Encoding or Post Encoding Mechanisms Invoke Enhanced Memory for Event Boundaries?

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Abstract

We perceive our environment by breaking it down into segments known as events. Event segmentation influences memory by enhancing the retention of information at boundaries as compared to information that is contained within the boundaries of an event (the event boundary advantage). This effect has been attributed to changes in attention during perception of events. Prior studies have demonstrated greater attention while perceiving event boundaries but have failed to demonstrate attention as the underlying mechanism for the event-boundary advantage. Two behavioral experiments were conducted to investigate, a) whether the event boundary advantage is observed even for events that are perceived while performing a concurrent task? and b) Is there a decrease in the boundary advantage when the concurrent task complexity is increased? In both experiments, participants watched videos related to performance of daily tasks, while simultaneously performing a probe detection task; either a simple dot detection (Experiment 1) or a go/ no-go task (Experiment 2). The probe was presented either at an event boundary or at pre-defined non-boundary time point and the memory for both temporal locations was measured after the completion of the detection task. A mixed effects logistic regression revealed an interactive effect for both detection accuracy and the boundary advantage; probe detection at event boundaries remained unaffected throughout an event irrespective of the level of the task complexity while, contrary to prediction, a boundary advantage in memory was also observed. But detection and memory accuracy for non-boundaries decreased successively for both low and high secondary task complexity suggesting greater interference for processing non-boundary information. These results indicate that greater attention may not be the only predictor of better memory for event boundaries as postulated by Event Segmentation theory.

Keywords: Event boundary advantage, Event segmentation, Attention and Event boundaries, Event memory

Introduction

An event is defined as, "a segment of time at a given location that is perceived by an observer to have a beginning and an end" (Zacks, 2001). We remember experienced or observed events in discrete chunks even though these events have unfolded continuously in real time. This discretization occurs during perceiving/ encoding of these events itself. This process has been termed as event segmentation (Zacks, Speer, Swallow, Braver & Reynolds, 2007).

The way we perceive and segment an event also influences the memorability for certain parts of the event (Kurby & Zacks, 2011; see Radvansky & Zacks, 2017 for review; Sargent et al, 2013; Swallow, Zacks, & Abrams, 2009). Memory for the beginning and the end of an event is greater compared to items in the middle, termed as the event boundary advantage (see Radvansky & Zacks, 2017 for review; Gold, Zacks, & Flores, 2017; Jeunehomme & D'Argembeau, 2018; Pettijohn, Thompson, Tamplin, Kraweitz, & Radvansky, 2016; Swallow et al, 2011; Swallow, Zacks, & Abrams, 2009).

One comprehensive account of the mechanism underlying the event boundary advantage is provided by the event segmentation theory (EST). According to EST, during perception of an ongoing episode, our brain forms schema-based predictions about the future state of the environment (Richmond & Zacks, 2017; Reynolds, & Zacks, 2011; Zacks et al, 2007; Zacks, Kumar, Abrams, & Mehta, 2009). An error in accurate prediction of the future state, triggers a set of processes aimed at predicting the environment in a better manner. The processes triggered by prediction error include enhanced attention towards the incoming sensory information and new schema retrieval for working model updating (Zacks, Kurby, Eisenberg, & Haroutunian, 2011). The rise in prediction error and working model updating is phenomenologically experienced as an event boundary (Kurby & Zacks, 2008; Zacks et al, 2007; Zacks & Tversky, 2001). Since greater attention is paid to the incoming information at these temporal locations, a concomitant result is better encoding of information at event boundaries (Swallow et al, 2011; Zacks et al, 2007).

