain emotional information in the early stages of stimulus processing, and then reinforce the perception of emotional events through feedback, thereby influencing the attentional processing of emotional stimuli.

The post-encoding processing of memory, like memory consolidation, is mainly completed in the hippocampus. The hippocampus is essential for episodic memory, where it controls memory. Initially, the amygdala and hippocampus were thought to belong to two independent memory systems with specific functions. However, under emotional conditions, these two systems interact importantly. Emotional arousal induces the release of stress hormones, which activate the related receptors in the amygdala. The activity of these receptors manipulates the effects of hormones on hippocampal consolidation (Roozendaal et al., 2009). A well-known neurotransmitter regulation study reported in Nature found that injecting β-adrenergic receptor blockers into normal people weakens the encoding and retention of emotional information in situational memory, which is similar to the direct damage to the amygdala (Cahill et al., 1994). Therefore, the amygdala can regulate the retention of hippocampal-dependent memory, and when emotional stimuli occur, the hippocampus can form an emotional representation of the event, thus affect the response of the amygdala. Although the hippocampus and amygdala are two independent memory systems, they work together when emotions encounter memory (McGaugh, 2018).

It is not only the medial temporal lobe system that is involved in this complex interaction. Parts of the prefrontal cortex are also involved in the processing of emotional memory. Sergerie et al. (2008) used fMRI to study the encoding of different facial expressions (happy, neutral, and fearful) and found that the prefrontal cortex is involved in the encoding of emotional information and the regulation of emotional responses.

To summarize, the interaction between emotions and memory mechanisms in the brain takes place primarily in the amygdala and hippocampus, both located in the medial temporal lobe. Emotional arousal triggers the release of stress hormones and neurotransmitters such as NE, which enhance memory consolidation. The amygdala plays a crucial role in identifying and responding to emotional stimuli, influencing the encoding, consolidation, and retrieval of emotional memories. Meanwhile, the hippocampus is essential for episodic memory and collaborates with the amygdala to regulate the retention of hippocampal-dependent memory. Other regions of the prefrontal cortex also contribute to emotional memory. The coordination between different brain areas results in varying memory performance influenced by the level of emotional arousal.

Current Study

The present 2 x 2 factorial study aimed to investigate the influence of high arousal materials and event boundaries on long-term memory performance (Table 1). Specifically, I hypothesized that high-arousal materials would amplify the effects of event boundaries on memory, resulting in enhanced memory performance. This hypothesis was based on previous research that has demonstrated that high-arousal materials can lead to improved memory performance, and that event boundaries can also enhance memory consolidation.

	high arousal	low arousal
at boundary	1	3
in event	2	4

Table 1. The current study's 2 x 2 design

To test the hypothesis, 44 participants were recruited and randomly assigned to one of four conditions: 1) participants receive high arousal stimuli at locations of predetermined event boundary, 2) participants receive high arousal stimuli at locations off event boundaries (in the middle of events), 3) participants receive high arousal stimuli at locations of event boundary, or 4) participants receive low arousal stimuli at locations in the middle of events (Figure 1). Participants in each condition were then presented with a narrative TV episode that was divided into four segments, with each segment containing a breakpoint made by inserting emotionally arousing materials. After the narrative was presented, participants were asked to complete a filler task. Then they were asked to complete a memory task including three types of questions aiming

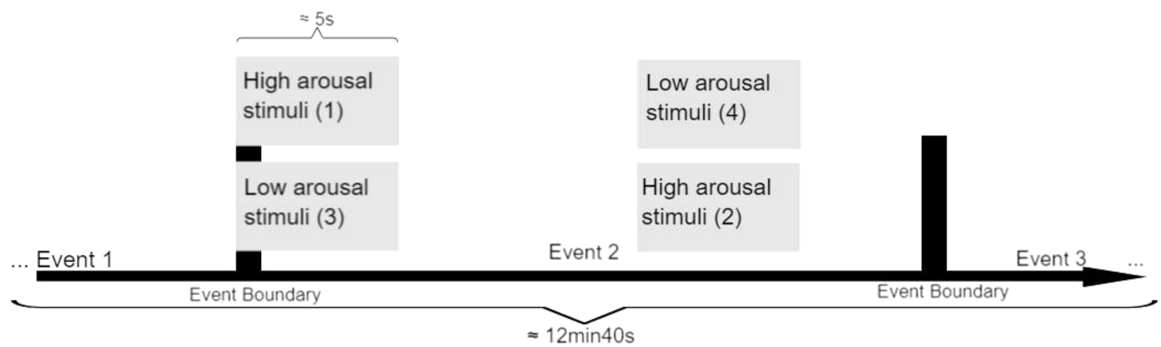


Figure 1. Flow chart of the encoding stage and conditions

to evaluate their memory of the given material in three aspects: recognition, recalling, and temporal order.

Regarding the experiment's design, I predicted that participants who were exposed to high-arousal materials at event boundaries would perform better on the memory tests compared to those who were exposed to low-arousal materials at event boundaries. Additionally, I predicted that the effect of arousal on memory performance would be stronger near the predetermined event boundaries compared to the locations off-boundary. As alternatives, the study also explored the possibility that either high arousal materials or event boundaries alone may enhance memory performance (Mather & Sutherland, 2011; Radvansky & Zacks, 2014). Finally, the study examined whether the participants' ability to spontaneously recall break materials during the recall task was related to the influence of high-arousal materials on memory performance.

The current study aimed to touch on the complex relationship between arousal, event segmentation, and memory performance; and to provide insight into how these factors may be manipulated to enhance memory consolidation.

Method

Participants

There were 44 participants (Age M=21.2) from Bard College randomly assigned to four conditions: at boundary-high arousal (n=11), at boundary-low arousal (n=11), in event-high arousal (n=11), in event-low arousal (n=11). The sample size is determined by an a priori power analysis conducted, reaching for an effect size of 0.80, considered large using Cohen's (1988) criteria. With a significance criterion of $\alpha = .05$ and power = .80, the minimum sample size needed with this effect size is N = 42. However, since there could not be fractional participants in a condition, the total sample size was increased to 44. Participants were naive to the purpose of the experiment. Study procedures were approved by the Bard College Institutional Review Board, and all participants were invited to enter their name and email in a raffle for a chance to win a $100 Amazon Gift card. The winner will be selected at random by May 11th and alerted via email.

Stimuli

TV Episode

The experimental stimuli were part of Episode 4 of *A Perfect Spy* mini-series, which aired on BBC2 and broadcast from November to December in 1987 and then later developed as an experimental material by Boltz (1992) mainly because of its subjective narrative and clear event boundaries. The current study utilized three of the event boundaries identified by Boltz, and the selected part for the current study has a duration of 12 minutes and 24 seconds. The clip initially did not include any breaks. However, the current study experimentally manipulated the episode to present high-arousal or low-arousal emotional breaks in boundary and non-boundary locations.

Emotional breaks

The emotional breaks automatically presented at boundary and non-boundary locations were from the Database of Emotional Videos from Ottawa (DEVO)(Ack Baraley et al., 2020). Ack Baraley et al. have identified the arousal level for each clip in the database; there is a total of 6 breaks (time M(s)= 4.6, SD=0.7) utilized in the current experiment, including three high-arousal breaks (arousal M(s)= 2.75, SD=0.36), and three low-arousal breaks (arousal M(s)=7.28, SD=0.25). The chosen break materials are those shown to be emotionally neutral (valence M=4.52, SD= 1.18) in order to minimize the effect of the emotional valence on the participant's memory of the TV episode.

Filler task and memory tasks

Following the complete episode viewing, participants were instructed to write down as many city names as possible within a two-minute timeframe on an answer sheet, aimed at serving as a filler task to distract the participants and erase any traces of the previously viewed episode content from their working memory before undergoing any memory tests.

After completing the filler task, participants were then asked 11 questions (See Appendix F) to test their ability on:

1) Recalling: Participants were asked to narrate the episode events in chronological order and with the highest level of precision possible. Their responses were entered into an empty text field with no time limits. However, the response time for each participant was recorded to evaluate the overall score of this task. The aim of the task was to assess the participant's capacity to retain and reproduce information, particularly with regard to the episode's sequence of events and its details.

