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THEORETICAL/REVIEW

Toward an integrative account of internal and external determinants of event segmentation

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Abstract
Our daily experiences unfold continuously, but we remember them as a series of discrete events through a process called *event segmentation*. Prominent theories of event segmentation suggest that event boundaries in memory are triggered by significant shifts in the external environment, such as a change in one's physical surroundings. In this review, we argue for a fundamental extension of this research field to also encompass *internal* state changes as playing a key role in structuring event memory. Accordingly, we propose an expanded taxonomy of event boundary-triggering processes, and review behavioral and neuroscience research on internal state changes in three core domains: affective states, goal states, and motivational states. Finally, we evaluate how well current theoretical frameworks can accommodate the unique and interactive contributions of internal states to event memory. We conclude that a theoretical perspective on event memory that integrates both external environment and internal state changes allows for a more complete understanding of how the brain structures experiences, with important implications for future research in cognitive and clinical neuroscience.

Keywords Event segmentation · Event boundaries · Episodic memory · Internal states

Introduction

Our memories of past events are accompanied by rich contextual details: recalling a friend's recent wedding brings to mind sunset at the outdoor venue, conversations with other guests, as well as internal thoughts and emotions at the time. Many accounts of how the mind structures experience (event cognition) propose that changes in the external environment such as a shift in the scenery can organize events in perception and memory, where experiences that occur under the same context are grouped together (Clewett et al., 2019; Radvansky & Zacks, 2017; Zacks et al., 2001, 2007). Though it may be intuitive that a moment of sudden insight can generate a change in context just like a shift in the physical environment, how such an internal context shift may impact memory organization has not been addressed much in the prior literature.

In this review, we argue that this under-appreciated factor of internal state change is in fact an important determinant of event perception and memory, and we aim to explore and situate it within a broader framework of discontinuities in external stimulation and internal states (Fig. 1). An experienced or observed event can be defined as a segment of time at a given location that has a beginning and an end (Zacks & Tversky, 2001). The beginning and end of events are typically attributed to discontinuities or changes in the sustained event representation for the observer (Ezzyat & Davachi, 2011; Zacks et al., 2007). Our main contention here is that the event memory literature has near-exclusively focused on changes in external stimulation (such as moving to a different room, observing a change in an agent's behavior, etc.) at the cost of considering changes in internal states as possible markers of the beginning or end of an event. By contrast, we contend that sustained event representations include internal states such as goals, affective states, and motivational states. When the environment is stable, sustained event

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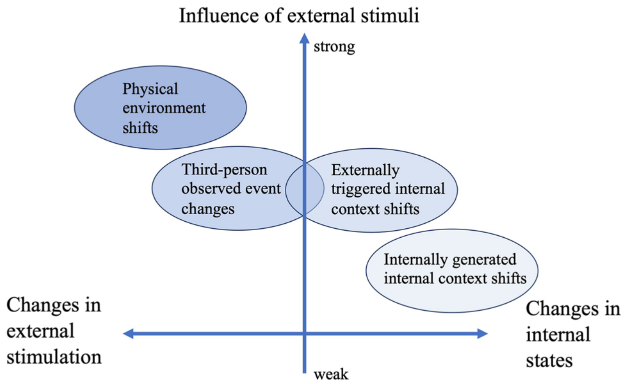

Fig. 1 Proposed taxonomy of event boundary triggers based on the source of discontinuity in sustained event representation. The literature on event segmentation has largely focused on changes in external stimulation, such as shifts in the physical environment or observed event changes when reading a narrative or watching a video. We propose that changes in internal states also contribute to event segmentation. Such internal state changes can be triggered by external stimuli (such as being presented an aversive image) or generated entirely internally (as in the case of voluntary task switching). Third-person observed event changes involve the construction and internal representation of contexts based on the observer's existing event schemas, therefore they touch on internal states despite being largely driven by external changes. Externally triggered internal state shifts are mainly related to changes in internal context, nevertheless the trigger for these changes come from the external environment. Thus, both categories straddle the line between external stimulation change and internal state change, represented as a small area overlap

representations can slowly drift over time, with the representations for consecutive memoranda being similar, thus supporting successive binding in memory (DuBrow et al., 2017). Critically, event representations can shift abruptly at event boundaries such as a change in the external physical environment (Radvansky & Copeland, 2006) or a change in internally maintained task goals (Polyn et al., 2009b; Wang & Egner, 2022), resulting in memory discontinuities.

Internal state changes can be classified into two broad categories: those that are externally triggered and those that are endogenously generated. For example, a cue signaling a shift in task rules triggers a change in internal goal state (e.g., Polyn et al., 2009b), and a cue signaling a shift in the amount of reward available influences internal motivational state (e.g., Rouhani et al., 2020). Those would be examples of externally triggered internal state changes. In contrast, endogenously triggered changes are not the direct result of a shift in perceptual input. For instance, suddenly remembering an unfinished task in absence of any external cue may trigger a shift in goal state and thus a change in internal context. This kind of shift is internally generated and occurs independent of percept. A recent review has proposed that internally driven event segmentation can occur in the absence of external changes or with minimal external changes, suggesting endogenously generated neural activities such as hippocampus sharp wave ripples (SWRs) as the cellular-level mechanism based on a large body of research in non-human animals (Ross & Easton, 2022). Here, we extend this idea by proposing a novel classification scheme of event boundaries based on their internal or external origin. Moreover, rather than focusing on the level of spontaneous changes in cellular dynamics, we here primarily draw from cognitive neuroscience and psychology studies in humans, focusing our discussion of internally driven event segmentation at the level of subjective internal state changes, such as affective states, goal states, and motivational states.

What does studying internal state changes add to our understanding of event segmentation? We argue that investigating the influence of both externally triggered and endogenously generated internal changes provides a more complete view on event organization. Memory continuity and segmentation are two sides of the same coin in understanding the structure of event memories. Internal states, such as goals, affective states, and motivational states, play an important role in successive binding of memory within events, and changes in internal states should be considered potential triggers that can disrupt memory continuity and create boundaries between events. Accordingly, even when the external environment is stable and continuous, changes in internal states could nonetheless segment events in memory. Instead of reviewing how internal states contribute to the formation of event memories more generally, in this paper we focus on event boundaries and segmentation specifically, as these breakpoints rather than continuities in experience have received greater attention in the empirical literature and existing theoretical perspectives. Hence, they provide a suitable entry point into understanding how internal states influence the segmentation and structure of event memories.

Furthermore, consideration of internal state changes in event perception and memory also has potential clinical significance. For example, schizophrenia has been associated with deficits in executive functions and maintaining a goal state (Poppe et al., 2016), sustaining an emotional state despite normal in-the-moment emotional experiences (Gard et al., 2011), as well as motivational impairments (Strauss et al., 2014). Deficits in task set shifting, or updating one's internal goal states, have also been reported in adults with attention deficit hyperactivity disorder (ADHD) (Rohlf et al., 2012) and Parkinson's disease (Monchi et al., 2004). Greater understanding of how internal states and internal state changes impact how people make sense of everyday experiences and organize them in memory has the potential to clarify how these processes may go awry in psychopathology and contribute to the development of therapeutic interventions.

In the following sections, we first summarize key behavioral and neuroscience findings in the event boundary literature, and delineate a novel classification scheme of event-triggering context changes according to their origin: external or internal. We then review evidence for event segmentation driven by changes in internal states in three core domains: affective states, goal states, and motivational states. While most of the empirical evidence comes from studies manipulating external cues that drive internal changes, a small but notable minority shed light on endogenously generated discontinuities in sustained event representations. Next, we review prominent models of event segmentation and examine how these perspectives – many of which were primarily developed to account for event segmentation effects in narrative reading, video watching, and list learning paradigms – may or may not be able to accommodate internally generated shifts in internal states as an additional driver of event memory. Lastly, we propose some novel approaches that leverage behavioral and neural markers of internal state change to investigate endogenously generated shifts in event representations as a future research target.

Event boundaries structure episodic memory

Behavioral effects of event segmentation

Everyday activities are experienced continuously, yet they are grouped into distinct events in perception and memory through a process called event segmentation. In this section, we present a brief summary of a number of behavioral phenomena that characterize the impact of event segmentation on episodic memory. Rather than providing an exhaustive overview, we highlight several key memory effects of event segmentation that have often been used to determine the presence of event boundaries in behavioral paradigms (see Table 1).

First, event segmentation prioritizes the encoding of boundary-related information, as reflected in enhanced memory for stimuli presented at the boundary (Boltz, 1992; Schwan & Garsoffky, 2004; Swallow et al., 2009). For instance, when participants were shown a movie and later completed recognition memory tests, scenes from around event boundaries were better recognized than scenes from the middle of events (Boltz, 1992). Additionally, source memory for boundary items is superior to that for items in non-boundary positions due to enhanced item-context binding (Clewett et al., 2020; Heusser et al., 2018; Siefke et al., 2019). These results support the idea that salient contextual changes that trigger event segmentation recruit attentional mechanisms at event boundaries, leading to enhanced recognition and source memory (Clewett et al., 2019; Zacks et al., 2007).