Empirical work has provided some support for attention-based account of event segmentation in line with EST; dwell time for slide-shows describing an event is greater at event boundaries (Hard, Recchia, & Tversky, 2011, Kosie & Baldwin, 2019). Huff, Papenmeier, Zacks (2012) using a combined go/no-go and MOT task overlaid on an artificial football game found a decrease in go/no-go performance for probes occurring at event boundary suggesting that there was greater allocation of attentional resources at event boundaries. However, the evidence in support of increased attentional resources at event boundaries as an explanation of greater recall of event boundary is not conclusive. Although prior studies (Hard et al, 2011; Kosie & Baldwin, 2019) have consistently shown increased dwell times for boundaries, evidence for longer dwell-times predicting recall memory for boundaries has been inconsistent. Hard et al (2011) found that greater dwell-times predicted better recall only for coarse boundaries whereas Kosie & Baldwin. (2019) reported an overall pattern of longer dwell times predicting recall memory for both boundaries and within-events. Further when the effect of dwell time on within-event recall was eliminated, greater dwell time no longer predicted recall performance at boundaries (Kosie & Baldwin, 2019). Huff et al. (2012) too found greater attention being paid (indicated by a decrease in performance of a go/no-go task) at event boundaries but their study did not investigate memory recall as a function of probe type (occurring at the event boundary versus the event middle). Thus, although there is robust evidence for greater attention being allocated to event boundaries, evidence for this enhancement resulting in boundary advantage is inconsistent. It has also been suggested that the online hippocampal activity time-locked to event-boundaries reflects retrieval rather than encoding processes and event boundaries play an important role in memory consolidation (Dudai, Karni, & Born, 2015). This would mean that event-boundary advantage may reflect processes other than being a consequence of mere fluctuations of attention during event perception.

In order to understand how attention influences the event boundary advantage, we used a dual task paradigm where participants were asked to perform a probe detection task while viewing a standardized video. Firstly, a dual task paradigm allows investigation of how the two tasks (event perception and detection) interact with each other. Secondly, dual task paradigm allows us to vary attentional load over different event timepoints, without changing the event segmentation task. If boundary advantage depends on attention, one would expect that varying the attentional load would either interfere with secondary task performance or inversely affect boundary advantage and conclusively establish the role of attention in the occurrence of event boundary advantage for memory. As memory recall was tied to probe locations, this also gave us an opportunity to see how attention and memory at different probe locations varied with duration between probe and later recall.

The following two experiments reported here investigated the event boundary advantage in recall of actions from standardized movie clips while performing a concurrent probe detection task (Experiment 1) and how the event boundary advantage is affected by increase in complexity of the concurrent task (Experiment 2). Additionally, we also investigated how sequential processing over time interacts with attention and memory for events.

Experiment 1

Prior studies that have looked at how attention influences boundary advantage have used a self-paced task with dwell time as a measure of attention. Dwell time on a stimulus measures not only attentional allocation, but is also influenced by a large number of top-down and bottom-up factors (Parks & Hopfinger, 2008). To isolate the relationship between attention and event boundary effect, we used a dual task paradigm, where participants performed a dot-probe task while a video clip was played in the background. The performance on dot-probe task was taken as a measure of attentional load due to event-segmentation. Participants were asked to recall information (action being performed) at the time of probe presentation. We hypothesized, based on predictions of EST and earlier work of Huff et al (2012), if detection accuracy for probes at event boundary would be lower compared to probes in event middle a boundary advantage in memory would be observed or vice versa. For probe position, based on EST, we expected that similar interaction would be observed between probes at non-boundary and boundary locations both for accuracy as well as memory recall.

Method

Participants Fifty-one students of IIT Kanpur, India; within the age range of 18 to 28 years (mean age: 23.5 yrs) participated in the experiment. All participants reported normal or corrected to normal vision. All participants received monetary compensation for their participation.

Stimuli and Apparatus The stimuli consisted of short videos of an actor performing day to day activity (Making a sandwich, planting a sapling, etc.); stimuli were developed and standardized in our lab based on the script and parameters specified in prior studies (Hanson and Hirst, 1989; Zacks, Tversky & Iyer, 2001) except all videos were filmed on a single actor. The temporal position of event boundaries and non-boundaries was obtained earlier by asking a separate set of participants (30) to segment the stimuli (at coarse level). and looking at frequency distribution of responses in bins of size 1 seconds (bins with frequency greater than Mean+2SD were marked as event boundaries and bins with less than Mean-2SD were marked as event-middles). These videos subtended an angle of 15.48 degrees in width and 7.82 degrees in height. Stimuli videos were displayed on a 24” screen at a resolution of 1920 x 1080 using Psychopy (version 1.90). All videos were presented over a black background. Similar to the original stimuli (Zacks, 2001), the videos were not matched for duration (mean duration= 119.88 ± 51.35 SD).

