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OBSERVATION

Discrete Events as Units of Perceived Time

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In visual images, we perceive both space (as a continuous visual medium) and objects (that inhabit space). Similarly, in dynamic visual experience, we perceive both continuous time and discrete events. What is the relationship between these units of experience? The most intuitive answer may be similar to the spatial case: time is perceived as an underlying medium, which is later segmented into discrete event representations. Here we explore the opposite possibility—that our subjective experience of time itself can be influenced by how durations are temporally segmented, beyond more general effects of change and complexity. We show that the way in which a continuous dynamic display is segmented into discrete units (via a *path shuffling* manipulation) greatly influences duration judgments, independent of psychophysical factors previously implicated in time perception, such as overall stimulus energy, attention and predictability. It seems that we may use the passage of discrete events—and the boundaries between them—in our subjective experience as part of the raw material for inferring the strength of the underlying "current" of time.

Keywords: time dilation, event perception, segmentation, object persistence

"Time is a sort of river of passing events, and strong is its current."

—Marcus Aurelius (1909–1914, [translated version] *Meditations, IV, 43*)

In the physical world, time seems to flow inexorably forward, and always at the same objective pace (see Carroll, 2010). In our subjective experience, in contrast, the pace at which time seems to flow can speed up or slow down, as a function of lower-level variables such as stimulus energy (e.g., Brown, 1995), and higher-level factors such as attention (e.g., Tse, Intriligator, Rivest, & Cavanagh, 2004) and predictability (e.g., Pariyadath & Eagleman, 2007). Continuous visual input is also carved up in our subjective experience into discrete units, so that we perceive durations as being filled by particular events. There is considerable agreement between observers on where such units begin and end across a wide range of stimuli (e.g., Zacks, 2004; Zacks, Speer, & Reynolds, 2009), and discrete event representations also influence attention and memory for dynamic scenes (e.g., Levin & Varakin, 2004; Swallow, Zacks, & Abrams, 2009).

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How do these two primary features of our dynamic perceptual experience—time and events—relate to each other? Intuitively, time is the underlying medium for event segmentation—the "river" on which events flow. Here, in contrast, we explore the possibility that subjective time is influenced by how temporal experience is segmented into discrete events. This study is inspired by analogous explorations of space and object perception: though space seems like the underlying medium for object segregation, the way in which perceptual experience is segmented into discrete objects influences spatial perception (e.g., Vickery & Chun, 2010), attention (e.g., Scholl, 2001), and memory (e.g., Luck & Vogel, 1997). Might the underlying "units" of time perception be similarly discrete?

Experiment 1: Path Shuffling

Here we explore whether temporal judgments are influenced by incidental visual event segmentation. To isolate a role for segmentation, we used animations of simple shapes that could be carefully controlled, and segmentation cues that relied on simple and universal visual properties such as objecthood and spatiotemporal continuity. In particular, an object moving along a continuous spatiotemporal path is perceived to be a single persisting individual, whereas disruptions to perceived spatiotemporal continuity result in the percept of multiple independent objects (for a review, see Scholl, 2007). This kind of cue—the perceived disappearance of old objects followed by the appearance of new objects—has been found in previous work to induce event boundaries (e.g., Zacks et al., 2009).

To induce event segmentation in the current study, we introduced stark spatiotemporal gaps into brief animations of a single moving object (e.g., Figure 1). When the resulting segments are played "in order" (on "Forwards" trials), observers see a single

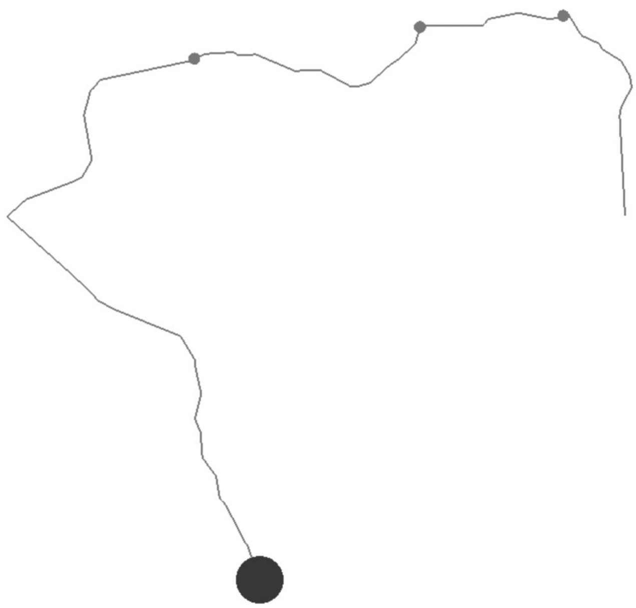

Figure 1. A sample screenshot from a Forwards trial of Experiment 1. The image depicts the initial frame of a sample trial, with the dynamic disc (depicted as the largest of four circles, in black) superimposed on a static path (the thin gray line) and its associated nodes (the small gray circles). (In the actual displays, the dynamic disc was white, and background was black.) During experimental trials, the path and nodes were always visible, and the dynamic white disc was visible except during the three brief (500 ms) interruptions when it momentarily disappeared.