Second, event boundaries not only enhance memory for boundary-related information but also influence the temporal aspect of episodic memory. Studies that contrast memory for information from the same event with memory for information encoded across different events illustrate how event boundaries disrupt successive memory binding. Items encoded across an event boundary exhibit reduced sequential binding, as evident in reduced accuracy for cued recall across a boundary (Ezzyat & Davachi, 2011). Furthermore, depending on whether retrieval context information is present at the time of memory test, event boundaries can either impair or enhance temporal order memory accuracy for item pairs encoded across a boundary (Clewett et al., 2019, 2020; Clewett & Davachi, 2021; DuBrow & Davachi, 2013, 2014; Heusser et al., 2018; Horner et al., 2016; Rouhani et al., 2020; Sols et al., 2017; Wen & Egner, 2022). For example, in one study

Table 1 Key memory effects of event boundaries

Behavioral effect	Studies
Enhanced recognition memory for information presented at boundaries	Boltz, 1992; Schwan & Garsoffky, 2004; Swallow et al., 2009
Enhanced source memory for boundary items	Clewett et al., 2020; Heusser et al., 2018; Siefke et al., 2019
Impaired cued recall accuracy across a boundary	Ezzyat & Davachi, 2011; Sols et al., 2017
Impaired temporal order memory accuracy across a boundary	Clewett et al., 2019, 2020; Clewett & Davachi, 2021; DuBrow & Davachi, 2013, 2014; Heusser et al., 2018; Horner et al., 2016; Rouhani et al., 2020; Sols et al., 2017; Wang & Egner, 2022; Wen & Egner, 2022
Expanded estimation of temporal distance between items across a boundary	Brunec et al., 2020; Clewett et al., 2019, 2020; Ezzyat & Davachi, 2014; Lositsky et al., 2016; Rouhani et al., 2020; Wang & Egner, 2022; Wen & Egner, 2022
Over-estimation of temporal duration for intervals containing more boundaries	Bonasia et al., 2016; Faber & Gennari, 2015; Jeunehomme & D'Argembeau, 2018; Lositsky et al., 2016; Poynter, 1983
Reduced serial transition across boundaries in free recall	DuBrow & Davachi, 2016; Heusser et al., 2018; Polyn et al., 2009b

that defined event boundaries using shifts in stimulus categories and category-specific tasks, participants remembered the relative order of stimuli that spanned an event boundary less accurately (DuBrow & Davachi, 2013). Other studies have found that compared to item pairs within the same event, items encoded across a boundary are also remembered to be farther apart in time (Brunec et al., 2020; Clewett et al., 2019, 2020; Ezzyat & Davachi, 2014; Lositsky et al., 2016; Rouhani et al., 2020). Relatedly, temporal intervals that contain a greater number of event boundaries or perceived number of events have been associated with over-estimation of retrospective duration judgments (Bonasia et al., 2016; Faber & Gennari, 2015; Jeunehomme & D'Argembeau, 2018; Lositsky et al., 2016; Poynter, 1983). Together, these results show that event segmentation not only affects how we remember the order of events, but also influences our memory of time itself.

Finally, the impact of event boundaries on the temporal organization of memory is also evident in free recall. In one study, when participants recalled a list of items interspersed with event boundaries, serial transitions were less likely for boundary items compared to non-boundary items, whereas non-serial jumps to boundary items were made more frequently (DuBrow & Davachi, 2016). Similarly, the likelihood of recalling the next item from the encoding list (local forward transition) is lower for items right before a boundary (the last item in an event) compared to boundary items (the first item in the next event), while distal forward transitions are more likely for items right before a boundary (Heusser et al., 2018). In addition, one study found that boundary items are more likely to be recalled compared to non-boundary items, and items within the same event tend to cluster together (Polyn et al., 2009b). These findings suggest that event segmentation disrupts sequential binding across events while enhancing between-item binding within events.

In summary, event segmentation produces a range of robust effects on recognition memory, temporal memory, and free recall, resulting in enhanced memory for information experienced at the boundary but reduced sequential binding for items encoded before and after a boundary (see Table 1). Conversely, items from the same event sharing similar representations are more closely bound in memory. Accordingly, as we see later in this review, these memory signatures are commonly employed as outcome measures to provide evidence for event segmentation in studies that employ novel manipulations of changes in context, including internal states, that may or may not affect the parsing of experience into discrete events.

Neural mechanisms of event segmentation

In addition to the behavioral findings reviewed above, many neuroscience studies have shed light on the underlying neural mechanisms of event segmentation. These findings have identified a number of brain regions, such as the hippocampus, as playing a key role in representing distinct events. As we discuss later in this review, these same brain regions are also sensitive to changes in internal state and therefore provide a potential mechanism for event segmentation as a result of internal state shifts.

Converging evidence has shown that activity in the medial temporal lobe, in particular the hippocampus, is sensitive to event segmentation (see Ross & Easton, 2022, for a recent review on the physiological mechanisms). For instance, a recent study identified single neurons in the human medial temporal lobe (including the hippocampus, parahippocampal gyrus, and amygdala) that are responsive to event boundaries and whose boundary firing activity was predictive of later recognition and temporal order memory performance (Zheng et al., 2022). Relatedly, neuroimaging studies have shown that activity in the hippocampus is sensitive to the end of events, and this boundary-related hippocampus activity has been linked to subsequent memory success (Ben-Yakov & Dudai, 2011; Ben-Yakov & Henson, 2018; DuBrow & Davachi, 2016). Furthermore, stability in hippocampal activity patterns across an event boundary is predictive of temporal order memory success for items encoded across a boundary as well as subjective temporal distance (DuBrow & Davachi, 2014; Ezzyat & Davachi, 2014). Together, these results suggest that both single-unit activity and multivariate activity patterns in the medial temporal lobe and in particular the hippocampus carry information about event boundaries and temporal context.

In addition to boundary-related activity, interactions between the hippocampus and various cortical areas are also important for sustaining ongoing representations within events, both of which are critical to the formation of event memories. Specifically, it has been proposed that hippocampus interactions with adjacent regions in the medial temporal lobe and posterior medial cortex bind features together to form coherent event representations (Ranganath & Ritchey, 2012). Another study has found that within-event memory integration is associated with a gradual increase in activity in the medial temporal lobe, ventral striatum, and medial prefrontal cortex over the course of an event (Ezzyat & Davachi, 2011). Using fMRI pattern similarity analysis, a recent study found that when objects persisted within a mental model during stable events, activity in the object-sensitive left occipital cortex was more similar compared to between events, which was correlated with activity in the medial prefrontal cortex (Ezzyat & Davachi, 2021). In addition, functional connectivity, as inferred from fMRI time-series correlations, between the hippocampus and ventromedial prefrontal cortex (vmPFC) during encoding has been associated with later sequential recall of items within the same event (DuBrow &

Davachi, 2016). Thus, these hippocampus-cortical interactions may play a crucial role in maintaining a stable context during the ongoing encoding of an event.

Finally, fMRI studies have found that different brain regions support event segmentation on distinct timescales, providing neural evidence for hierarchical event segmentation observed in many behavioral studies. When describing ongoing activities and recounting activities from recent memory, people are able to segment events at both coarse and fine timescales, where coarse event units comprise of finer-grain sub-events (Hard et al., 2006; Zacks et al., 2001, 2007). A recent study using naturalistic film stimuli found that online brain-activity patterns are structured as nested events with timescales varying from seconds to minutes along the cortical hierarchy, with sensory regions sensitive to fine-grained changes while higher-order regions (including the angular gyrus and the posterior medial cortex) as well as the hippocampus respond to longer-scale events (Baldassano et al., 2017). These longer-scale events are consistent with human-annotated event boundaries in the film. Another study reported similar findings of hierarchically nested neural states that are shorter for sensory regions and longer for lateral and medial prefrontal cortex, and neural state boundaries across the cortical hierarchy overlapped with subjectively perceived event boundaries (Geerligs et al., 2022). Preliminary evidence suggests that hippocampus responses to event boundaries may be supported by theta organized activity at the cellular level (Ross & Easton, 2022). In everyday life, experiences structured by internal states (rather than the narrative arc in a film) may also have a hierarchical structure, such as an overarching goal state that encompasses a number of sub-goals. How events structured by internal states at different timescales are represented in the brain is an open question for future research.

To sum up, the hippocampus, a crucial region for episodic and temporal memory, is sensitive to event boundaries. Temporal stability in hippocampal multivariate activity patterns supports the maintenance of a stable context that allows successive memory integration (see Clewett & Davachi, 2017, for a review). Furthermore, fMRI studies have found that activity in the prefrontal cortex, the posterior medial cortex, and the medial temporal cortex also plays an important role in event segmentation and event binding. Interestingly, these regions largely overlap with the Default Mode Network, which has been shown to be involved in a wide range of cognitive functions from episodic memory and situation model construction to abstract thought (Raichle, 2015; Ranganath & Ritchey, 2012; Smallwood et al., 2021). Hence, it is plausible that events structured by external environment and internal states share similar neural representations, and event representations in these regions may provide a potential neural mechanism to track the continuity of, and changes in, internal states.

Categories of event boundaries

As reviewed above, prior research has identified a number of brain regions involved in event segmentation and a broad range of behavioral effects of event boundaries on memory, but the precise conditions giving rise to event boundaries are not yet fully understood. According to one prominent account, Event Segmentation Theory, observers construct internal mental models of the ongoing event based on perceptual input in the moment and conceptual knowledge of the event type (Zacks, 2020; Zacks et al., 2007). These event models, which are working memory representations of ongoing activities during encoding, are used to predict the upcoming sensory inputs. When a major change in perceptual information (such as object position) or conceptual information (such as an actor's goals in a movie) is observed, predictions generated from the current event model become less accurate and prediction errors increase. Such increases in prediction error are thought to generate event boundaries, whereby the working memory representation of ongoing events is reset and updated to a model befitting the new event (Zacks et al., 2007). These external changes trigger a cascade of internal operations such as attention allocation that support event representation updating. Empirical findings showing the relative inaccessibility of before-boundary information support the idea of a working memory reset. For example, it has been shown that recognition memory for objects from the previous event is reduced compared to recognition memory for objects from the current event, despite identical delays of several seconds between object presentation and test in both cases (Swallow et al., 2009).

However, event boundary is not a unitary construct. Perspectives that rely on prediction errors to explain event segmentation account for the category of event change where the changes are external, such as shifts in physical surroundings. For instance, emerging from the subway and stepping into a city park can trigger an update in the ongoing event model that generates new predictions for perceptual inputs that one may encounter in the context of the park. A subset of the external change category reflects event segmentation from an observer's perspective, commonly used in laboratory experiments of event segmentation, such as when a person is watching a film or reading a narrative where there is a change in the actor's activity or a phrase indicating time passing (Ezzyat & Davachi, 2011; Hard et al., 2019; Schwan et al., 2000; Speer & Zacks, 2005). In this case, the environment and changes thereof are largely constructed based on the individual's internal representations and event schemas. Changes in the external environment here are not experienced physically as in active first-person experiences, where such changes bear greater implications for action (e.g., looking out for traffic when crossing the street after a subway ride). For this reason, third-person observed event changes are separated from first-person physical environment changes in our proposed scheme, even though they are both changes in external stimulation. (Fig. 1).