Probe was a red colored circle (diameter =0.47^{o}) centered over the video frame, presented at time-points corresponding to an event-boundary or a non-boundary (120ms).

Procedure Participants were instructed in detail about the experimental task after obtaining written consent. On each trial, participants watched a video while simultaneously performing the probe detection task. The dots appeared at the pre-defined event boundaries or non-boundaries for each video. They were asked to remember the action of the actor and the object acted upon at the time of probe onset and recall these actions after the video finished. At the time of recall, participants were asked to type-in their responses. They were

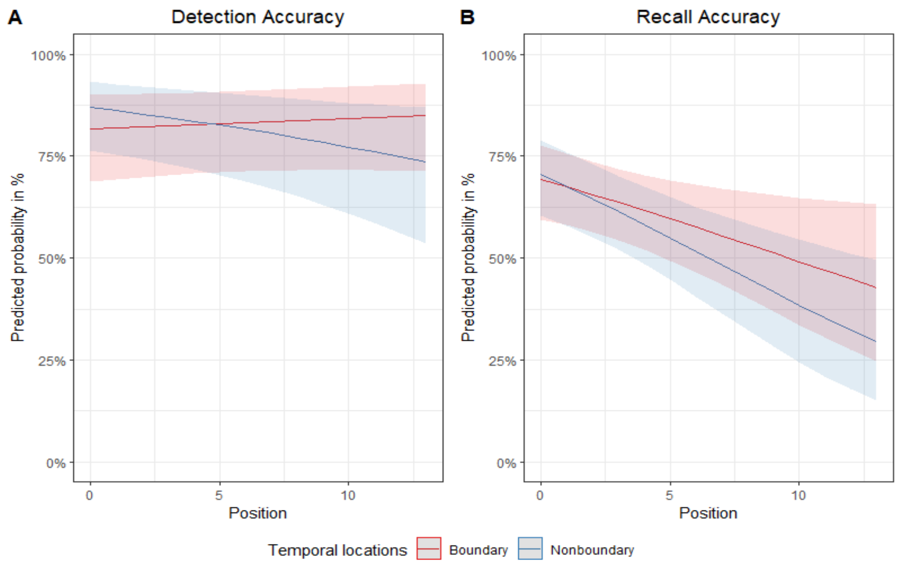

Figure 1: A) Predicted probability (%) of detecting probes occurring at boundary and non-boundary time points. B) Predicted probability of recalling boundary/ non-boundary information. Ribbons represent 95% CI.

asked to recall actions in the order of occurrence. After receiving instructions, participants practiced performing the task on two videos. They responded by typing in the responses. After finishing recall task, they compared their typed responses to sample written responses provided by the experimenter to model the structure, and the level of detail expected. For example, if the video was about making coffee and if a probe occurred when the actor opened the lid of the coffee jar, the expected response was 'Opened coffee jar/bottle' involving both the object and action description.

This was followed by the main experiment. On each trial, participants were shown a unique video while they performed the probe detection task. After the video was over, they recalled the actions as instructed earlier. No written/ verbal feedback about responses was given in the main block of the experiment. There was a self-paced break at the end of each trial. Order of the videos was randomized. Each video (including the practice videos) was presented only once. The total number of trials per participant in the main block was 8 and the experiment took 60 minutes to complete.