The recall task score was evaluated using the Flores et al. (2017) normalized recall method. This method involves calculating a score that accounts for the number of correctly recalled items, the order in which they were recalled, and the time taken to recall them. The method exhibits a strong correlation with hand-scored recall ($r = 0.77$) for shorter videos of routine activities, indicating its reliability in assessing the accuracy and completeness of participants' memory retrieval.

This recall task provided valuable information about the participants' ability to retain and reproduce information from the episode they had just viewed. The results of this task enabled the researcher to better understand the participants' cognitive abilities and the underlying mechanisms of their memory processes. Additionally, the utilization of a standardized scoring method ensured that the results were accurate and replicable.

2) Recognition: Participants were presented with a series of pairs of screenshots taken from the TV show, with one of the screenshots being from the episode they had just watched and the other being a comparable screenshot from a different episode. The two screenshots in each pair were visually similar, making it difficult to distinguish which screenshot belonged to the watched episode. Participants were required to carefully examine each pair of screenshots and

identify the one that was from the episode they had just watched. This task aimed to assess their ability to recognize and differentiate between similar visual stimuli and their memory retention of the watched episode.

3) Detailed memory: Participants were asked about details in the episode, like a name, the number of times an action was repeated, etc. They were also asked to fill in a blank from a line in the episode.

Procedure

Prior to the experiment, participants were presented with a detailed set of instructions outlining the objectives and procedures of the study. Specifically, they were informed that they would be watching a 12-minute segment of a television episode, following which they would be required to respond to a series of questions pertaining to the episode. Upon receiving these instructions, the participants commenced viewing the selected segment of the episode from *A Perfect Spy*.

After the viewing, the participants were asked to do a 2-minute filler task, which aimed to distract and clear their working memory of the just-watched episode content prior to any of the memory tests. This was followed by a series of questions designed to assess the participant's ability to recall, recognize, and temporally order the events that appeared in the video. These questions were designed to evaluate the participants' memory of the episode and their cognitive abilities in differentiating between similar visual stimuli after different types of conditionings.

Following the completion of the memory test, participants were asked to indicate whether they had previously seen the episode or not. This information was collected to assess whether prior exposure to the episode had any impact on the participant's performance in the memory tasks and decide whether to exclude the data. Finally, the participants were debriefed and thanked for their participation in the study.

Overall, the experimental protocol was designed to elicit a comprehensive evaluation of participants' memory and cognitive functioning after different conditions. The utilization of a series of memory tests, coupled with the incorporation of a filler task, aimed at getting reliable and replicable results.

Analysis Methods

The current study aimed to explore the interrelationships between event boundary effects and arousal levels in affecting participants' memory of relevant events. To accomplish this goal, several two-way analyses of variance (ANOVA) were employed, which allowed for an examination of how the joint influence of these two factors impacted memory performance.

Notably, experiments have demonstrated that participants exposed to high-arousal materials tend to spontaneously recall content from intervening break materials during memory recall tasks (10 out of 22). Therefore, the present study employed a chi-square test to assess the potential relationship between this observed phenomenon and varying levels of arousal.

Deviations from Preregistration

One of the main deviations from preregistration is a change in the hypothesis. Initially, the hypothesis was that the presence of emotionally valenced materials at event boundaries would lead to a greater enhancement of memory compared to materials without emotional valence. However, during the course of the study, the hypothesis was modified to test for an amplifying effect of high arousal materials on the event boundary effect on long-term memory because it was later discovered that Peterson et al. (2021) had already examined the relationship between event segmentation, valence, and memory and found a significant effect. Because of this modification of the hypothesis, everything related to emotional valence in the preregistration was changed to information about emotional arousal (e.g., in the method section and the title of the study).

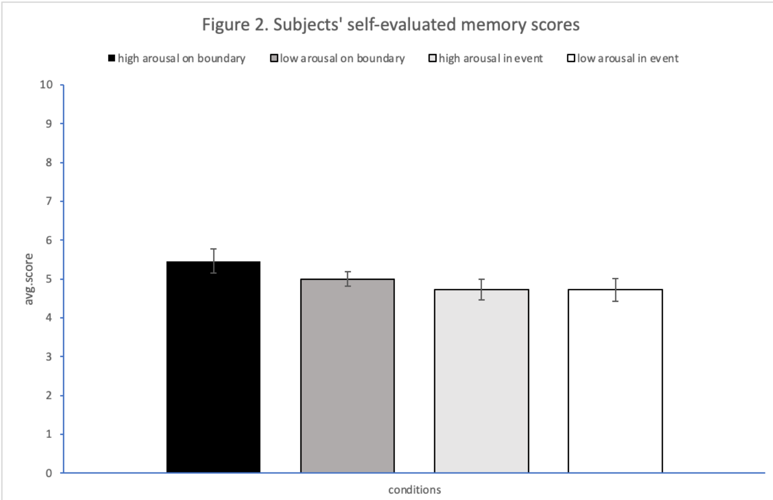
These deviations could be considered limitations of the study as it was not consistent with the preregistered hypothesis.

Results

The purpose of this 2 x 2 factorial study was to investigate the co-effects of emotionally arousing materials and event boundary effects on memory. Participants were randomly assigned to one of the four conditions. Their memory scores were measured using Flore et al.'s (2017) normalized recall method, and the levels of arousal for materials were given by the Database of Emotional Videos from Ottawa (DEVO; Ack Baraley et al., 2020). I identified one outlier in the dataset using Tukey's fences method (Tukey, 1977). The outlier was defined as any data point that fell outside the range of 1.5 times the interquartile range (IQR) below the first quartile (Q1) or above the third quartile (Q3). The outlier was located in recall scores of high arousal in-event condition with a value of 32.

Participants' self-reported ratings of their memory

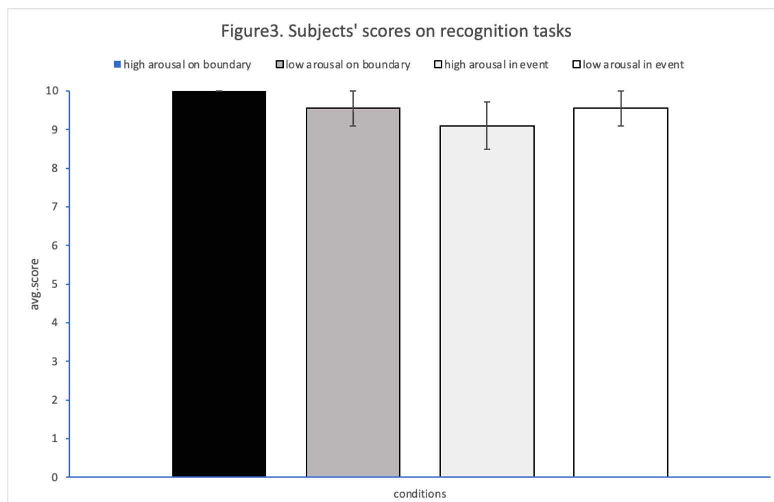
A two-way ANOVA was conducted to examine the effects of arousal levels and break location on participants' ratings of their memory of the episode they watched (Figure 2). There were two levels of arousal (high and low) and two break locations (at- boundary and in-event).



The results revealed no significant main effect for arousal ($F(1,40) = 3.70$, $p = 0.078$) or location ($F(1,40) = 2.63$, $p = 0.122$). However, there was a trend toward a significant interaction effect between arousal and location ($F(1, 40) = 3.95$, $p = 0.064$, $\eta^2 = 0.09$).