In contrast, some event boundaries may result from changes in internal states, such as shifts in a person's own goal state, emotional state, or motivational state (Fig. 1, horizontal axis). Here, event segmentation related to internal state changes can be further divided into two categories: those that are triggered by external stimuli and those that are generated entirely internally (Fig. 1, vertical axis).

The first category is seen more frequently in empirical studies. For example, a visual or auditory stimulus with negative valence can initiate a change in the participant's affective state, and both the emotional stimulus and the internal state change could contribute to event segmentation (Clewett & Davachi, 2021; Talmi et al., 2019). Similarly, a cued change in encoding task during word list learning can produce a change in the participant's internal goal state, which also leads to event segmentation effects during subsequent recall (Polyn et al., 2009b). Here, the shift in internal states is directly linked to a stimulus in the external environment. Such environmental cues that trigger a shift in internal states often also signal a change in the causal structure. For example, hearing the sounds of a wild animal approaching might turn a camper's peaceful state of mind into a state of heightened arousal, a shift in internal affective states that would be accompanied by an inferred causal break. The auditory cue, the change in internal states, and the causal structure could all contribute to segmenting events of the evening. Most of the empirical evidence reviewed in the following sections fall under this category of internal state shift as a consequence of external stimuli. For this type of event boundaries, the respective contributions of the external stimulus change and the resulting internal state shift to event parsing are difficult to tease apart.

The second category of event boundaries related to internal state change, which occurs independent of external stimuli, is harder to experimentally manipulate but is abundant in anecdotal experience. For example, a sudden moment of insight, a shift in internal attention, a spontaneous memory or a change in mood could demarcate the onset of a new event. Internally generated goal state changes, such as spontaneously remembering a task without any discernable external cue or reminders, can bring about causal consequences through actions. In such instances, changes in internal states lead to, rather than result from, breaks in the causal connectivity between events, which is an essential element in event memory (Radvansky, 2012; Radvansky & Zacks, 2017). Accordingly, a recent study found that voluntary task switches, which were goal state changes generated entirely internally by the participants, created event boundaries that impacted subsequent temporal order and distance memory (Wang & Egner, 2022). This is important because in this experiment, the event boundaries generated by voluntary changes in goal states occurred independent of any external sensory inputs or prediction errors, which means that prediction errors do not account for all cases of event segmentation. While this study provides initial empirical support for internally driven event segmentation, more research is needed to fully understand the similarities and differences between endogenously generated event boundaries and externally triggered event boundaries in behavioral memory effects and neural underpinnings. The concept of internally generated event boundaries is of theoretical importance because their origin and the sequence of neural processes giving rise to them would naturally be expected to differ from those involved in externally triggered event boundaries. We consider this a crucial gap in the current literature, but as we elaborate below, the mind-wandering literature, which studies spontaneous shifts in mental states, and the literature on changes in neuromodulatory states may provide important insights into internally generated event boundaries.

In summary, we argue that event boundaries can be categorized as due to changes in either external stimulation or internal states (Fig. 1), and that within each of these categories, there are different subtypes based on the origin of the boundary trigger. Changes in external stimulation may include first-person experiences in shifts in physical surroundings, such as walking through a doorway, as well as observed changes from a third-person perspective in reading or viewing a narrative, where the actual shifts in sensory inputs are minimal. As for event boundaries related to changes in internal states, they could be either triggered by an external stimulus, such as a task-switching cue, or be entirely internally generated independent of any external input, for example in voluntary task switching (Wang & Egner, 2022). In other words, internal state changes can occur with or without environmental changes: a researcher sitting at the same desk all day may shift their thinking in response to different prompts on the computer screen, or they may move on to a new train of thought without any external cues. While in the former case changes in internal goal states could be the consequences of environmental changes, in the latter case event boundaries are created by internally generated internal state changes. Using this novel classification scheme as a guide, we next review (and in some cases, reinterpret) empirical findings relevant to event segmentation driven by changes in internal states, namely, affective states, goal states, and motivational states.

Affective states

Affective state changes influence temporal memory

The literature on the interplay between affect and memory is vast, and a thorough review is beyond the scope of this paper. We therefore focus primarily on affective state changes induced by emotionally charged stimuli, such as an aversive sound or image, which fall under the category of internal state change triggered by external stimuli. Since a major hallmark of event memory is temporal order between items in an event and separation between events, we limit the review to studies that examine some aspect of temporal memory.

Several studies using emotional stimuli to manipulate participants' affective states found that changes in affective states have temporal memory effects similar to those that characterize event segmentation. One recent study using a sequential item encoding paradigm typical in event segmentation experiments tested this question most directly. In this study, participants viewed a series of objects each accompanied by a tone that created an auditory context, and the tone changed in source (left vs. right ear) periodically throughout the task (Clewett & Davachi, 2021). Each change in auditory context was preceded by a short naturalistic audio clip of positive, negative, or neutral valence, which established "affective event boundaries." This study found that compared to neutral audio clips, highly arousing, negative valence audio clips were associated with impaired temporal order memory for items spanning an event boundary, indicating a disruption in sequential temporal binding. Crucially, relative to neutral event boundaries, these negative, high-arousal event boundaries also enhanced order memory for the subsequent within-event item pair, when the within-event pair was close to the boundary but not far from it, suggesting a carryover effect of negative arousal that integrates an emotionally relevant episode. Another recent study that used custom musical stimuli to elicit different emotional states during encoding of a series of images found that changes in emotional valence created event boundaries in memory, and that the size of valence shifts predicted the magnitude of boundary-related temporal order and distance memory effects (McClay et al., 2022). Furthermore, the direction of valence shift also impacted temporal organization of memory, where more positive change in emotional states were associated with greater temporal compression and integration (McClay et al., 2022). Taken together, these results provide evidence that changes in affective states – in this case induced by affectively charged auditory stimuli – created event boundaries that disrupted across-event binding and enhanced within-event binding.

Although the studies discussed above only measured behavioral effects, findings from prior research can help explain the underlying neural mechanism by which affective state changes may give rise to these temporal order memory effects. One candidate mediator is the arousal-related noradrenergic system, since increases in arousal share similar effects on temporal order memory as boundary-triggering contextual shifts. Event boundaries (not induced by affective stimuli) have been shown to elicit transient increases in autonomic arousal, as indexed by pupil dilation, which increases in response to phasic norepinephrine release (Clewett et al., 2020; Reimer et al., 2016). Other prior research has also implicated the noradrenergic system in memory selectivity under arousal (Mather et al., 2016). In particular, the noradrenergic system has been shown to modulate memory processes in the hippocampus, which is a critical region for representing temporal order and temporal context (Clewett et al., 2019; Harley, 2007; Hsieh et al., 2014). However, most studies to date have only examined the influence of emotional arousal on temporal order memory using behavioral methods, and future research is needed to provide a more direct link of how activities of the noradrenergic system might map onto affective state change triggered event segmentation.

In addition to boundary-related temporal order memory effects, other studies in the time-perception literature suggest that affective states also influence temporal duration perception, which has also been associated with event segmentation. Physiological arousal and attentional control can contribute to emotional distortions in time perception both independently and interactively (Lake et al., 2016). In prospective timing studies, emotional stimuli can lead to overestimation or underestimation of duration depending on their task relevance (Lake et al., 2016). Prospective and retrospective timing tasks using taboo words (which were rated as more negative and more arousing) and neutral words found that the duration of intervals involving taboo words were underestimated in prospective timing tasks and overestimated in retrospective timing tasks (Johnson & MacKay, 2019). These results are consistent with the finding that retrospective duration judgments are longer for intervals involving a greater number of event boundaries (Faber & Gennari, 2015), while prospective timing judgments tend to be shorter when attentional resources are allocated to stimulus processing rather than temporal information processing (Block & Zakay, 1997). In other words, negative and highly arousing stimuli, such as taboo words (Johnson & MacKay, 2019), can likely act as event boundaries that impact our perception and memory for time.

The studies discussed above used discrete emotional stimuli to elicit momentary shifts in affective states, whereas other studies found that the impact of emotional stimuli on temporal context binding is influenced by sustained affective states as well. One study found that temporal order memory accuracy was lower for sequences of high-arousal images than sequences of low-arousal images, and that this effect was more pronounced in participants who reported high state anxiety (Huntjens et al., 2015). Moreover, a study that asked participants to segment and then recall highly negative, stress-inducing, and neutral film clips found that stress-inducing clips increased state anxiety in participants, and that higher state anxiety was associated with more normative segmentation performance (i.e., identifying the same event boundaries as the rest of the participants) while normative segmentation performance was negatively correlated with stressful event recognition (Sherrill et al., 2019). This is especially interesting as prior studies using neutral materials did not find more normative segmentation performance to be predictive of lower memory performance. Exploratory analyses found that participant-identified event boundaries in the stressful clip were mostly related to perceptual changes, whereas boundaries in the neutral clip were mostly related to conceptual changes (Sherrill et al., 2019). These results suggest that a heightened state of arousal increases attention to perceptual details, which may come at a cost to sequential binding and coherent event memory. Consequently, a sustained state of high arousal may be associated with over-segmentation and worse overall temporal order memory.

However, evidence on the relationship between affective state and temporal order memory is somewhat mixed and dependent on the experimental paradigm and task demands (Petrucci & Palombo, 2021). For instance, a recent study presented two groups of participants with a series of film clips that were either highly arousing and negative or low in emotional content (Dev et al., 2021). The authors found that temporal order accuracy on a clip order reconstruction task was higher for the high-emotion group than the low-emotion group, but there was no difference in the temporal clustering scores between the two groups during a free-recall task. One caveat is that in this study, participants in the high-emotion group recalled more episodic details during free recall and the free-recall task always preceded the clip order reconstruction task. Thus, it is possible that superior recall performance, rather than superior temporal order memory per se, benefitted later clip order reconstruction for those in the high-emotion condition. More research is clearly needed to clarify how affective states' impact on event order memory may vary in different memory assessment tasks, for video and narrative stimuli vs. sequential list stimuli, and in tasks involving the same sustained affective state throughout (e.g., Dev et al., 2021) vs. tasks that involve shifts in affective states (e.g., Clewett & Davachi, 2021).