Analysis and Results The correct responses for the memory task were formulated prior to the conduction of the experiment using Schwartz's criteria for identifying action units (Schwartz et al, 1991) for all the pre-defined probes. Raw data for the recall task was manually scored as "1" for correct (responses where participant correctly recalled both action and object) and "0" for incorrect (either incorrect action or incorrect object or both). One participant's data was removed after they reported forgetting to perform probe detection task. Median absolute deviation (MAD) method with median+/- 2.5*MAD as criteria for rejection (Leys et al, 2013) was used to further remove outliers which led to the removal one more participant. Mean detection and mean recall accuracy were computed for the remaining 48 participants. Mean detection accuracy for boundaries *(M = 0.74, SD = 0.29)* and non-boundaries *(M = 0.74, SD = 0.31)* was the same. Mean recall accuracy for event boundary *(M = 0.61, SD = 0.09)* was greater than non-boundary *(M = 0.56,* SD = 0.09), t (47) = 2.8, $p < 0.01$.

Mixed effects logistic regression analysis was performed on the data since both outcome variables (detection and recall accuracy) were categorical (Correct/Incorrect). All statistical analysis and data plotting were conducted using R-studio. The mixed model was assessed with the 'glmer' function in lme4 package. Predicted probabilities were computed using the 'ggpredict' function from 'ggeffects' package. Graphs were generated with 'ggplot2' package. Fixed effects comprised of an interaction term for temporal locations (boundary/ non-boundary), serial position of probe occurrence and intercept for Participant and Videos as random effects (other random effects in terms of slopes and intercepts were ruled out).

Detection results indicate a significant interaction between temporal location and serial positions $\beta = -0.09$, $SE = 0.033$, $p < 0.01$. The log odds for detecting a probe at boundaries increased by 0.01 for each unit increase in Position while the log odds decreased by 0.09 for non-boundary. The predicted probabilities of detection for event boundary across positions increased from 82% to 84% whereas for non-boundaries it decreased from 86% to 79% (see Figure 1A), the detection accuracy for event-positions remained similar across the length of videos. Interestingly the detection accuracy was similar for boundaries and non-boundaries for probes at initial locations but decreased only for non-boundary locations for the latter probes.

Another model with the same fixed and random effects was run to assess recall accuracy as a function of temporal locations and probe position. Interaction between temporal location and position was significant, $\beta = -0.049$, $SE = 0.024$,

$p = 0.045$. Log odds for recalling information at event boundaries reduced by 0.084 at successive positions of serial recall whereas they reduced by 0.049 for non-boundaries. The predicted probability of recalling information from event boundaries decreased across serial positions from 67% for initial positions to 53% for latter serial position or towards later parts of the video. Probability of accurately recalling information for probes at non-boundaries decreased from 67% for earlier parts of the video to 45% towards the end of the videos (Figure 1B). Suggesting that boundary advantage for memory seen in overall recall becomes apparent only for recent probes and is negligible (if not absent) for initial probe locations.

Discussion EST attributes the enhancement of memory at event boundaries to greater attention paid to these temporal locations during event perception. Studies that report increased attention at event boundaries have found inconsistent effects of attention on boundary advantage (Hard et al, 2011; Kosie & Baldwin, 2019) or have not tested for memory (Huff et al, 2012). One reason for the inconsistent results could be due to the static nature (self-paced slide viewing) of stimuli used rather than real-life (videos) which differ from dynamic stimuli and which have been used in studies that find boundary advantage (Gold et al, 2017; Kurby & Zacks, 2011; Pettijohn et al, 2016; Sargent et al, 2013; Swallow, Zacks & Abrams, 2009; Swallow et al., 2011; Zacks et al, 2001). The artificial scenarios lack the potential to test for memory and the slide viewing stimuli lacks the dynamicity in incoming information. If processing of event boundaries indeed requires greater attention and is generalizable across stimuli then, one would expect the same pattern of results as prior studies when a concurrent task is performed while watching dynamic videos i.e. performance of the concurrent task is affected at event boundaries as compared to non-boundaries (Huff et al, 2012).

Results of Experiment 1 where participants performed a dot detection task while watching videos were not as hypothesized by EST. Performing a concurrent task of detecting dots while viewing an event was more challenging when the dots appeared at temporal locations other than event boundaries. One explanation for these contrary results could be that participants were paying more attention to remembering the information at non-boundary locations. But the recall performance suggests otherwise. Probability of recalling information at non-boundary locations decreased more over the course of viewing the events whereas recall memory for information encountered at event boundaries, although decreased over positions, was still better than non-boundaries. Taken together, these results suggest that performing a concurrent task does not affect event boundaries as much as non-boundaries.