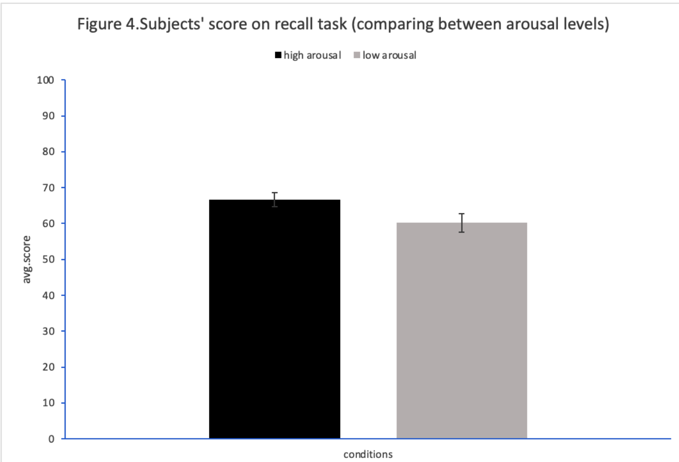
Recognition task

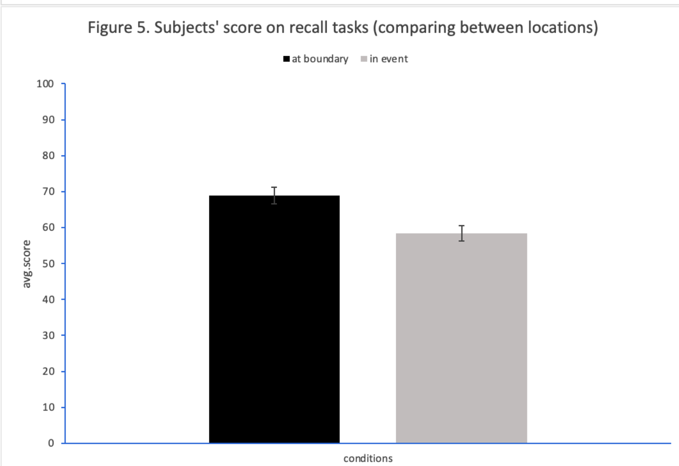
A two-way analysis of variance was conducted to examine the effects of arousal level (high vs. low) and break location (at-boundary vs. in-event) on participants' recognition scores (Figure 3). The results indicated that there was no significant main effect of arousal level ($F(1, 40) = 1.05$, $p = 0.31$), no significant main effect of break location ($F(1, 40) = 0.00$, $p = 1.00$), and no significant interaction between arousal level and break location ($F(1, 40) = 1.05$, $p = 0.31$).



Recall task

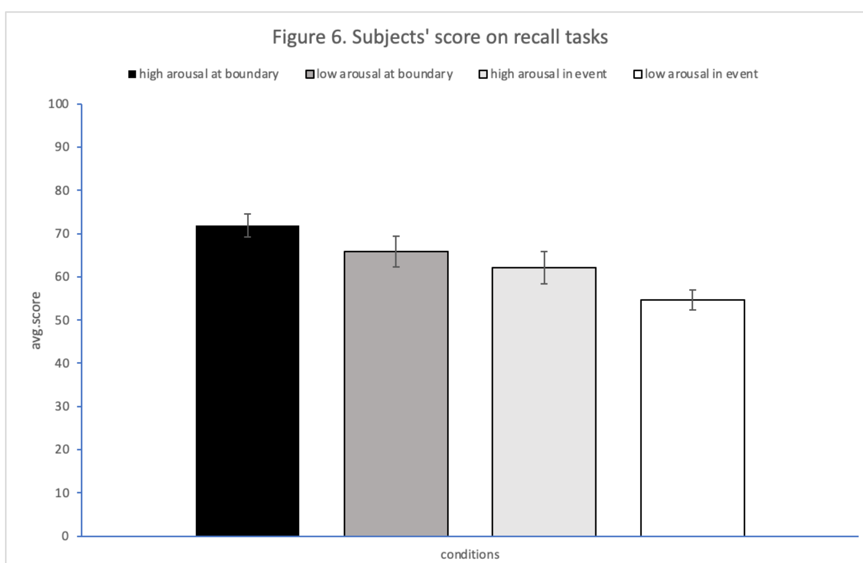
A 2-way ANOVA was conducted to examine the effects of arousal level (high vs. low) and location of breaks (on-boundary vs. in-event) on the dependent variable. There was a significant main effect of arousal level (See Figure 4), $F(1, 40) = 5.73$, $p < .05$, $\eta p^2 = 0.12$, with higher mean scores observed in the high arousal condition ($M = 66.7$, $SD = 9.3$) compared to the low arousal condition ($M = 60.2$, $SD = 12.1$).





There was also a significant main effect of the location of breaks (See Figure 5), $F(1, 40) = 4.68$, $p < .05$, $\eta^2 = 0.08$, with higher mean scores observed in the at-boundary condition ($M = 68.9$, $SD = 10.5$) compared to the in-event condition ($M = 58.4$, $SD = 10.1$). Additionally, there was a significant interaction between arousal level and location of breaks, $F(1, 40) = 2.39$, $p < .05$, $\eta^2 = 0.06$, indicating that the effect of the location of breaks was stronger in the high arousal condition than in the low arousal condition (Figure 6).

A post-hoc analysis (Tukey HSD) was conducted to further examine the significant main effects and interactions. The results revealed that the mean score in the high arousal at-boundary condition



(*M* = 71.9, *SD* = 8.7) was significantly higher than the mean score in the low arousal in-event condition (*M* = 54.7, *SD* = 12.3), $t(40) = 5.15$, $p < .05$, $d = 1.77$, as well as the mean score in the low arousal at-boundary condition (*M* = 65.8, *SD* = 11.8), $t(40) = 2.98$, $p = .02$, $d = 1.03$. Moreover, the mean score in the low arousal at-boundary condition was not significantly higher than the mean score in the high arousal in-event condition but shows a trend doing so (*M* = 62.1, *SD* = 7.8), $t(40) = 2.61$, $p = .055$, $d = 0.90$). No other pairwise comparisons were significant.

A chi-square test of independence was conducted to examine the association between the arousal levels (high vs. low) on the percentage of participants who automatically reported the content of break material during the recall test. The contingency table showed that out of 22 participants who received high arousal materials, ten reported break material during the recall test, while out of 22 participants who received low arousal materials, only four reported about break material. The expected counts for each cell were calculated based on row and column totals, and the chi-square test statistic was calculated to be 2.29 with 1 degree of freedom. The p-value for the test was 0.130, indicating that there was no significant association between arousal levels on the percentage of participants who automatically reported the content of break material during the recall test ($\chi^2(1) = 2.29$, $p = 0.13$).

In conclusion, this 2 x 2 factorial study found significant main effects of arousal level and location of breaks on memory, as well as a significant interaction between the two factors. Post hoc analysis showed that high arousal at-boundary condition resulted in significantly higher recall scores than low arousal in-event condition and low arousal at-boundary condition, while low arousal at-boundary condition resulted in significantly higher recall scores than high arousal in-event condition. The chi-square test did not reveal a significant association between arousal levels and automatic reporting of break material during recall. These findings suggest that emotionally arousing materials and event boundary effects can influence memory performance.

Discussion

The current study was centered on investigating whether there is an event boundary effect on long-term episodic memory (Pettjohn et al., 2016) and whether it could be enhanced by the use of highly arousing materials. The event boundary effect is a phenomenon where memory recall is affected by a transition between events (Kurby & Zacks, 2008). The transition is characterized by a shift in the environment, context, or experience. The event boundary effect has been observed in a variety of memory tasks, including free recall, cued recall (Swallow et al., 2009), and recognition memory (Kurby & Zacks, 2011). To explore the event boundary effect and its relationship with arousal, the current experiment was designed to collect data on participants' memory score. As part of the experiment, participants viewed a segment of a TV episode that included emotional stimuli intentionally inserted by the researcher. These stimuli were designed to either accentuate an event boundary (at-boundary) or not (in-event) and were divided into two groups based on their level of arousal (high and low arousal). The participants' memory scores were evaluated to assess the influence of both the highlighted event boundary and the level of arousal on memory retrieval. By examining the event boundary effect and its potential amplification using emotionally arousing materials, the study aims to provide insights into the mechanisms that underlie memory encoding and retrieval, and event segmentation.