In summary, prior studies have shown that changes in affective states create event boundaries that can impact subsequent memory for temporal order and temporal duration. In all the studies reviewed above, event boundaries were created by externally induced changes in affective states. While there is also evidence that a sustained state of high arousal affects event memory, the picture is less clear as different studies have presented conflicting results (see Petrucci & Palombo, 2021, for a recent review). A set of well-controlled experiments that systematically compare the effects of a sustained state of high arousal on temporal memory across a range of stimuli and memory tests would be a valuable contribution to this emerging literature. Clarifying event boundary perception and the relative fidelity of temporal memory under different affective states – including those externally induced such as when watching a stressful video clip as well as those internally generated such as when strategizing for an upcoming competition – would also inform our understanding of how transitions between these different affective states influence event memory. Conceptualizing changes in affective state as changes in context is predicated on the idea that the given affective state during an experience is a form of context that is encoded within the episode and may later be retrieved along with other event information (Palombo & Cocquyt, 2020). In the next section, we turn our attention to theoretical and empirical support for the idea that affective state is a contextual element of episodic memory.

Affective states as contexts for memory

Like other forms of contexts such as temporal context, affective context is also thought to be incorporated into event memory and thus held to influence recall organization. This idea has been formalized in a computational framework. Talmi et al. (2019) proposed a variant of the Context Maintenance and Retrieval model that takes into account emotion, a model originally developed to explain temporal clustering, semantic clustering, and source clustering in free recall (Polyn et al., 2009a). The emotion Context Maintenance and Retrieval (eCMR) model incorporates the influence of emotion (in the external stimuli) on memory encoding and retrieval. According to this model, emotion can be an item feature, a source context shared by multiple items, and a factor that enhances item-source context binding through attentional modulation (Talmi et al., 2019). Compared to neutral items, emotional items share the same emotional context, similar to how items encoded under the same task goal share the same source context. Additionally, emotional stimuli receive greater attention during encoding. The putative mechanism for this attentional modulation is amygdala-dependent activation of the locus coeruleus noradrenergic system, which has been shown to modulate hippocampus-dependent memory processes (Mather et al., 2016). At retrieval, recalling an emotional item facilitates the recall of another emotional item due to their shared emotional context (Talmi et al., 2019). Simulated data from the model can account for a range of experimental findings including mixed list-composition effect, recall-order effect, enhanced emotion memory after delay, and the emotional oddball effect. Although the eCMR account does not explicitly address event boundaries, it follows that a change in emotional state during encoding should have similar effects as other types of contextual changes in segmenting experiences. At retrieval, items from before and after a change in affective state should be associated with different affective contexts and therefore be remembered as separate events.

Accordingly, the idea that affective states can function as contexts during encoding and organize memory is in fact supported by some empirical studies. Using a free-recall paradigm with word lists comprised of neutral, negative, and positive words, one study found that participants were more likely to recall items of the same valence consecutively, and the emotional clustering effect was still present when controlling for semantic similarity (Long et al., 2015). In this case, emotional valence presumably served as a retrieval cue that facilitated the recall of other items with the same emotional context. Another study using a cued-recall paradigm found that positive emotion enhanced associative memory when both words in the pair were positive, but not when one word was positive and the other neutral (Madan et al., 2019). This was interpreted as selective enhancement in associative memory “when a sufficient amount of positive emotion is present” (Madan et al., 2019). However, shared affective context might be a more parsimonious explanation for this result, as positive-positive word pairs shared the same emotional context and therefore would be more tightly bound together in memory compared to positive-neutral word pairs, encoded across a change in emotional context. Taken together, these results demonstrate that items that share an affective context are more closely bound together in memory compared to items associated with different affect contexts.

While the eCMR framework is mainly focused on the effect of emotional arousal on recall, as the studies mentioned above illustrate, emotional valence can also be part of the affective context and influence what is remembered. For example, positive emotion has been shown to broaden the scope of attention (Fredrickson & Branigan, 2005), while positive emotion associated with high approach motivation has been shown to reduce the breadth of attention (Gable & Harmon-Jones, 2008; Harmon-Jones et al., 2012). These and similar results suggest that emotions of different valence and arousal may represent different types of internal states that have diverging effects on the richness of event representation and the extent of relational binding. At low arousal, positive and negative valence may have different effects on selective attention, while high positive and negative arousal can both bias attentional competition to prioritize behaviorally relevant stimuli (Mather & Sutherland, 2011). As a consequence, events encoded under a state of heightened arousal may be relatively lacking in contextual details, including information about temporal context. In line with this idea, a more recent theoretical account proposes that arousal-related noradrenergic activity drives selective attention toward the most salient features and sensory details at encoding, at the expense of processing surrounding spatial and temporal context (Clewett & Murty, 2019). Most of the existing evidence on affective states and temporal memory have focused on stimuli with high arousal, often also with negative valence. Future research that aims to tease apart negative valence and high arousal would inform the respective contributions of valence and arousal in event segmentation triggered by affective state changes.

To sum up, affective states are a key determinant of event structure, serving as contexts to organize memory. Moreover, as reviewed in the previous section, a shift in affective states, for example elicited by an emotional stimulus in a stream of neutral stimuli, disrupts sequential temporal binding and creates an event boundary. In addition, the recruitment of arousal-related attentional mechanisms can influence the type of information encoded in memory, prioritizing item features at the expense of relational details. All of the studies reviewed above employed external stimuli such as aversive sounds or stressful video clips to trigger shifts in affective states, but an important open question is whether internally generated affective state changes would segment experience in similar ways as those triggered by external stimuli. For example, remembering an upcoming presentation (independent of an external cue) could increase one’s autonomic arousal due to nervousness, and this would be an internally generated internal state shift. Future research is needed to understand whether such an endogenously triggered affective state shift would create an event boundary, and whether it would have similar impact on subsequent memory as externally triggered affective state shifts.

Goal states

Task goals structure episodic memory

In addition to affect, goal states are another important aspect of internal context. Many studies in the field of event segmentation have found explicitly instructed task goals to be a key factor in organizing how episodic experiences are later remembered. For instance, in a series of studies, DuBrow and Davachi used changes in stimulus set and stimulus-specific tasks to manipulate context changes in episodic encoding tasks. They found that this kind of context shift created event boundaries, which impaired temporal order memory for items encoded across a boundary compared to items encoded in within a single context (DuBrow & Davachi, 2013, 2014). Additionally, boundary items associated with both stimulus set change and task goal change were more likely to be recalled out of sequential order during free recall (DuBrow & Davachi, 2016). A similar study has shown that cued sequential recall accuracy was lower for boundary items, which were cued by the last item in the previous task context, compared to non-boundary items that were cued by another item in the same task context (Sols et al., 2017). However, task goal changes always coincided with stimulus category changes in these studies, so the effect of goal state shifts could not be dissociated from the effect of perceptual changes.

Another study using a word list free-recall paradigm has also provided evidence for the role of task goals in memory structure. Polyn and colleagues asked participants to encode word lists while doing a classification task (pleasantness judgment or size judgment), with a task switch halfway through some of the lists (Polyn et al., 2009b). They found that items encoded after a task shift were more likely to be recalled compared to items in similar list positions encoded without a task shift, and same-task transition probability was higher than across-task transition probability in free recall (Polyn et al., 2009b). These results suggest that task goal information was part of the retrieval cue that facilitated same-task sequential recall. This is consistent with the predictions of Context Maintenance and Retrieval (CMR) model (Polyn et al., 2009a). According to the CMR model, distinct goal states provide source contexts that associate items encoded under the same task, while changes in goal states may disrupt temporal continuity for across-task sequential recall.

Building on this line of research, a recent study has demonstrated that entirely internally generated changes in goal states can in fact create event boundaries in absence of any changes in external stimuli features or other perceptual changes (Wang & Egner, 2022). In a sequential list encoding paradigm, participants were shown a series of trial-unique object images and asked to classify each image either by origin (natural or manmade) or by size (larger or smaller than a shoebox). We found that task switches can create event boundaries that result in impaired temporal order memory and exaggerated temporal distance memory for items encoded across a task switch, suggesting that changing task goal created event boundaries. Across five experiments, we systematically ruled out alternative explanations and showed that task set changes in the absence of shifts in stimulus set or response set were sufficient to create event boundaries, and that these results cannot be explained by changes in task cues or task difficulty. Critically, we also replicated these results using a voluntary task switching paradigm, where task goal changes were internally generated by the participants themselves rather than instructed by the experimenter (Fig. 2). In this experiment, participants were asked to repeat