The mean recall accuracy and predicted probabilities both indicate that event boundary advantage is observed even in the presence of a concurrent task. There is a possibility that the concurrent task did not demand attention to an extent that would interfere with encoding boundary information. Hence, Experiment 2 was conducted to understand whether increasing task complexity would result in the same pattern of results as observed in Experiment 1.

Experiment 2

Huff et al (2012) showed greater attention resources are devoted at event boundaries using a target-distractor task with a multiple-object tracking (MOT) paradigm. Target detection was selectively impaired at event boundary locations as compared to non-boundary timepoints. However, they did not test, and the stimulus they used was not conducive to test, for memory at these timepoints. Kosie & Baldwin (2019) obtained similar results; dwell times were greater for those images/ frames that were initially marked as event boundary by raters.

Experiment 1 results show a memory advantage even though the performance on dot-detection task is similar for boundary and non-boundary probes. This may be due to the simplicity of the concurrent task being performed. Specifically, Huff et al (2012) have employed a MOT task while a dynamic event was being perceived which may have resulted in capturing the difference between attention requirements at boundaries and non-boundaries.

Experiment 2 aimed to reproduce these attention results in close to real-life scenarios by trying to employ a concurrent task which is similar to that used by Huff el al (2012). Participants performed an identity go/ no-go probe task while viewing videos. The spatial location of probe occurrence was also randomized to closely match the target/ distractor task in Huff et al (2012) and increase the complexity of the concurrent task. However, the primary aim of Experiment 2 was to evaluate whether event boundary advantage is observed when the concurrent task complexity increases.

Method

Participants Fifty new students from IIT Kanpur who had not participated in the prior experiment; within the age range of 18 to 28 years (mean age: 23.5 years); volunteered for this study. All participants reported normal or corrected to normal vision. All participants received monetary compensation for their participation.

Stimuli and Apparatus The stimuli videos, screen and video specifications were the same as Experiment 1. The go/ no-go probes consisted of circles (radius = 0.01, 0.01; norm units) subtending an angle of 0.47° and at an eccentricity of 0.38°, and were either red or green in color (green = 30.16 cd/m^2 and red = 30.73 cd/m^2). The use of green and red probes as ‘go’ and ‘no-go’ probes was counterbalanced across participants. The ratio of go to no-go trials was 4:1.

Procedure The procedure for practice and main experiment was the same as Experiment 1 except participants were instructed at the beginning of the experiment the color of the dot for which they had to respond (Go) and the color for which they had to withhold response (No-go).

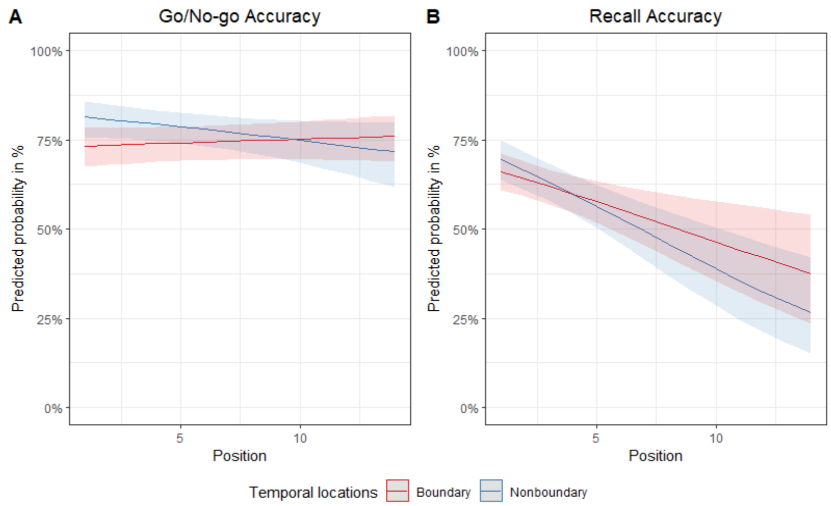

Figure 2: A) Predicted probability (in percent) of accurately responding to both 'go' and 'no-go' responses across serial positions for the two temporal locations; boundary and non-boundary. B) Predicted probability of accurately recalling information from boundaries and non-boundaries across probe position. Ribbons represent 95% CI