Based on the results of the recall task, it was found that both the level of arousal and the positioning of breaks had a significant effect on the participants' memory scores for the TV episode. Specifically, a higher memory score was observed in the high arousal condition compared to the low arousal condition, indicating that memory retention is facilitated by higher levels of arousal. Additionally, the at-boundary condition demonstrated superior performance in terms of memory scores compared to the in-event condition, indicating that the highlighting of event boundaries enhanced the subjects' memory. Furthermore, consistent with the hypothesis, the effect of break positioning was found to be more pronounced in the high-arousal condition scores posted to the low arousal condition.

Previous research has demonstrated that memory following event segmentation is more accurately recalled and more readily retrieved than non-segmented memory. According to Flores et al. (2017), this phenomenon may be attributable to the differential allocation of attention across events. The event segmentation theory, as proposed by Zacks et al. (2007), posits that individuals revise their model of an event to accurately reflect the current situation when their prediction error exceeds a threshold. For example, while attending a concert, small prediction errors occur frequently, such as changes in notes or performer movements. However, when a significant prediction error occurs, such as the performer finishing a piece and the audience beginning to applaud, event segmentation is likely to occur. Consequently, the timing of updating the event model plays a crucial role in determining the information available for consolidation into long-term memory as discrete events. In other words, the identification of event boundaries within normative segments of an event leads to adaptive chunking of ongoing activity, resulting in memory representations that are more enduring and retrievable. These findings align with previous research indicating that information contained within a discrete event is better recalled than information spanning multiple events (Swallow et al., 2009; DuBrow & Davachi, 2013;

Ezzyat & Davachi, 2014), with this memory enhancement stemming from more effective encoding of segmented information (Swallow et al., 2009).

The process of event segmentation is a critical aspect of perception and cognition that allows individuals to selectively extract and encode meaningful information from their environment. Attention plays an important role in this process, as it has been shown that under experimental conditions, the way in which participants segment events varies based on the task given to them (Zacks & Tversky, 2001). This suggests that the observer's attention and goals can significantly influence event segmentation. However, most event segmentation in daily life occurs implicitly, without the conscious attention of individuals. While segmentation may not be a conscious, explicit process, it is dependent on a number of top-down factors such as prior knowledge, sensory experiences, and information processing goals that determine the locations of event boundaries. As an example, the familiarity of individuals with a musical Playlist can have an impact on how they segment events. In the context of a concert, individuals who are well-versed in the Playlist may have a pre-existing expectation that the final performance will be a waltz. As a result, compared to individuals who are unfamiliar with the Playlist, the former group may be less likely to establish a robust event boundary between the last piece of the waltz and the ensuing sounds of the audience exiting the music hall. This might be because the unfamiliar group's attention could be led to focus on the unexpectedly "sudden" ending of the concert, which is likely to exceed their prediction error thresholds. This also highlights the role of top-down processing in event segmentation, as the prior knowledge and expectations of the observer can shape how they segment events.

Apart from top-down factors, sensory information can also influence event segmentation. In the present study, participants' memory was better when event boundaries were highlighted using arousing stimuli. Consider this sensory highlight like an emotional vibration: In the same concert scenario, the feeling of a phone vibrating during the performance may constitute a salient sensory event that can potentially form an event boundary. However, whether or not this event would affect people's prediction error and lead to a robust boundary depends on a variety of factors, such as the intensity and duration of the vibration, as well as the observer's attentional state and cognitive load at the time. It is also possible that the sensory event may not be perceived as salient by some individuals, thereby not leading to the formation of a distinct event boundary. The results of the current study suggest that the sensory input of arousal stimuli may enhance memory at event boundaries, although the influence of other types of sensory input remains unclear. Furthermore, this study did not investigate the effects of newly formed event boundaries in the in-event condition, where subjects received stimuli in the middle of an event, potentially leading to the formation of additional event boundaries. Given that the stimuli were presented abruptly, it is reasonable to predict the presence of robust event boundaries. The influence of these boundaries on both working memory and long-term memory may vary depending on the intensity of the unexpected stimuli and could demonstrate a similar pattern of memory improvement as observed in the current study. Therefore, further investigations focusing on this perspective are required to verify this prediction. These explanations and examples underscore the intricate interplay between cognitive and sensory factors in event segmentation and the necessity for continued research in this field.

In the present study, the event boundaries that participants encountered were not generated spontaneously by themselves, but rather were predetermined by the director to signify transitions from one scene to another. This approach was implemented in order to standardize the event structure across all participants and minimize variability in the segmentation process. By controlling the identification of event boundaries in this way, the study was able to focus more closely on the effects of break locations and arousal levels. However, there are limitations to this approach.

One of the main limitations is that it does not fully reflect how people typically segment events in their daily lives. In real-life situations, event boundaries are often identified in a more dynamic and spontaneous way, based on a combination of various sensory and contextual cues, as well as personal goals and expectations (Zacks & Swallow, 2007). Therefore, the predetermined event boundaries in this study may not fully capture the complexity and variability of event segmentation in natural settings and may limit the generalizability of the findings to other types of events or stimuli. The effects of break locations and arousal levels on event segmentation, memory encoding, consolidation, and retrieval may differ depending on the specific characteristics of the stimuli, such as the level of complexity, novelty, or emotional valence. Another limitation is regarding the role of attention. In the present study, participants who were presented with break materials at event boundaries naturally would pay more attention to these boundaries, regardless of their arousal levels, due to the distinct emotional content of the clips that clearly distinguished them from the original TV episode. As a result, it is reasonable to assume that the prediction error for participants in these conditions was higher compared to those in the other two conditions, which indicates that the break materials drew more attention and may have enhanced memory encoding and retention. However, this approach raises potential limitations in terms of investigating the specific role of attention in event segmentation, as attention may have been confounded with emotional arousal or valence (Compton et al., 2003). To minimize the effect of attention, future studies could employ a more gradual shift in events, which could result in less obvious breaks between events and thus reduce the likelihood of attention being drawn to them. Additionally, using text-based materials could also be a viable solution to the confounding effect of sensory information on attention. Text-based materials require less sensory processing compared to visual or auditory materials and may offer a more controlled approach to investigating the impact of arousal and valence on event segmentation and memory consolidation.

In contrast to previous research suggesting memory impairment after event segmentation, the current study found that event boundaries enhance long-term memory. Radvansky and colleagues (2006, 2010) conducted experiments in which participants walked through a door and then tested their memory. Results showed that moving between two rooms induced forgetting of information about the currently processed item or vocabulary more than moving within the same room, confirming the location-updating effect. Radvansky et al. (2011) found consistent spatial location-updating effects in both a less immersive virtual environment and a realistic environment, with individuals showing slower responses and lower accuracy when recalling objects from the previous spatial exposure. Swallow et al. (2009) also found poorer recall of information that appeared in the previous event compared to the current event or event boundary in short videos.

The contradictory results between the current study and previous research may be attributed to differences in the types of memory being investigated. Specifically, while the current study examined the effect of event boundaries on long-term memory (LTM), the studies mentioned above explored the role of event segmentation in working memory (WM). The process of event segmentation is critical for organizing and storing information in LTM. In fact, event segmentation can enhance memory for segmented events by creating distinct and meaningful boundaries that facilitate the encoding and retrieval of information, thereby increasing the likelihood of long-term retention (Zacks, 2020). On the other hand, event segmentation can also negatively affect WM, which is the system responsible for temporarily holding and manipulating information for current cognitive tasks. This might be because the process of event segmentation requires attentional and working memory resources, which can lead to interference and impairments in WM performance, especially when multiple events are segmented and stored simultaneously. Although the results of the present study suggest an amplification of the event boundary effect by arousal levels in long-term memory, it is also important to look at whether this effect exists among working memories. Based on the series of studies done by Radvansky et al. and Swallow et al., the event segmentation might take space from working memory for one to have better long-term memory, causing WM impairments around boundaries; and based on the studies showing high arousal may negatively affect people's working memory (Mather et al., 2006; Costanzi et al., 2019), it is reasonable to hypothesize that high arousal levels might interfere with the impaired working memory after event segmentation and make it even more impaired. Future studies on this aspect could focus on investigating the interaction between arousal level and event segmentation on subjects' working memory, which could help researchers to understand the role of event segmentation in working memory. There are studies showing that temporarily impairing one's working memory can actually improve creativity and problem-solving skills (Wiley & Jarosz, 2012; Smeekens & Kane, 2016). This might be because when working memory is impaired, individuals may rely more on their long-term memory and draw from a wider range of past experiences and knowledge to solve problems. Also, creativity is associated with inefficient reallocation of attention and reduced task-induced deactivation (Takeuchi et al., 2011), which were highly occupied in working memory, thus finding ways to temporarily induce the activation of working memory could be beneficial for creativity and investigating the role of event segmentation and arousal in this could provide a stable and safe way to do so.