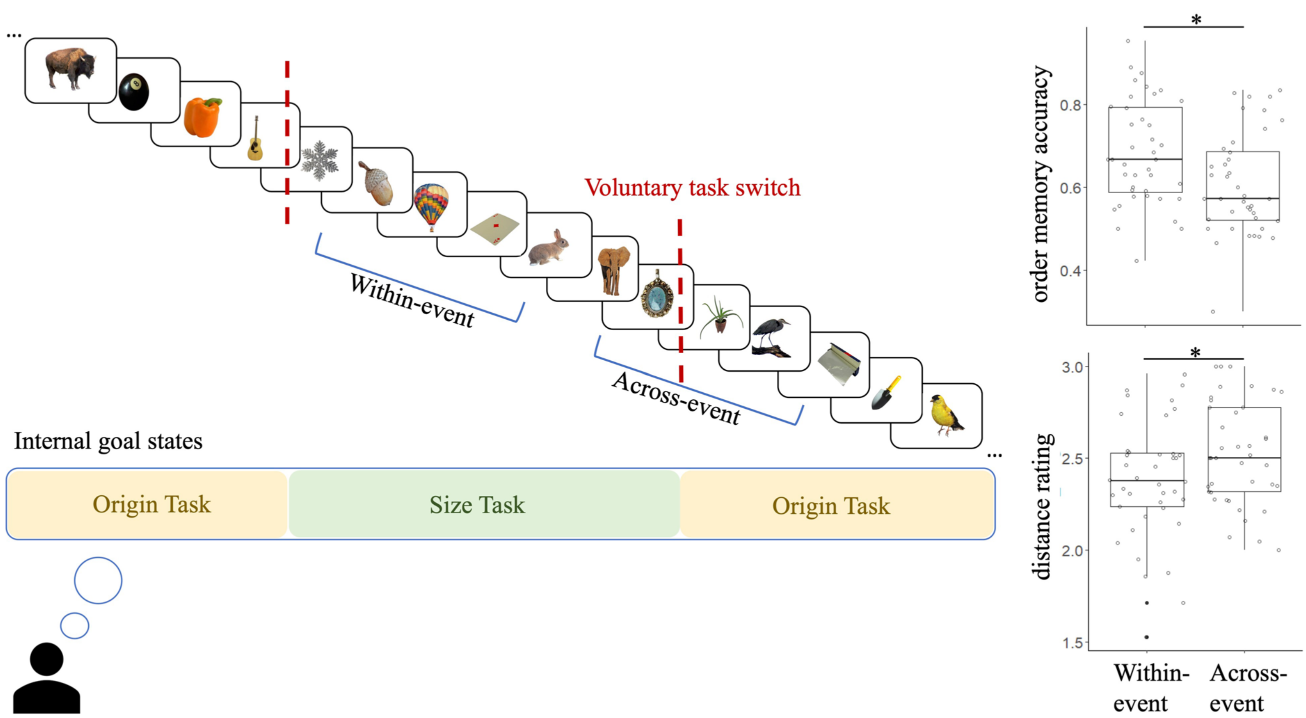

Fig. 2 Internally driven changes in goal states, such as voluntary task switches, can create event boundaries that reduce temporal order memory accuracy and exaggerate subjective temporal distance memory for across-event items compared to within-event items. Adapted from Wang and Egner (2022)

one of the two tasks for several trials and periodically switch to the other task, but which task to do on a given trial and on which trial to switch tasks were entirely up to them. Thus, in this experiment, changes in goal state were entirely internally generated but nevertheless created event boundaries as indicated by the temporal order and temporal distance memory effects. Together, these results show that sustained goal states can serve as contexts in item encoding and retrieval. Furthermore, changes in goal states – whether triggered by external cues or internally generated – segment continuous experience into distinct episodes.

Beyond experiments using sequential list encoding paradigms discussed above, other studies have shown that event perception in narrative comprehension is also biased by task goals. One study found that participants who were instructed to attend to spatial information were more likely to identify descriptions of spatial shifts as event boundaries compared to participants instructed to attend to character information (Bailey et al., 2017). Here, the instructed goal determined which dimension was task relevant and subsequently influenced segmentation behavior in narrative comprehension. More generally, many studies have found that people are able to segment events at fine or coarse grain according to instructions, showing that perceived event structure is sensitive to goal-related attentional changes (e.g., Hard et al., 2006; Zacks et al., 2001, 2007).

Relatedly, intentionally shifting one's internal state has been shown to influence memory retrieval in ways consistent with event segmentation. One study found that a mental context change between two study lists, such as an active imagery task, has similar effects as directed forgetting instructions that impair recall performance for list A and enhance recall performance for list B (Sahakyan & Kelley, 2002). In other words, changing one's mental context between two study lists appears to disrupt temporal continuity such that items in list A become less accessible, while items in list B have a context that is more similar to the retrieval context. Another directed forgetting study, using fMRI, found greater reduction in neural context representation following a forgetting cue, and that reduction in context representation was associated with successful forgetting across participants (Manning et al., 2016). These results suggest that deliberate updating of mental state and intentional forgetting – processes that can be interpreted as examples of externally cued changes in goal states – can cause a significant change in internal context that has similar effects as an event boundary, which can explain the across-context retrieval failure (or forgetting success).

Lastly, the idea that internal state changes structure memory organization has a long history in other domains of memory research, such as autobiographical memory where events are often organized by long-term personal and professional goals. Goal states influence the formation and demarcation of autobiographical periods, as both past experiences and future autobiographical periods are often organized by long-term goals such as professional or personal aspirations (Thomsen 2015). According to this literature, goals influence the construction of autobiographical periods because they bring about regularities in life experiences (e.g., beginning higher education) and goal-relevant memories are featured more prominently as the start of a new autobiographical period (Thomsen 2015). People tend to recall their live stories in autobiographical periods, which are “subjectively delimited life periods” with beginnings and ends and event features such as people, places, activities, objects, and emotional evaluations (Thomsen, 2015). Even though autobiographical periods typically span a much longer time frame than memory for individual events, they share many similarities with event memory in episodic memory research. Like memory for events, memory for autobiographical periods is also organized hierarchically (e.g., “my spring semester” and “my high school years”), and memories from the start and end of autobiographical periods tend to be recalled more often as they are more distinct and more significant, much like enhanced memory for boundary information in recalling individual events (Thomsen, 2015; Thomsen & Berntsen, 2005). However, in most cases autobiographical periods emerge in post hoc reflection of life experiences and the “boundary” experiences may not be recognized as such in the moment. As a result, even though some aspects of autobiographical memory can be conceptualized as influenced by goal state changes, other aspects might not be. Moreover, the neural mechanisms supporting organization of event memory on a short timescale and autobiographical periods on a long timescale are likely different, even though goals can play an important role in the continuity and segmentation of both types of memories.

In summary, behavioral results across different types of experimental paradigms have consistently found task goals to be an important determinant of event structure in episodic memory. Instructed task goals can impact the manner and frequency with which people identify event boundaries. Moreover, changes in task goals with or without explicit instructions can trigger event segmentation during encoding. Updating mental context similarly disrupts contextual continuity in encoding. In retrieval, goal states can serve as a source context that facilitates sequential recall and within-event order memory for items sharing the same task. On a longer timescale, goal states also influence the formation of autobiographical periods when recalling one's life story. While the studies reviewed above provide robust evidence showing that task goals structure event memory, most of the experiments used external stimuli (e.g., task-switching cues or directed forgetting instructions) to manipulate goal state changes. Hence, the event boundaries produced by task goal changes in many studies discussed above belong to the category of externally triggered internal state changes. A recent experiment using voluntary task switching extended these findings to internally triggered internal state changes, where internally driven changes in goal states created event boundaries in absence of any external stimuli shifts (Wang & Egner, 2022). In this voluntary task switching experiment, internally triggered internal state changes had similar behavioral effects as changes in external stimulation on temporal memory. However, future research is needed to provide a more complete picture of how internally generated changes in goal states may differ from external triggers. It is a given they would differ in terms of the origin and sequence of neural processes that trigger boundary creation, as the initiating factors reside within the individual in the internal case, and in the sensorium in the external case. The specifics of these differences are yet to be examined, however. More broadly, the literature on spontaneous thought, such as mind wandering, may offer an opportunity for additional exploration of internally driven event segmentation.

Spontaneous thought provides internally generated changes in goal states

Spontaneous thought can be defined as mental experiences that unfold in an unconstrained manner, in contrast to goal-directed thought which has strong deliberate constraints implemented through cognitive control (Christoff et al., 2016). Categories of spontaneous thought include dreaming, mind wandering, and creative thinking (Christoff et al., 2016). Spontaneous thought often arises internally rather than in response to external perceptual inputs. According to one theoretical perspective, the content of spontaneous thought can be influenced by internal mental states, an individual's current concerns, as well as the extrinsic environment (Mildner & Tamir, 2019). Similar to memory recall, the flow of spontaneous thought follows various types of contextual associations between different topics (Mildner & Tamir, 2019). When a stream of spontaneous thought arises during a goal-directed state, the constraints on the contents of and the transitions between mental states are loosened, thus leading to a shift in the internal context. It has been proposed that spontaneous thought such as mind wandering may elicit internal event boundaries as the result of transition between network states (Ross & Easton, 2022). Though there has not been a direct test of whether an internal state shift caused by spontaneous thought creates event boundaries, in this section, we review empirical evidence that lay important groundwork for this idea.

The hippocampus, which plays a critical role in event segmentation and memory, is also a neural substrate for generating spontaneous thought. Hippocampus sharp wave ripples (SWRs) have been identified as a candidate driver for spontaneous, internally generated thoughts (O'Callaghan et al., 2021; Pezzulo et al., 2017). A recent review proposed that SWRs may be a candidate neural signal that can serve as an event boundary marker (Bilkey & Jensen, 2021). SWRs occur both during sleep and quiet wakefulness, and this hippocampal rhythm has been implicated in memory consolidation, future planning, and imagination (O'Callaghan et al., 2021; Pezzulo et al., 2017). Neuromodulatory systems, such as the cholinergic system that innervates the hippocampus, have been proposed to play a key role in switching between externally driven and internally driven processes (O'Callaghan et al., 2021). Specifically, high cholinergic tone in the hippocampus promotes theta rhythms, favoring external sensory processing, whereas low cholinergic tone promotes SWR activity and supports internally driven processes (O'Callaghan et al., 2021). It has also been argued that fluctuations in cholinergic levels support switching between different memory modes (i.e., encoding or retrieval) by biasing hippocampus dynamics toward pattern separation or pattern completion (Decker & Duncan, 2020; Tarder-Stoll et al., 2020). These accounts suggest that hippocampal states and neuromodulation may be key determinants in shifting from an externally directed goal state to internally generated spontaneous thought.

Shifting from a goal-directed state to spontaneous thought with reduced deliberate constraints is a change in mental context, the sort of change we argue here that can potentially modulate event perception and memory. The attentional shift that occurs when a spontaneous thought arises internally is associated with perceptual decoupling and disengagement from external processing (Baird et al., 2014; Smallwood & Schooler, 2015). Though whether the initiation of spontaneous thought creates an event boundary has not been directly tested, a naturalistic study of episodic memory temporal compression sheds light on how strong and weak deliberate constraint affects event segmentation. In this study, participants walked around a college campus and performed a series of goal-directed tasks, such as buying a newspaper and mailing a letter, at different locations (Jeunehomme et al., 2018). When verbally recalling the experience, participants reported more events corresponding to goal-directed actions than spatial displacement (i.e., walking from one place to another), and this difference in event memory persisted for up to 1 month after encoding. In a follow-up study that asked participants to identify fine-grained event boundaries from pictures taken by a wearable camera on their walk, the researchers found that more fine-grained events were identified for goal-directed actions than spatial displacements (Jeunehomme & D'Argembeau, 2018). One possibility is that goal-directed actions were better represented because goal states provided structure to episodic memory, while participants were more likely to mind wander during spatial displacement and focus attention inward.