Analysis and Results The raw data scoring and outlier analysis were the same as Experiment 1. One participant's data was removed due to the program malfunctioning during the experiment. Outlier analysis led to removal of 5 participants' data. Results reported here are for 44 participants. In order to obtain the total accuracy scores for the go/ no-go task, those responses where the probe was a 'no-go' and participant did not respond and when it was a 'go' probe and participants responded by pressing a key, were scored as "1" while the rest were scored as "0". 'Go' and 'no-go' responses were not considered separately since the main aim of the study was to observe the differences in memory performance for boundaries and non-boundaries while performing a concurrent task.

Mixed effects logistic regression was performed on the go/no-go accuracy using the same fixed effects and random effects specified in Experiment 1. Interaction between temporal location and position was significant ($\beta = -0.052, SE = 0.026, p = 0.049$) such that detection of go/ no-go probes at boundaries was unaffected by positions (*Predicted probability: 74%(p1)- 75%(p14)*) but detection of probes occurring at non-boundaries decreased in accuracy over successive positions *(Predicted probability: 81%(p1) - 76%(p14)* as the video progressed (see Figure 3). The log odds for accurately performing the go/ no-go task decreased by 0.01 for boundaries as the video progressed while log odds decreased by 0.05 for non-boundaries for consecutive probe positions in the video.

Recall accuracy was analyzed using the same fixed and random effects as Experiment 1. Interaction between temporal locations and positions affecting recall accuracy was significant, $\beta = -0.055, SE = 0.023, p = 0.019$. The log odds for accurately recalling information at event boundaries decreased by 0.06 for successive serial positions whereas they decreased by 0.05 for non-boundaries. Probability of accurately recalling boundary information from initial positions of the video was 63% which reduced to 51% by the end of video (see Figure 4). For information from other parts of the video that were not event boundaries, the probability of accurate recall was 66% initially. This decreased to 45% towards the latter portions of the video.

Discussion The aim of Experiment 2 was two-fold. First, to analyze whether increasing task complexity produces detection results similar to those obtained by prior studies. That is, lowered detection performance at event boundaries. Second, if increased attention at event boundaries leads to boundary advantage (EST) then performing a concurrent attention demanding task will decrease/ invalidate event boundary advantage. Results obtained suggest that even as complexity of the concurrent task increased the pattern of results for both tasks remained almost the same as experiment 1. In terms of performance on the go/ no-go task, the probability that participants would give an accurate response, considering the probe appeared at an event boundary, remained stable at around seventy-four percent across all serial positions. However, performance varied selectively for go/ no-go task performance at non-boundaries. The initial performance was better than that at event boundaries but it greatly decreased over serial positions with the final position accuracy falling down greater than probability for event boundaries. Recall performance for both temporal locations were affected by the serial position of information being retrieved. Recall of information from event boundaries was progressively more difficult as the task progressed. This trend was also observed for recalling non-boundary information. But, the magnitude of failure to recall was greater for non-boundary information. Detection and recall data show the same decreasing trend which rules out the possibility of trade-off between tasks. Results of Experiment 2 showed that event boundary advantage is not prominent when the concurrent task is more complex.

General Discussion

The event boundary advantage refers to the enhancement in memory observed at the starting and end-points of an event generally termed as event boundaries (Hanson & Hirst, 1989; Zacks, Tversky & Iyer, 2001). EST explains this enhancement as a consequence of processes occurring during event perception (Zacks et al, 2007). When an event boundary is encountered, the process of reducing prediction error requires event model updating and newer schemas to be retrieved. To guide these processes more attention is paid to the sensory information. EST postulates that it is this greater attention that leads to better encoding and hence better retention of the information encountered at/ near event boundary locations (Swallow, 2011; Kurby & Zacks, 2008; Zacks, 2007).