The present study did not find a significant effect of either event boundary or arousal levels on participants' recognition scores, which may be attributed to several reasons. One possible reason could be the inefficiency of the experiment design in testing this effect. The current study only included two out of eleven questions to evaluate participants' ability to recognize scenes from the TV episode based on the scene that looks similar to them. The limited number of questions might not provide an accurate representation of the participants' recognition scores. Moreover, evidence suggests that attentional deficits can impair recognition performance (Rapport et al., 2002; Bonini & Radanovic, 2015). Therefore, it is reasonable to predict that the subjects of the present study might experience similar recognition impairments due to their attention being diverted to the break materials from the TV episode. Thus, the results of the current study might not reflect the participants' actual recognition ability. Research on attentional deficits and recognition impairment supports this hypothesis (Rapport et al., 2002; Bonini &

Radanovic, 2015). In terms of evaluating participants' recognition score, the limited number of questions used in the present study could be a noteworthy limitation. Future studies can use a more extensive evaluation method that includes a greater number of questions to improve the accuracy of the recognition score.

The results of the study revealed an intriguing interaction between arousal levels and break locations on memory. Specifically, it was found that the effect of event boundary was more pronounced in the high arousal condition compared to the low arousal condition. Post-hoc tests on subjects' recall scores suggested that high-arousal materials presented at event boundaries lead to better memory performance than low-arousal materials presented within events. However, the mean score in the low arousal at-boundary condition was not significantly higher than the mean score in the high arousal in-event condition but showed a trend in doing so. These findings suggest that the effects of high arousal on memory performance may not be limited to event boundaries and may generalize to other points in the narrative. These results support the hypothesis that high arousal materials can enhance event segmentation's enhancing effect on long-term memory performance. The findings have implications for understanding how arousal and event structure interact to influence memory encoding and retrieval. One possible explanation for the current study's results is that high arousal levels lead to stronger engagement of memory-related brain regions such as the hippocampus and amygdala (McGaugh, 2015). The formation and retrieval of episodic memories involve the hippocampus and amygdala, according to prior research (Tulving, 2002). Furthermore, their interaction is particularly noticeable when memories are associated with emotion. The process of event segmentation also occurs mainly in the hippocampus (Ross & Easton, 2022). Hence, it is possible that the heightened activation of the hippocampus in the high-arousal situation may have facilitated the tasks it performs, resulting in more effective event segmentation and memory enhancement. Moreover, research has shown that the amygdala plays a crucial role in processing emotionally arousing stimuli (Roozendaal et al., 2009; Beyeler et al., 2016), and it has been suggested that the amygdala activation may enhance memory for emotionally arousing events. Therefore, the observed interaction between arousal and event segmentation and their effects on memory may have been influenced by the amygdala's processing of the emotional content of the events. Specifically, the activation of the amygdala due to the emotional intensity of the stimuli, combined with the activation of the hippocampus due to event segmentation, may have resulted in the enhanced memory retrieval observed in the current investigation reflecting the roles of different brain regions during the encoding stage of memory formation. However, it is important to note that the major limitation of this study is the lack of a non-manipulated control group. This makes it difficult to determine the direction of the observed effect, whether high arousal enhances the memory effect of event segmentation or vice versa. Future research could investigate the direction of this effect by implementing a non-manipulated control group that does not receive any arousal materials or event segmentation cues for comparison. Additionally, a more detailed scoring method is needed for such an approach. In the current study, I utilized Flore et al.'s (2017) scoring method to evaluate subjects' recall ability from their answers, which includes evaluations based on the total word count and mentions of relevant event components. However, it was challenging to distinguish the scores between different locations (in event vs. at event boundary, before vs. after segmentation). Therefore, a more comprehensive scoring method would be needed to determine whether the current amplification is on the event boundary effect by arousal levels or on the arousal-enhanced memory effect.

Another possible explanation for the interaction between high arousal levels and event segmentation on memory is more related to the nature of high arousal materials and less to event segmentation. High arousal may result in an increased attentional focus on the task at hand, facilitating event segmentation and memory retention. Studies have shown that attentional focus is essential for successful event segmentation and memory encoding (Kurby & Zacks, 2008). High arousal may also lead to better efficiency of encoding, making it easier for individuals to form and consolidate memories. Emotional arousal has been found to enhance the efficiency of memory encoding and consolidation (Cahill & McGaugh, 1998). Furthermore, high arousal may increase the salience of event boundaries, making them more memorable. More salient event boundaries may be easily encoded and retrieved from memory. Research has indicated that salience can influence event segmentation and memory (Kurby & Zacks, 2011). In this context, high arousal may lead to increased salience of event boundaries, resulting in improved memory retention. This evidence suggests that high arousal materials may increase attentional focus, enhance encoding efficiency, and increase the salience of event boundaries, ultimately resulting in improved memory retention.

Another potential explanation for the findings of the current study is that high levels of arousal may have disrupted cognitive control processes, making it more difficult for participants to inhibit irrelevant information or distractions. Cognitive control refers to a set of mental processes that enable us to plan, monitor, and adjust our behavior in response to changing situations and goals. This includes processes such as inhibition, working memory, and attentional control, which allow us to ignore distractions, stay focused on the task at hand, and regulate our emotional responses (Braver, 2012). For example, participants in the high arousal condition may have been more likely to get distracted by their own emotional responses, such as feelings of anxiety or excitement, which could have interfered with their ability to encode and remember the information presented in the study. The effect of event boundaries may have therefore been more pronounced in this group because the boundaries provided a more salient cue to focus attention on the relevant information and suppress irrelevant information. In other words, the event boundaries may have served as a helpful aid to cognitive control, helping participants to organize and remember the information despite the disruptions caused by their high levels of arousal. To explore this possibility further, future studies could incorporate methods to assess subjects' working memory performance under varied conditions (see methods in Swallow et al., 2009 for a reference).

It is important to acknowledge that the present study did not provide a clear indication of the extent to which memory improvement occurred. As mentioned earlier, the current study utilized a scoring system that may have limitations in providing detailed information on the locations where the memory enhancement took place. Therefore, it is imperative to explore whether the enhancement is consistent throughout the entire TV episode or restricted to specific locations, such as those before and after the implemented break materials. Future research could aim to develop more sophisticated scoring methods to evaluate memory performance at distinct locations, thereby allowing for a more comprehensive investigation of the interaction between arousal levels and event segmentation. Given prior research findings on event boundary effects

(Swallow et al., 2009; Radvansky & Zacks, 2017), it is plausible to predict that memories associated with event boundaries would be the most impacted by high levels of arousal.

Regarding participants' self-evaluation of their memory of a TV episode, the analysis revealed a trend toward a significant interaction effect between arousal and location. This question aimed to assess participants' subjective sense of their memory, which has been demonstrated to be influenced by their actual capacity for remembering (Rimmele et al., 2012). The study by Rimmele et al. investigated whether the subjective sense of remembering negative stimuli is linked to improved memory accuracy for specific contextual details, such as spatial location and temporal context. Their results suggest that a strong subjective sense of remembering is associated with better recollection of these details, indicating that people are more likely to accurately remember the where and when of an event if they have a strong sense of remembering it. The trend observed in the present study can be viewed as a piece of minor supporting evidence for the main finding of a significant interaction between arousal level and the location of breaks in memory.