While it seems intuitive that shifting from goal-directed thought to spontaneous, unconstrained thought (and vice versa) represents a shift in mental states, transitions between different states of spontaneous thought (e.g., thinking about grocery shopping to vacation planning) are less well defined. One recent fMRI study examined transitions between internal mental states by asking participants to freely recall a series of movie clips from memory in no particular order and without external cues (Lee & Chen, 2022). The Default Mode Network, especially the posterior medial cortex, showed a distinct activation pattern at between-movie boundaries across both encoding and recall phases, following the offsets of the preceding movie. This is consistent with the idea that the posterior medial cortex is involved in representing event models (Ranganath & Ritchey, 2012; Ritchey & Cooper, 2020). Interestingly, between-movie boundary patterns were found to be negatively correlated with within-movie boundary patterns, raising the possibility that within-narrative boundary signal qualitatively differs from major transitions between different narratives (Lee & Chen, 2022). While this study examined internally generated mental state transitions without external cues, the movie recall task does impose considerable deliberate constraint on mental content. Future research is needed to better understand the behavioral and neural responses to unconstrained thought transitions, such as flights of thought during mind wandering.

The mind-wandering literature offers an opportunity to examine internally generated internal context shifts. On one level, shifting attention inward when spontaneous thought arises reduces the amount of deliberate constraint on mental state, and can thus be considered a shift away from a goal-directed state (Christoff et al., 2016). During internally directed spontaneous thought, an individual may be less sensitive to event boundary cues in the external environment and better tuned to internal state changes (Baird et al., 2014; Smallwood & Schooler, 2015). On another level, shifting between different trains of thought during an episode of mind wandering could also be considered a change in goal states, especially if certain topics of spontaneous thought are related to an individual's current concerns (e.g., thinking about a work-related problem on the walk home). How these internally generated experiences are remembered and how transitions between different trains of thought affect the perceived flow of time and relation between events remain to be answered by future research.

In the past two sections, we reviewed empirical evidence demonstrating that explicitly cued as well as internally triggered changes in goal states create event boundaries, and suggested spontaneous thought – in particular mind wandering – as an avenue for future research into endogenously generated goal state changes and their impact on event segmentation. In the next section below, we turn to a third core domain of internal states: motivational states, which are closely related to both affective and goal states discussed so far.

Motivational states

Reward motivation as context for episodic memory

Similar to the literature on emotion and memory, many studies on motivation and memory employ stimuli with high and low reward levels to manipulate motivational state. The reward levels are typically interpreted as a proxy for participants' internal motivational states. Hence, these studies fall under the category of externally triggered internal state changes. While there is a large body of work that has shown reward motivation to influence episodic memory in a variety of ways, here we specifically focus on studies that have examined reward motivation as a context that structures episodic memory.

It has been proposed that reward context has similar effects on temporal memory as emotional context (Talmi et al., 2021). Like stimuli associated with negative valence, stimuli associated with high reward also engage selective attention, and are encoded under a source context that is distinct from those associated with neutral valence or low reward. One study using word lists associated with high or low reward found that reward significantly benefited immediate recall performance in lists with mixed reward levels, but not in pure lists where high- and low-reward words were presented separately (Talmi et al., 2021). Applying the eCMR framework to reward, these authors proposed that attentional modulation strengthens item-source context binding for high-reward items, which biases recall competition against low-reward items in mixed lists but not against other high-reward items in pure lists. However, another recent study using a similar word list learning paradigm found that reward improved immediate recall in both mixed and pure lists (Horwath et al., 2022). This study additionally found that within-category recall transition probability was higher for items in the high-reward category than items in the low-reward category, suggesting that reward provided a context to organize memory for high-reward items but not necessarily the less important, low-reward items. These authors simulated data using different variants of the CMR model and found that representing different reward conditions in different source contexts and modeling enhanced item-context binding for high-reward items produced results that most closely resemble their empirical findings (Horwath et al., 2022). While these two studies demonstrate that reward motivation provides a context for organizing memory, they did not test whether transitions between different reward levels within mixed lists reduced the likelihood of recalling consecutive items, which would be more directly relevant to the question of how changes in reward context impact event segmentation.

Another study addressed this question more explicitly and showed that changes in reward levels created event boundaries using a passive sequential reward task (Rouhani et al., 2020). In this task, the reward amount associated with each trial fluctuated around a mean that shifted periodically, where large (unsigned) reward prediction errors signaled shifts in the underlying reward distributions. These large reward prediction errors functioned as markers of new latent contexts, likely accompanied by changes in the participants' motivational states (though neither the latent context inference nor participants' motivational states were directly queried). Compared to sequential pairs encoded within the same reward context, sequential pairs across a high-reward prediction error item exhibited no recognition priming and worse temporal order memory (Rouhani et al., 2020). These authors captured the behavioral effects qualitatively via simulation, using a modified version of the CMR model (Polyn et al., 2009a), where large reward prediction errors temporarily accelerated the drift rate of internal temporal context (Rouhani et al., 2020). This study showed that unsigned reward prediction errors, which were presumably associated with changes in motivational states in either direction, led to event segmentation that disrupted sequential binding across event boundaries.

Relatedly, not only does a change in reward context affect event memory, but high reward level also influences the quality of encoded events. Thus, similar to affective states, motivational states not only serve as contexts to which items are bound, but also affect the breadth of content encoded and the strength of the encoding. In one study, participants were asked to make one of four semantic judgments (different task contexts), cued by distinct background scenes, on sequences of objects in high or low reward blocks (Gruber et al., 2016). Behaviorally, recognition memory and task source memory (i.e., which semantic judgment was done) was better for items encoded in a high reward context compared to those encoded in a low reward context. Though this study does not explicitly test event representations for high and low reward contexts, these results show that reward motivation not only affected the strength of item memory, but also influenced the binding of items to reward-independent task contexts.

Motivational state is closely related to goal states. In the study described above, reward context is arguably more behaviorally relevant than the semantic task contexts, which means that "obtain more rewards" may have been a superordinate goal that supersedes the "perform the correct semantic judgment" task goal. In line with this conjecture, fMRI data showed that hippocampal activity pattern during encoding distinguished between the two reward contexts but not different task contexts (Gruber et al., 2016). This finding suggests that reward context was more salient than semantic task contexts in this study and was therefore represented with higher fidelity, where high and low motivational states during encoding encompassed perceptual feature changes and task goal states associated with different semantic task contexts. In this situation, an event segmented according to a reward context may consist of several sub-events with different task contexts, following a hierarchical structure.

While the above studies conceptualize motivation as reward salience or reward anticipation, motivation has also been conceptualized as a multidimensional construct that encompasses information incentives and approach/avoidance orientation (Murty & Adcock, 2017). Informational-based motivational states can be classified as interrogative, which emphasizes both current goals and future goals, and imperative, which prioritizes current, immediate, highly salient goals (Dickerson & Adcock, 2018; Murty & Adcock, 2017). While an interrogative information seeking state supports better encoding of relational memories, an imperative information seeking state is associated with sparse, decontextualized memories (Dickerson & Adcock, 2018). One study manipulated motivational states using rewards and punishments in a spatial learning task, where the threat of shock put participants in an imperative motivational state and reward prospect encouraged interrogative information seeking (Murty et al., 2011). Surprisingly, a subset of participants learning under the reward condition, who showed high skin conductance levels similar to those learning under the punishment condition, exhibited similarly poor spatial navigation performance (Murty et al., 2011). In this case, the participants who exhibited high arousal under reward condition were likely under an imperative motivational state, suggesting that the impact of motivation on memory may be more complex than it appears at first blush. As this study did not directly measure event memory, future research needs to consider interrogative/imperative information seeking states in order to gain a more complete understanding of how reward motivation affects event cognition.

In summary, motivation states – often manipulated via external rewards – provide an important internal context during the formation of event memories. While no study to date has investigated internally generated motivational state changes, prior research has shown that externally triggered motivational state changes play a role in event segmentation. Large reward prediction errors, which may correspond to shifts in motivational states, create event boundaries and disrupt sequential binding in episodic experience (Rouhani et al., 2020). Additionally, motivational states also affect the strength and fidelity of memory for rewarded events (Gruber et al., 2016). One caveat is that reward manipulation does not always result in the same motivational state: approach orientation coupled with high arousal may bias individuals toward imperative rather than interrogative information seeking state, which have diverging effects on subsequent memory (Murty et al., 2011). In the next section, we review neural evidence supporting the idea that reward motivation is a contextual element of episodic memory.

Hippocampal representations incorporate motivational context during encoding

As we discussed in a previous section on the neural mechanisms of event segmentation (see above), the hippocampus is sensitive to event boundaries and hippocampal activity patterns have been found to carry temporal context information about events (Baldassano et al., 2017; Ben-Yakov & Dudai, 2011; Ben-Yakov & Henson, 2018; DuBrow & Davachi, 2016; Zheng et al., 2022). Specifically, items experienced in the same event have more similar hippocampal representations than items experienced in separate events (see Cohn-Sheehy & Ranganath, 2017, for a recent review). In what follows, we review recent neuroscience evidence from both rodent and human studies suggesting that motivational context is an integral component of hippocampal event representations, and that hippocampal representations distinguish between distinct motivational contexts. Although these studies did not directly test whether shifts in motivational states are associated with neural activity patterns that characterize event segmentation, we argue that their findings support the conjecture that motivational state changes establish event boundaries by creating distinct event representations.