A few prior studies have provided some evidence for greater attention being required at event boundaries (Hard et al, 2011; Huff et al, 2012; Kosie & Baldwin, 2019). Two of these studies (Hard, 2011; Kosie, & Baldwin, 2019) employed a dwell time paradigm to understand which temporal locations were being attended to more while viewing self-paced slideshows of an event. They found that dwell time was longer for event boundaries than non-boundaries. Similarly, Huff et al (2012) employed a target-distractor detection task while participants viewed an artificial football game, with across team ball passes signifying event boundaries. They too found that performing the detection task was difficult at temporal locations considered as event boundaries as compared to non-boundaries. But, so far, to the best of the authors' knowledge, only two studies have tried to correlate whether greater attention at event boundaries leads to an additive increase in memory for these temporal locations (Hard et al, 2011; Kosie & Baldwin, 2019). Hard et al (2011) report that longer dwell times predicted memory for only coarse event boundaries while Kosie & Baldwin, (2019) reported an overall effect of attention on memory recall for both boundaries and non-boundaries.

In the present study, we decreased the amount of attentional resources available to process events by asking participants to perform a concurrent task while viewing events. The primary goal was to understand if a decrease in attention (contrary to the approach by Kosie & Baldwin, 2019) would differentially affect memory for information at the event boundaries compared to non-boundaries. Aim of the first experiment was to see whether the event boundary advantage is observed while performing a concurrent task. The second experiment investigated whether increasing complexity of the concurrent task would differentially affect the pattern of results in experiment 1. It was observed in both experiments that relative serial position and temporal location of probe occurrence both influenced detection and memory outcomes. The pattern of results for both the first and second experiment were consistent. Performance on the simple (dot detection) or complex (go/ no-go) concurrent task was more variable when the probe was at a non-boundary location, such that the initial accuracy depleted as the videos progressed. Concurrent task performance was unaffected and remained stable when the task was being performed at boundaries of the event. Thus, both experiments find evidence for differential processing of the concurrent task across boundaries and non-boundaries but this difference is contrary to the Zacks et al's (2007) predictions. Recall accuracy in both experiments showed that memory for information at boundaries was better than memory for non-boundary information, across serial positions. Results suggest that accuracy on probe-detection task is not negatively correlated with memory recall. This finding is opposite to what one would expect based on EST and the reports of earlier studies. One reason for this difference might be attributed to the probe-location based analysis of data, which would disappear when averaging across trials.

Additionally, if greater attention at event boundaries leads to event boundary advantage, one would expect to observe the same trend of serial effects for detection at non-boundary points of an event as observed for boundary memory. A decreasing trend for detection over serial positions would indicate depletion of attentional resources at event boundaries over time which would translate to gradual decrease of memory overtime as well. But detection does not show this trend suggesting no variation in attention occurs across positions at the time of perceiving or encoding these event boundaries. There might be a possibility that poorer attention at non-boundaries led to fluctuations in both tasks' performance at these locations. But prior research also indicates that once an event boundary is encountered that event model is a part of the long-term memory (Swallow et al, 2011). Thus, any pattern or trend that one sees for memory in the current data would be due to post-encoding mechanisms that lead to re-organization of event constituents (Clewett et al, 2019) or greater forgetting of some parts of an event which give rise to event boundary advantage. Interpretation of results of the present study has relied heavily on considering sequential processing of information. The study design is not conducive to assess event boundary advantage without the influence of serial positions. But, since EST is postulated to understand the perception of events which are sequential in nature, considering event boundary advantage for absolute instances would always lead to erroneous conclusions.

One proposition for such post-encoding re-organization that could explain the current results is retrieval-based enhancement of event boundaries wherein better boundary encoding leads to better access to associated within-event units (DuBrow & Davachi, 2016, Clewett et al, 2019). Further studies are required to test whether event boundaries increase access to within event information. To conclude, the present study did not find evidence for attention modulations resulting in enhancement for memory at event boundaries.

Instead, the results indicate that event boundary advantage is probably a result of post-encoding mechanisms. Further research is required to identify these mechanisms to explain this selective memory enhancement.

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