Practical use

The findings of the current study could be practically used in film production. The art of filmmaking is centered on the ability to weave compelling stories that capture the viewer's imagination and leave a lasting impression. Immersion is a crucial aspect of the film's production process, as it is crucial for filmmakers to create an experience that captivates the audience from start to finish. To this end, filmmakers are constantly seeking new ways to improve the viewing experience and make their films more memorable. The present results have revealed that the use of high arousal level materials at event boundaries in film can significantly amplify the effect of event boundaries on memory. High arousal level materials in terms of filmmaking are those shots that provoke a strong emotional response from viewers, such as intense action scenes or poignant emotional moments. The findings suggest that the use of such materials can effectively mark event boundaries within a film, enhancing the viewer's memory of these events and making them more impactful.

One potential application of this research in the realm of film production is to use high arousal level materials to create event boundaries that help to structure the film's narrative. For example, a dramatic action sequence could be used to signal a shift in the story's tone or direction. This technique can help the audience to better understand and remember key moments in the film, resulting in a more engaging and memorable experience. The study also offers filmmakers a valuable tool for enhancing the effectiveness of montage sequences. Montage is a technique used in film editing to condense time and conveys information quickly. By using high arousal level materials as event boundaries in montage sequences, filmmakers could try to ensure that viewers retain important information and remember the sequence more vividly. For instance, a montage sequence of action scenes could be structured around key and highly arousing events, such as the hero overcoming a major obstacle or achieving a significant goal.

The implications of the research extend beyond event boundaries and montage sequences. Filmmakers can use high arousal level materials strategically throughout the film to create an emotional arc that engages the viewer and keeps them invested in the story. The use of high-intensity action scenes, emotional moments, or other stimuli that elicit a strong emotional response from the viewer can contribute to the overall design of the film's emotional background and structure. By strategically using high arousal level materials to mark event boundaries, filmmakers can create more impactful and engaging films that resonate with their audience long after the credits roll.

The practical implications of the current study extend beyond the realm of film production and can also be applied to the advertising industry. Advertising is a powerful tool for companies or institutions to reach their target audience and promote their products, ideology, or services. To make an impact, advertisers must create compelling and memorable ads that capture the attention of viewers and leave a lasting impression. The present study offers valuable insights into how the use of high arousal level materials can be strategically employed in advertising to enhance the effectiveness of the ads. By using emotionally engaging content in an ad and inserting it at the event boundaries of, for example, a TV episode, advertisers can increase the likelihood of their target audience remembering the key message and taking action. The study suggests that the use of high arousal level materials can be particularly effective in ads that aim to convey a specific emotion or message, such as an ad promoting a charity or a social cause. In such cases, the use of emotionally charged content can create a more impactful and memorable ad that motivates viewers to take action or support the cause.

Conclusion

In conclusion, the findings of this study provide evidence of an intriguing interaction between arousal levels and break locations on memory performance. The study suggests that event boundaries have a greater impact on memory retention when experienced during a state of high arousal. These results have important implications for understanding how our emotional and physiological states can affect memory processing and retention, and could inform the development of new strategies for improving memory performance in a variety of contexts.

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Appendix A: IRB Proposal

Section 1

1. Today's date: Thursday, February 26th, 2022

2. Name: Haonan Chen

3. Email: hc8358@bard.edu

4. Your Academic Program/Department/Office:

   Psychology Program

5. Your status (faculty, staff, graduate or undergraduate student):

   Undergraduate student, Senior II

6. Adviser or Faculty Sponsor (if applicable):

   Justin Hulbert

7. If you are a graduate or undergraduate student, has your Adviser or Faculty Sponsor seen and approved your application?

   Yes.

8. Your Adviser's or Faculty Sponsor's email address (if applicable):

   jhulbert@bard.edu

9. Please list all individuals (full name and status, i.e. faculty, staff, student) involved in this project that will be working with human subjects. Note: Everyone listed must have completed Human Subject Research Training within the past three years.

   Haonan Chen.

10. Do you have external funding for this research?

    No.

11. If so, state the name of the sponsor and the title of the project as it was submitted to that sponsor.

    N/A

Section 2

1. What is the title of your project?

   The Effect of Emotional Stimuli Within Event Boundaries on Memory

2. When do you plan to begin this project? (Start date):

March, 3rd, 2023

3. Describe your research question(s):

The experiences in our lives can be broken up into a series of events, even though one event flows into the next. We do this naturally, but individuals can differ on where they draw the dividing line between one event and the next. Researchers have been investigating the factors that influence the placement of these so-called event boundaries and the consequences of those placements (e.g., on the ability to later remember details from those events). Event segmentation theory suggests that people parse a continuous stream of activity into separate meaningful events (segments); the pauses between each segment are known as the boundaries of events (Zack & Swallow, 2007). This notion is being increasingly supported by literature that highlights its significant cognitive ramifications such as memory (Kurby & Zacks, 2008) and attention (Bezy, Kibbe & Mills, 2013). However, it is still unclear how the boundary of an event influences people's memory about the information they perceive after segmentation. Because emotional stimuli have been demonstrated to affect perception and attention, I will be utilizing them in the current study to investigate the influence of event boundaries on participants' memory. I hypothesize that participants who receive highly arousing emotional stimuli placed at a naturally occurring boundary will have a better recall of details and sequences about the TV show than participants who received low-arousing stimuli. And participants who receive emotional stimuli placed at a naturally occurring boundary will have a better memory of details and sequence about the TV show than participants who received emotional stimuli outside of the event boundary (e.g., during an ongoing event).

4. Describe the population(s) you plan to recruit and how you plan to recruit participants. Please submit all recruitment material, emails and scripts to IRB@bard.edu.

Participants will be recruited from the Bard community via email and posters. Before they agree to participate, they will be determined to be above the age of 18 and fluent in English. All participants will be informed that the experiment will involve each participant watching a video and several positive and neutral emotional materials. Any participants will be provided a description of the task's purpose, length, and use of videos in the experiment. Any participants recruited from the Bard community may be solicited through publicity measures such as posters in campus locations or through social media or emails.

5. Will your participants include individuals from vulnerable or protected populations (e.g., children, pregnant women, prisoners, or the cognitively impaired)?

No.

6. If your participants will include individuals from the above populations, please specify the population(s) and describe any special precautions you will use to recruit and consent.

N/A.

7. Approximately how many individuals do you expect to participate in your Study?

44 participants.

8. Describe the procedures you will be using to conduct your research. Include descriptions of what tasks your participants will be asked to do, and about how much time will be expected of each individual. NOTE: If you have supporting materials (printed surveys, questionnaires, interview questions, etc.), email these documents separately as attachments to IRB@bard.edu. Name your attachments with your last name and a brief description (e.g., "WatsonSurvey.doc).

Participants will be asked to watch part of Episode 4 of A Perfect Spy mini-series (Boltz, 1992), which aired on BBC2 and broadcast from November to December in 1987 and then later developed as an experimental material mainly because of its subjective narrative. According to Boltz's research, there are 7 known events and 6 event boundaries in the episode. The current project will use 2 of the known event boundaries and 3 of the known events. One group of participants will receive emotional stimuli at the points where the known event boundaries are. Playing the emotional stimuli will pause the episode for 10 seconds, the stimuli would be either emotionally positive or neutral based on the groups they are randomly assigned to. For another group, the emotional stimuli are going to be played outside of the predefined event boundaries (within the ongoing event). A separate control group consisting of 8 participants will be asked to press “SPACE” whenever they think the previous event ends and a new event begins, in other words, an event boundary appears. Pressing “SPACE” will pause the episode for 10 seconds and participants will receive emotional stimuli at the points where they think event boundaries are. This group will be used to confirm whether the boundaries identified through previous research (Boltz, 1992) generalize to the current population under investigation.

Emotional stimuli will be coming from the Emotional Movie Database (EMDB) and Database of Emotional Videos from Ottawa (DEVO). An example of the highly arousing material from DEVO is a 3 second clip for base jumping (https://drive.google.com/file/d/1GHsSIS_6F169M-kFhqxQaTkNCK_MdxOr/view?usp=share_link), and a low-arousing material example would be a bird standing on a pole from the documentary Finland-Into the Wild Land (https://drive.google.com/file/d/1hX4bky--402vi3zKj2lJJYGC79DGUqQw/view?usp=share_link)(Ack Baraley et al., 2020).