Converging evidence suggests that event representation in the hippocampus provides a mechanism for incorporating motivational context in memory. Rat hippocampus neuronal ensemble activity patterns are more similar for items that share a reward valence than items with different reward valence (McKenzie et al., 2014). Other studies have shown that the hippocampus is required for flexible contextual memory retrieval based on motivational states, and different motivational states have distinct hippocampal codes that distinguish between competing goal-directed actions (Kennedy & Shapiro, 2004, 2009). Similarly, in humans, it has been shown that activation patterns in the medial temporal lobe are more similar for events encoded following the same reward cue (Wolosin et al., 2013). Importantly, this study used reward cues to manipulate motivational state during encoding but did not deliver rewards until the retrieval phase, thus dissociating the effect of reward prospect from that of reward itself. Furthermore, a follow-up study using reward cues in both picture and word forms to dissociate the perceptual features and abstract value of reward cues replicated these findings, confirming that hippocampal and parahippocampal cortex activity patterns distinguish between different reward contexts (Zeithamova et al., 2018). Together, these results indicate that different motivational states, as induced by varying reward prospects, are incorporated into memory through medial temporal lobe representations during encoding. These neural representations of motivational states provide a neural basis for segmenting events by motivational context.

What is the mechanism by which information about motivational states is encoded in memory? Prior research suggests that neuromodulation underlies the formation of distinct event representations for different motivational contexts. Specifically, the dopaminergic system has been proposed to play a crucial role in prioritizing memory for motivationally significant events via modulation of the hippocampus (Shohamy & Adcock, 2010). While phasic dopamine bursts have been shown to encode reward prediction error (reviewed in Schultz, 2007), tonic dopamine levels are related to behavioral vigor, which is a function of the salience of the reward incentive and subjective "wanting" (Shohamy & Adcock, 2010). Midbrain dopaminergic neurons project directly to the hippocampus and other medial temporal lobe regions, modulating the hippocampus during states of reward anticipation and novelty (Shohamy & Adcock, 2010). A reward cue may trigger a sustained dopaminergic release, which in turn modulates hippocampus activity for encoding the event that follows. Thus, a reward cue, which triggers a shift in motivational states, can also lead to a shift in hippocampus activity patterns such that a new event is formed and differentiated from the previous event.

Several studies have found empirical evidence for dopaminergic modulation of memory for motivationally salient events during encoding. Successful encoding under reward anticipation has been shown to be associated with activation in the ventral tegmental area (VTA), the nucleus accumbens, and the hippocampus, and greater correlation between VTA and hippocampus activity was predictive of memory success (Adcock et al., 2006). In an intentional encoding experiment with varying reward conditions, reward-related activity changes in the dentate gyrus and connectivity between the dentate and dopaminergic midbrain correlated with reward modulation of cued recall performance across participants (Wolosin et al., 2012). In addition, another study examined how reward anticipation affected the encoding of incidental novel events and found that reward motivation amplified hippocampal responses to novel events (Murty & Adcock, 2014). This increased sensitivity was predicted by increased functional connectivity between the VTA and cortical regions (Murty & Adcock, 2014). In this study, the VTA-cortical coupling enhanced encoding of hippocampus-dependent novelty memory, even though the memoranda were goal-irrelevant. This suggests that the VTA modulates a distributed cortical network to facilitate hippocampus encoding of novel events, which results in a more enriched representation of events encoded under a high motivational state. Hence, similar to the effect of affective arousal on event memory discussed in previous sections, motivational states also influence both the distinctiveness of events (i.e., segmenting experiences with different motivational states into different events) as well as the fidelity of the encoded content in events.

While the studies reviewed above demonstrate that motivational context manipulated by external rewards are part of event representations and may relate to externally triggered internal state changes, these findings have also been extended to internally driven motivational states, such as curiosity. One study using trivia questions that elicited curiosity found greater activity in the nucleus accumbens and VTA/substantia nigra (SN) areas during states of high curiosity compared to low curiosity (Gruber et al., 2014). Furthermore, curiosity-related enhancement in incidental memory during a high-curiosity motivational state was supported by anticipatory activity in VTA/SN and the hippocampus, as well as the functional connectivity between these regions. These results suggest that internally driven motivational states such as a state of heightened curiosity are supported by similar neural processes as externally driven reward motivation. Hence, we predict that internal motivational state changes such as an increase in curiosity for an anticipated outcome may also trigger changes in hippocampus event representations and establish event boundaries.

In sum, the above studies suggest that hippocampus representations during learning provide a mechanism for incorporating motivational state and other behaviorally relevant event features in memory (McKenzie et al., 2014; Wolosin et al., 2013; Zeithamova et al., 2018). This is supported by dopaminergic modulation involving the VTA and the nucleus accumbens, both during encoding (Adcock et al., 2006; Gruber et al., 2014; Murty & Adcock, 2014; Wolosin et al., 2012) as well as post-encoding dynamics (Gruber et al., 2016; Murty et al., 2017). However, most of the studies reviewed above did not address the relationship between changes in motivational state and event segmentation directly. Thus, whether transitions between different motivational states (e.g., from low reward motivation to high reward motivation in Rouhani et al., 2020) manifest in marked shifts in hippocampus activity patterns or hippocampus-midbrain connectivity remains an open question. In addition, whether a shift in hippocampal representations during encoding corresponds to subjective identification of event boundaries and subsequent temporal memory effects is also an important question to investigate in future studies. Finally, addressing whether internally driven changes in motivational states, such as shifts in curiosity, create event boundaries like externally driven reward prediction errors will provide a more complete picture on the impact of motivation on event memory.

Theoretical perspectives on event memory

Historical and contemporary models of event segmentation

The above sections summarized studies presenting direct and indirect evidence for internal state change as a key factor in event perception and memory. However, few models of event perception and memory explicitly incorporate internal drivers of event segmentation. In what follows, we briefly review influential theoretical accounts of event cognition and evaluate their suitability for explaining event parsing driven by internal states and their transitions.

Early theories of event cognition focused on event parsing in third-person narrative comprehension. Research on written narrative comprehension has given rise to the idea of "situation models," which are mental representations of specific described situations (Zwaan & Radvansky, 1998). Like real-life experiences, these situation models are multi-dimensional and consist of integrated events (here defined in the fine-grained sense as moments that make up temporally extended episodes). Each event can be indexed on five dimensions: time, space, causation, intention, and protagonist (Zwaan et al., 1995; Zwaan & Radvansky, 1998). These dimensions can be updated separately, and new events that share indices with the current situation model become integrated (Zwaan et al., 1995; Zwaan & Radvansky, 1998). Behaviorally, situation model updating at an event boundary results in longer reading time (Zwaan et al., 1995). One crucial prediction is that events sharing more indices will be more interconnected in long term memory. This is similar to contextual memory models (described further below), where items sharing similar contextual features are clustered together in memory (Howard & Kahana, 2002).

The idea that situation models guide event cognition, and can be updated when event features change, has parallels in the Event Segmentation Theory. According to this theory, multimodal representations of event models are maintained in working memory and used for generating predictions of upcoming sensory inputs (Zacks et al., 2007). These event representations are updated at event boundaries, where transient increases in prediction error elicit an update to the current event model (Zacks et al., 2007). Although "events" here are defined as "goal-directed human activities" lasting between seconds to tens of minutes, most of the relevant empirical studies underpinning the model were concerned with observing goal-directed actions and event parsing based on inference of an actor's goals (Zacks et al., 2007). However, transitions between internally driven goal states may not necessarily generate increases in prediction errors like third-person observations of goal-directed actions, and recent empirical evidence demonstrates that prediction errors are not necessary for event segmentation to occur (Wang & Egner, 2022). Thus, prediction error from changes in the external environment is only one among many possible drivers of event segmentation, as entirely internally produced changes in goal states can also create event boundaries in memory (Wang & Egner, 2022).

The Event Horizon Model expands upon Event Segmentation Theory with principles that account for memory effects of event segmentation (Radvansky, 2012; Radvansky & Zacks, 2017). Because experiences are segmented into a series of event models and only the current event model is held in working memory, information from before an event boundary becomes less accessible (Radvansky, 2012; Radvansky & Zacks, 2017). Furthermore, segmentation provides a "chunking" mechanism that could improve overall memory (Radvansky, 2012; Radvansky & Zacks, 2017). While event models and their transitions may be relatively well-defined for spatial boundaries and perceptual boundaries, whether more abstract internal states such as affective and goal states correspond to distinct event models in working memory is less clear.

While these earlier theoretical accounts mainly focus on event parsing from a third person observer perspective, the more recent Fluid Events Model proposes a framework that predicts the probability of shifting action during first-person experiences in response to a potential change in task demand (Radvansky et al., 2015, 2016). For example, a driver may start to adjust the radio when the cognitive demands of driving are relatively low, but then shift back to pay full attention to the road when the traffic situation becomes more complicated. The Fluid Events Model predicts when people will change how they are doing a task in response to the environment and the consequences of their own actions, while the task remains the same. The model considers a number of factors in computing the probability of changing actions, including external environmental changes like merging onto a highway, as well as experience-based factors such as recent action shift history, internal performance monitoring, and intrinsic propensity to shift actions (Radvansky et al., 2015, 2016). Thus, according to the Fluid Events Model, the likelihood of shifting action is influenced by both external and internal factors, which could include internally generated event boundaries. Whereas the model gives an account of the circumstances under which an individual decides to change actions during an interactive experience, it does not touch on how internally driven action changes (which could be correlated with goal state changes) influence event perception.

Lastly, another recent theoretical account proposes that event segmentation occurs when the inferred latent cause of experience (event type) changes, which can happen independent of extrinsic perceptual changes or prediction errors (Shin & DuBrow, 2020). Under this framework, event type inference works in a similar fashion as category learning: more common event types are more likely to be inferred, and a new event type can be generated when none of the existing clusters fit. At any moment in time, there is a probability distribution for the likelihood of a range of possible event types, and event boundaries correspond to moments of high uncertainty over inferred event types (Shin & DuBrow, 2020). Compared to previous models, this proposal emphasizes that event boundaries correspond to inferred event type changes rather than observed feature changes, such that contextual feature changes that do not lead to inference of a new event type do not cause event segmentation (Shin & DuBrow, 2020). Though the latent cause inference model could thus account for situations where environmental changes drive shifts in internal state, it is less clear how event type inference would apply when internal context transitions are generated from within the individual.