After watching the video, participants will be asked to fill out a questionnaire that tests their memory on the information shown in the video. The questions will be asking about the details of the videos and the sequence of the videos (see Appendix D).

9. Describe any risks and/or benefits your research may have for your participants.

Risks for this study are minimal. While watching the videos will demand participants’ attention, the total viewing will be kept to under 12 minutes. Participants should also be reminded that, should they become fatigued or in any way uncomfortable during the experiment, they may withdraw at any time without penalty.

The video and emotional stimuli participants may encounter during the experiment are intended to be neutral or positive. Still, should anyone feel uncomfortable watching the videos, they only need to alert the experimenter in order to stop the experiment.

While this research experiment may not provide participants with any direct benefits, the data collected from this study may help improve the scientific understanding of the effect of emotional stimuli within event boundaries on people's memory. Moreover, the researcher hopes that participants gain insight into the research process at Bard College through their involvement with this experiment.

As a token of appreciation for their time and effort, participants will be invited to enter their name and email in a raffle for a chance to win a $100 Amazon Gift card. The winner will be selected at random by May 11th and alerted via email.

10. Describe how you plan to mitigate (if possible) any risks the participants may encounter.

The *A Perfect-Spy* mini-series is short and entertaining to watch, which can ward off boredom for the participants. Although the video and emotional stimuli participants may encounter during the experiment are intended to be neutral or positive, some people might feel uncomfortable with the given visual materials. They will be informed while giving consent that they can always let the experimenter know if they wish to end the experiment at any point. By doing so, they will be free to leave without penalty.

11. Describe the consent process (i.e., how you will explain the consent form and the consent process to your participants):.

Participants will be going through informed consent (see Appendix D) at the beginning of the in-person session. They will have enough time to read through the materials and ask questions regarding the materials.

12. Have you prepared a consent form(s) and emailed it as an attachment to IRB@bard.edu?

Yes.

13. If you are collecting data via media capture (video, audio, photos), have you included a section requesting consent for this procedure(s) in your consent form(s)?

N/A.

14. If your project will require you to employ a verbal consent process (no

written consent forms), please describe why this process is necessary and how verbal consent will be obtained and stored.

N/A.

15. What procedures will you use to ensure that the information your participants provide will remain confidential and safeguarded against improper access or Dissemination?

Data collected during the experimental tasks will remain separate from participants' identifying information (e.g., name on their consent form and contact information for the raffle). All information provided through the Qualtrics platform will be temporarily stored on their servers in Michigan, USA. Their security statement is accessible via this link: https://www.qualtrics.com/security-statement

While it is stored there, it is only accessible to the primary investigator through their password-protected account. At the conclusion of data collection, data will be stored offline on a password-protected computer to which only the primary investigator has Access.

The emails and names participants provide to get in a raffle for a chance to win a $100 Amazon Gift card will be used only for the raffle. I will use a random number generator in Excel to select one of those names at random, and then send them the Amazon gift card.

Study data will be reported only in aggregate for my Senior Project, which will be permanently and publicly available in the Bard College library and online through the Digital Commons.

16. Will it be necessary to use deception with your participants at any time during this research? Withholding details about the specifics of one's hypothesis does not constitute deception, this is called incomplete disclosure. Deception involves purposefully misleading participants about the nature of the research question or about the nature of the task they will be completing.

No.

17. If your project study includes deception, please describe here the process you

will use, why the deception is necessary, and a full description of your debriefing procedures.

N/A.

18. For all projects, please include your debriefing statement. (This is information you provide to the participant at the end of your study to explain your research question more fully than you may have been able to do at the beginning of the study.) All studies must include a debriefing statement. Be sure to give participants the opportunity to ask any additional questions they may have about the study. See Appendix E for the Sample Debriefing Sheet.

19. If you will be conducting interviews in a language other than English, will you conduct all of the interviews yourself, or will you have the assistance of a translator? If you will be using the assistance of a translator, that individual must also certify that he or she is familiar with the human subject protocol and has completed the online training course.

N/A.

20. If your recruitment materials or consent forms will be presented in languages other than English, please translate these documents and email copies to IRB@bard.edu.

N/A.

Appendix B: IRB Approval

Bard College Institutional Review Board

Date: 03/13/2023
To: Haonan Chen
Cc: Justin Hulbert; Nazir Nazari
From: Ziad M. Abu-Rish, IRB Chair
Re: The Effect of Emotional Stimuli Within Event Boundaries on Memory

DECISION: AMENDMENTS APPROVAL

Dear Haonan,

The Bard Institutional Review Board has reviewed and approved your amendment submitted on 2-28-2023 to protocol 2022DEC05-CHE.

Please notify the IRB if your methodology changes or unexpected events arise.

We wish you the best of luck with your research.

Ziad M. Abu-Rish, Ph.D.
IRB Chair
Associate Professor of Human Rights and Middle Eastern History
Bard College
zaburish@bard.edu

Email: irb@bard.edu | **Website:** https://www.bard.edu/irb | **Phone:** 845-758-6822
PO Box 5000, Annandale-on-Hudson, New York 12504-5000

Appendix C: Preregistration

Contributors

Haonan Chen

Date Registered

February 6th, 2023

Affiliated institutions

This registration has no affiliated institutions

Have any data been collected for this study already? Note: 'Yes' is a discouraged answer for this preregistration form.

No, no data have been collected for this study yet.

Hypothesis

The experiences in our lives can be broken up into a series of events, even though one event flows into the next. We do this naturally, but individuals can differ on where they draw the dividing line between one event and the next. Researchers have been investigating the factors that influence the placement of these so-called event boundaries and the consequences of those placements (e.g., on the ability to later remember details from those events). Event segmentation theory suggests that people parse a continuous stream of activity into separate meaningful events (segments); the pauses between each segment are known as the boundaries of events (Zack & Swallow, 2007). This notion is being increasingly supported by literature that highlights its significant cognitive ramifications such as memory (Kurby & Zacks, 2008) and attention (Bezy, Kibbe & Mills, 2013). However, it is still unclear how the boundary of an event influences people's memory about the information they perceive after segmentation. Because emotional stimuli have been demonstrated to affect perception and attention, I will be utilizing them in the current study to investigate the influence of event boundaries on participants' memory. I hypothesize that participants who receive positive emotional stimuli placed at a naturally occurring boundary will have a better recall of details and sequences about the TV show than participants who received neutral stimuli. And participants who receive emotional stimuli placed at a naturally occurring boundary will have a better memory of details and sequence about the

TV show than participants who received emotional stimuli outside of the event boundary (e.g., during an ongoing event).

Dependent variable

Participants' memory of the given video after different interventions.

Conditions

How many and which conditions will participants be assigned to?

There will be 4 conditions in the 2 x 2 design. All of the participants are going to watch the same episode of a TV show. Participants will be randomly assigned to each condition. Prior knowledge on the spot of event boundaries is from one of the articles by Boltz in 1992.

1) Participants will receive positive emotional stimuli at the points where the known event boundaries are.

2) Participants will receive neutral emotional stimuli at the points where the known event boundaries are.

3) Participants will receive positive emotional stimuli at points outside of known event boundaries.

4) Participants will receive neutral emotional stimuli at points outside of known event boundaries.

There will also be a control group to confirm whether the boundaries identified through previous research (Boltz, 1992) generalize to the current population under investigation. This control group will be asked to watch the same episode as other participants but without automatic interruptions. Instead, they will be asked to press a button on the keyboard whenever they feel that the previous event ends and a new event has occurred, aka. at the event boundary.

Analyses

I will conduct a two-way ANOVA to formally test whether or not the independent variables have a statistically significant relationship with participants' memory of the given video after different interventions.

Outliers and Exclusions

I will be excluding the data from participants who did not follow instructions.

There will be 2 or 3 filter questions in the questionnaire that will help me to exclude the data from those who answer the questions without reading them.

I will be using the interquartile range to distinguish outliers from other data. I'll take 1.5 times the IQR and then subtract this value from Q1 and add this value to Q3. Any observations that are more than 1.5 IQR below Q1 or more than 1.5 IQR above Q3 are considered outliers.

Sample Size

44 observations will be collected. The sample size is determined by an a priori power analysis conducted using a calculator provided by www.danielsoper.com, based on data from Peterson et al., (2021). The effect size in Peterson et al.,'s study was 0.80, considered to be large using Cohen's (1988) criteria. With a significance criterion of $\alpha = .05$ and power = .80, the minimum sample size needed with this effect size is N = 42. Since I could not have fractional participants in a condition, I am proposing to increase the overall number of participants from 40 to 44, which would include 11 participants for each of the four conditions.

Other

Nothing else to pre-register.

Name

The Effect of Emotional Stimuli Within Event Boundaries on Memory, Bard College Senior Project, 2023, Haonan Chen

Finally

Experiment

Other

No response

Appendix D: Informed Consent Form

INFORMED CONSENT AGREEMENT
BARD COLLEGE

Title: The Effect of Emotional Stimuli Within Event Boundaries on Temporal Memory
Principle Investigator: Haonan Chen

You are being asked to take part in a research experiment at Bard College that's investigating the effect of emotions on event memory. To decide whether or not you wish to participate, you should know enough about its risks and benefits to make an informed judgment. This consent agreement gives you information about the research study, and the experimenter will provide you with additional information about the specific tasks that you will be performing. Once you are ready, you will be asked if you wish to participate and, if so, to sign the consent form at the bottom. You can choose not to participate, and you can choose to end your participation at any time during the study, even if you do.

Background:

This study is investigating how presenting emotional materials at different places in a video affects memory.

Experimental Tasks:

In this study we will ask participants to watch part of a TV show with some "breaks" preceding or during the show. The "breaks" will actually be short video clips selected because of their positive or neutral emotional qualities. While watching the videos, some participants may be asked to press a keyboard button to indicate when they have perceived an event boundary (i.e., in their judgment, an event ends and another starts). After this, participants may be asked about what they remembered from the videos. This work will be carried out in person with the researcher at Bard College. Participation is expected to take approximately 17 minutes.

Risks and Benefits:

Risks for this study are minimal. While watching the videos will demand participants' attention, the total viewing will be kept to under 13 minutes. Participants should also be reminded that, should they become fatigued or in any way uncomfortable during the experiment, they may withdraw at any time without penalty.

The video and emotional stimuli participants may encounter during the experiment are intended to be neutral or positive. Still, should anyone feel uncomfortable watching the videos, they only need to alert the experimenter in order to stop the experiment.

While this research experiment may not provide participants with any direct benefits, the data collected from this study may help improve the scientific understanding of the effect of emotional stimuli within event boundaries on people's memory. Moreover, the researcher hopes that participants gain insight into the research process at Bard College through their involvement with this experiment.

Compensation:

As a token of appreciation for their time and effort, participants will be invited to enter their name and email in a raffle for a chance to win a $100 Amazon Gift card. The winner will be selected at random by May 11th and alerted via email.

Participant Rights:

Participation in this experiment is completely voluntary, and participants may opt to skip any portion of the experiment or fully withdraw from the experiment at any time without penalty. Once participation in the study is complete, a debriefing statement will be provided to you describing the specific aims of the study.

Confidentiality:

Data collected during the experimental tasks will remain separate from participants' identifying information (e.g., name on their consent form and contact information for the raffle). All information provided through the Qualtrics platform will be temporarily stored on their servers in Michigan, USA. Their security statement is accessible via this link: https://www.qualtrics.com/security-statement

While it is stored there, it is only accessible to the primary investigator through their password-protected account. At the conclusion of data collection, data will be stored offline on a password-protected computer to which only the primary investigator has access.

The emails and names participants provide to get in a raffle for a chance to win a $100 Amazon Gift card will be used only for the raffle. The privacy policy of the raffle website is accessible via this link: https://www.galabid.com/global-privacy-policy?&lang=US

Study data will be reported only in aggregate for my Senior Project, which will be permanently and publicly available in the Bard College library and online through the Digital Commons.

Contact:

If you have questions about this study, please ask your researcher during the experiment or contact Haonan Chen (hc8358@bard.edu) or his Senior Project supervisor, Prof. Justin Hulbert (jhulbert@bard.edu). If you have questions about your rights as a research participant, please contact the Bard College Institutional Review Board at irb@bard.edu.

Agreement:

The nature and purpose of this research have been sufficiently explained and I agree to participate in this study. I understand that I am free to withdraw at any time without incurring any penalty.

By signing below, I agree with the above statement of consent and further certify that I am at least 18 years of age and am fluent in English.

______________________________	______________________________
Signature of Participant	Signature of the Researcher
______________________________	______________________________
Print Name	Date

Appendix E: Debriefing Statement

Please Keep This Sheet For Your Record

Title: The Effect of Emotional Stimuli Within Event Boundaries on Temporal Memory
Researcher: Haonan Chen
Contact Information: hc8358@bard.edu

Thank you for participating in this study!

The general purpose of this research is to investigate how presenting emotional materials at different places in a video affects people's memory. During the study, you watched part of an episode from *A Perfect Spy* and several positive or neutral stimuli in different locations of the episode. You then were asked to fill out a questionnaire that tested your memory on the show.

As a token of appreciation for your time and effort, you will be invited to enter your name and email in a raffle for a chance to win a $100 Amazon Gift card. The winner will be selected at random by May 11th and alerted via email. Good luck!

The information you provided will remain confidential and safeguarded against improper access or dissemination.

You are welcome to ask your experimenter now if you have any remaining questions or contact Haonan Chen (hc8358@bard.edu) or his Senior Project supervisor, Prof. Justin Hulbert (jhulbert@bard.edu). If you have questions about your rights as a research participant, please contact the Bard College Institutional Review Board at irb@bard.edu.

If you are distressed by any aspect of the experiment, please contact the Bard Counseling Center at 845-758-7433 during normal business hours or 845-758-7777 after hours or on weekends.

Again, I would like to thank you for your participation. Please do not discuss this study with any friends or acquaintances who are eligible to participate until they have had the opportunity to participate. Prior knowledge of the study's questions may invalidate the results.

Your cooperation is greatly appreciated.

Appendix F: Questions and Instructions after the Video Watching

Filler Task

In 2 minutes, please write down names of cities as much as possible:

Good Job, the next section includes several questions. You will be answering the questions on an answer sheet. You can go from a question to the next by left-clicking the mouse.

Please try to select the best answer from the episode you just watched.

If you don’t know the answer, just choose “I don’t know”.

Memory Tests

Question #1

On a scale of 0 to 10, how well have you remembered the episode?

0: I remember nothing - 10: I remember everything

Question #2

Please choose the scene from the episode you just watched:

A.

B.

C. I don’t know

Question #3

Please choose the scene from the episode you just watched:

A.

B.

C. I don’t know

Question #4

Recall the actions from the video in order in which you saw them as detailed as possible.

Question #5

Did the man take his gun with him to the prison?

A. Yes.
B. No.
C. I don’t know.

Question #6

What is the major color of the Police car?

A. White.
B. Blue.
C. Black.
D. Yellow.
E. I don’t know.

Question #7

"I'd like to know more about _______. Next time..."

Please choose the name that fits in the blank.

A. Jessy
B. Mary
C. Alice
D. Zoe
E. I don’t know.

Question #8

What was the man wearing when he ran to the bathroom after hearing the police coming?

A. Pajama.
B. Bath towel.
C. T-shirt.
D. Nothing.
E. I don’t know

Question #9

Who did the man meet in the prison?

A. His friend.
B. His father.
C. His supervisor.
D. A stranger.
E. I don’t know.

Question #10

In this scene, How many times did the man put photos on the table?

A. 2
B. 3
C. 4
D. 5
E. I don’t know.

Question #11

Who is described as “A long-stemmed English Rose”?

Appendix G. Answer Sheet

Names of Cities:

____

____

____

____

____

1 _____

2 _____

3 _____

4 Please follow the researcher's instructions.

5 _____

6 _____

7 _____

8 _____

9 _____

10 _____

11 _____

Participant's Number: ___