Applying associative memory models to event cognition and internal context

The above models of event cognition mainly describe determinants of online event segmentation during externally focused activities. Because they were developed to account for segmentation in the context of observed (external) event changes, these models are not well-suited to accommodate internal states as a factor in event cognition. In contrast, associative memory models that describe relationships between items through shared contextual features offer an opportunity to incorporate various types of internal states as different kinds of contexts that can structure memory both independently and interactively.

The seminal Temporal Context Model was originally developed to explain recency and contiguity effects in free and serial recall (Howard & Kahana, 2002). Here, "context" is defined in somewhat loose and abstract terms, as a set of elements that fluctuates from moment to moment and is reflective of changes in the environment or the subject's internal state (Howard & Kahana, 2002). The Temporal Context Model proposes that study items are bound to a temporal context signal during encoding, which gradually drifts over time. The temporal context at the time of retrieval is most similar to the last encoded item, which explains the recency effect (Howard & Kahana, 2002). Furthermore, the recall of an item activates its associated temporal context, which facilitates the recall of the next item sharing a similar contextual representation, accounting for the contiguity effect (Howard & Kahana, 2002). The Temporal Context Model and similar associative memory models provide a useful framework for conceptualizing how items are bound together through shared contextual features. A similar account posits that event organization in episodic memory depends on shifts in contextual stability, which includes "changes in stimulus features, goal states, or internal representations of time" (Clewett & Davachi, 2017). This account makes similar predictions as the Temporal Context Model, where fluctuations in the rate of temporal signal drift influence event structure.

Though it does not directly address event segmentation, the Temporal Context Model has been used to explain behavioral phenomena associated with event boundaries. Such associative memory models can be criticized for having a limited ability to capture the embodied aspect of event cognition. Representing and segmenting events are useful for planning future actions and interacting with the physical world, as event cognition has been found to be influenced by one's physical perspective (Radvansky & Zacks, 2014). These embodied facets of event cognition are typically not explicitly incorporated in associative models. However, such information about spatial relations and physical perspective shifting may be represented as part of the overall "context" signal. One study using a virtual reality simulation of spatial contexts found that temporal order memory was reduced for items encoded before and after walking through a doorway (i.e., changing spatial contexts) compared to items encoded in the same room (Horner et al., 2016). The authors qualitatively captured this effect by simulating data using a computational model that associates items with a "context" signal at encoding. To incorporate the effect of spatial context change, they varied the rate of context change over time, increasing the rate of context update at the boundary time points. This resulted in representational dissimilarity at retrieval between items encoded in different rooms, reproducing the effect of spatial context shifts on temporal order memory. Here, the context layer of the model incorporated spatial context, in addition to temporal context. This type of associative memory model can flexibly incorporate multiple types of contexts, including internal states, as many different factors can contribute to the overall rate of change in contextual representations.

The Context Maintenance and Retrieval model extends the Temporal Context Model by adding additional layers of contexts – namely semantic and source contexts (Polyn et al., 2009a). In this model, long-standing associations between study items in a word list constitute the semantic context, while episodic associations from the learning phase such as the encoding task form the source context (Polyn et al., 2009a). Different kinds of context interact in guiding memory search. As a result, items sharing more similar contexts (e.g., the same encoding task and being temporally adjacent) tend to be recalled together, and sharing more contextual features predicts stronger clustering of items (Polyn et al., 2009a). Though the original Context Maintenance and Retrieval model only considered temporal, semantic, and source contexts for a word list learning task, variants of this model have since been used to explain other types of contextual associations between items.

As described in earlier sections, modified versions of the Context Maintenance and Retrieval model have been used to capture the influence of emotional context and reward context on memory (Horwath et al., 2022; Rouhani et al., 2020; Talmi et al., 2019). On the simplest level, affective, goal, or motivational state can be treated as just another context feature shared between items. Internal states can also structure event memory through modulation of other key parameters, including the rate of temporal context drift, the strength of item-context binding, and the richness of contextual representation. For example, emotional state associated with high arousal has been proposed to increase attentional focus during encoding (Talmi et al., 2019). A change in goal state may accelerate the rate of temporal context drift and reduce sequential binding between items, thus creating an event boundary at the moment of goal state shift. Motivational state may modulate the strength of item-context binding and the fidelity of event representation. The Context Maintenance and Retrieval model, therefore, can in principle accommodate these different types of internal states as additional context layers to explain memory for the flow of time and how events relate to each other.

Generalizing the Context Maintenance and Retrieval model to incorporate internal contexts, such as affective, goal, and motivational states, would allow us to make novel predictions about how different types of internal states interact in structuring memory. For example, items that share both motivational and goal states would be more closely bound to each other and to their context than items that only share a goal state. Longer term goals and more immediate action goals can interact to create hierarchical event structure. It has been well established that in observing (including narrative reading) and recounting activities, people tend to perceive and describe events in a hierarchical structure where fine-grain units are nested within coarse-grain events (e.g., Zacks et al., 2001). Interactions between internal states that are sustained over different timescales should also lead to segmentation of events on multiple levels, with overarching states linking across finer-grained events to create continuity. Some types of internal states may be more salient than others and exert greater influence over event structure. For example, a highly salient motivational state can link across disparate task goal states and organize memory according to the shared motivational states among experiences (e.g., Gruber et al., 2016). Hence, conceptualizing internal state change as a driver for event parsing allows us to test a range of novel predictions in future research and enrich our understanding of how people make sense of everyday experiences.

In summary, existing theories of event segmentation depend on prediction error and event type inference, and they primarily draw from empirical studies on text narrative comprehension, observation of naturalistic events, or observation of sequential item lists. In the majority of these studies, the participant is the reader or the observer rather than the actor, and events are defined by changes in sensory input. However, in situations where changes in events are internally generated, event segmentation mechanisms proposed by the Context Maintenance and Retrieval model are still applicable, as – in principle – a wide variety of internal states can serve as context that all contribute to memory structure. The Context Maintenance and Retrieval model thus provides a promising framework for how multiple types of internal states may contribute to memory structure both uniquely and interactively.

Conclusions and open questions

Event segmentation research in the past few decades has produced important insights about how we perceive and remember continuous experience as distinct episodes. The majority of existing studies and theories have focused on the role of external environment change in creating event boundaries. Although internal states – such as our affective states, goal states, and motivational states – are also crucial in structuring our memory for events, internal determinants of event segmentation have received relatively little attention in the literature. In this review, we pointed out this gap in research and proposed a novel taxonomy of event boundaries based on whether they are triggered by external or internal context shifts. We reviewed behavioral and neuroscience evidence for affective, goal, and motivational states as contextual elements in event memory. Based on studies that directly linked internal state changes to event segmentation as well as closely related evidence, we argued that shifts in internal states create event boundaries and impact subsequent memory. Evidence from a recent voluntary task switching experiment has shown that entirely internally generated changes in internal goal states can trigger event segmentation, as indexed by behavioral memory effects that characterize event boundaries (Wang & Egner, 2022). However, as we elaborate below, more research is necessary to understand the neural mechanisms of internally generated internal state change and to clarify the relationship between externally and internally triggered discontinuities in sustained event representations in structuring event memory.

Many prior studies described in this review involved changes in internal states triggered by shifts in external stimuli. Recalling the classification scheme from Fig. 1, endogenously generated internal state shifts are also important for broadening our understanding of event organization. While recent empirical evidence has provided the basic proof-of-existence of internally triggered event segmentation (Wang & Egner, 2022), future studies are needed to fully understand the similarities and differences between event boundaries created by externally triggered internal state changes and internally generated ones. One major challenge is that internally generated internal state shifts are much harder to experimentally manipulate or measure. Behaviorally, internally generated context shifts by definition occur independent of external stimuli or manipulations, and it would require creative solutions to record such moments without confounds in motor responses (such as having subjects report spontaneous internal state changes via button presses). Here, combining neuroimaging approaches with physiological markers such as pupil dilation and behavioral reports of self-generated emotional, goal, or motivational state change could be a promising avenue for examining the neural correlates of internally driven context shifts, and comparing them with externally driven shifts. For example, temporal autocorrelation in hippocampal activity is reduced at event boundaries caused by spatial context shift or sensory prediction error (Brunec et al., 2018; Sinclair et al., 2021). Recent research using single-neuron recording in humans has provided further evidence that neural state (specifically in the medial temporal lobe) changes slowly as a function of time when encoding film clips in the absence of a boundary, and abruptly shifts following an event boundary (Zheng et al., 2022). Whether internally generated internal state shifts would result in similar disruptions in medial temporal lobe representations remains unknown.

Another open question is the relative strength of external environment change and internal state change, and which one exerts greater influence on event segmentation under different circumstances. For example, an office worker can spend a whole day at the same desk with minimal changes in the external environment, despite many changes in the internal goal state associated with various tasks throughout the day. Physical environment change can also weaken internally maintained goals, where walking into a different room might cause someone to forget what they went there to do. One possibility is that the processing of both changes in external stimulation and changes in internal states is biased by top-down goals and priorities. A recent study examined the impact of internally generated variations in attentional states on recall clustering, and found that internal attentional fluctuations did not affect the temporal organization of recall while slowly drifting temporal context exerted a stronger influence on recall organization (Jayakumar et al., 2022). In this study, internal attentional fluctuations were indexed by reaction time variability, presumably without involving metacognitive awareness or explicit goal change. Future research is needed to clarify what kind of internal state change may constitute a mental context that organizes event memory, and how it interacts with temporal context and external environmental context in constructing events.

Last but not least, understanding internal state changes and their contribution to event segmentation also has potentially important clinical implications. For example, patients with schizophrenia exhibit decreased performance in emotion maintenance and goal maintenance as well as deficits in online event segmentation (Gard et al., 2011; Kurby & Zacks, 2008; Poppe et al., 2016), but to what degree the deficits in maintaining internal states relate to the impairment in event perception is currently unknown. Moreover, an inability to shift internal states when needed has also been associated with conditions such as Parkinson's disease and attention-deficits/hyperactivity disorder (Monchi et al., 2004; Rohlf et al., 2012). However, less is known about whether these findings are related to other findings about memory deficits in patients with these conditions (Skodzik et al., 2017; Whittington et al., 2006). Future research on internal state change triggered event segmentation will not only inform our understanding of how the healthy brain structures experiences but also contribute to translational approaches and clinical applications.

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