persisting object moving along a path from end to end (with gaps perceived as momentary occlusions; see Figure 2a). When played in reverse order (on "Memento" trials), observers see 4 distinct objects (see Figure 2b).[1] These conditions were equated for stimulus salience, motion energy, attention, and predictability, but differed in terms of their degree of event segmentation. Participants viewed each animation, then reproduced the subjective duration via a keypress.

Method

Observers. Twelve observers participated in a single 40-min session for a small payment or to satisfy a course requirement. All had normal or corrected-to-normal acuity.

Apparatus and stimuli. The displays were presented on a PC via MATLAB and the Psychophysics Toolbox libraries (Brainard, 1997; Pelli, 1997). Observers sat without head restraint approximately 50 cm from the monitor, which subtended 37.6° by 30.4°.

On each trial, a 1.52° white disk moved for 6-10s at 5.47°/s across a 0.06° gray line (the "path") interspersed with four 0.38° gray disks (the "nodes") that signaled the gaps in the object's trajectory (to equate for predictability). The trajectories (and thus the visible paths) were constructed randomly (see Figure 1 for an example), similar to previous multiple-object tracking displays (e.g., Liverence & Scholl, 2011). As the object approached each node, it disappeared for 500 ms, then reappeared atop the node. Nodes and gaps were randomly distributed within each trajectory so that each segment lasted 1-4 s and successive segments were at least 33% longer or shorter.

Trials were created in matched pairs with the same motion trajectory (thus equating for stimulus energy), but differing in the order in which the segments were displayed: the ordering was spatiotemporally correct during Forwards trials (Figure 2a), but reversed during Memento trials (Figure 2b). Critically, the number and duration of gaps was equated, so that this could not explain any differences (see Fortin & Massé, 2000).

Procedure and design. Each trial began with the simultaneous onset of the path and nodes—along with the disk, which immediately began to move. Observers' primary task was to watch each animation, and then immediately reproduce its full duration (including gaps) by holding down a key (during which a central 1.52° red disk turned green for visual feedback). If observers failed to begin their response within 3 s, the trial aborted, and observers received a notice to respond more quickly. To assure that participants carefully attended to the moving disk, they also had to press a key whenever they detected a luminance probe: a 61% dimming of the disk, lasting 167 ms, and occurring on 1/3 of trials).

Sixty paths were generated, and each was utilized in both a Forwards and Memento trial, for a total of 120 trials, played in a different random order for each observer.

Results and Discussion

Luminance probe detection rates were high (averaging 93.6%) and did not differ by condition, $t(11) = 0.012$, $p = .991$—suggesting that observers were equally successful at maintaining visual attention on the disk in each condition. Furthermore, the absolute error in duration reproductions did not differ by condition (Forwards = 28.9%; Memento = 28.1%; $t(11) = 0.590$, $p = .567$)—suggesting that these conditions resulted in memory traces of equivalent precision.

For the primary analysis, we first calculated signed reproduction error ([Reproduced–Actual]/Actual) on a trial-by-trial basis—so that positive values signal time dilation, and negative values signal time compression. Pairs in which either trial was more than 2.5 *SD*s beyond the participant's mean were excluded from further analysis (2.1% of trials). Differential error was calculated for each remaining matched pair of trials as the Memento signed error minus the Forwards signed error.

The mean differential error, averaged across observers, was −4.0%, which differed from chance, $t(11) = 2.686$, $p = .021$, $d = 0.78$, all tests two-tailed, indicating that observers estimated Forwards trials to have lasted longer on average than matched Memento trials. Ten of 12 observers exhibited this pattern (binomial test: $p = .039$).

Since gaze was unconstrained in this experiment, it is possible that differences in saccadic eye movements (as in Morrone, Ross, & Burr, 2005) drove the observed differences in duration reproduction. We ruled out this possibility by replicating these results with a new group of 19 observers who had their fixation on a static

[1] This manipulation was motivated by the analogous temporal structure of the film *Memento* (Nolan, 2000), which cleverly simulated the protagonist's retrograde amnesia: the film was segmented into discrete scenes, with each scene played as usual, but the order of the scenes reversed.

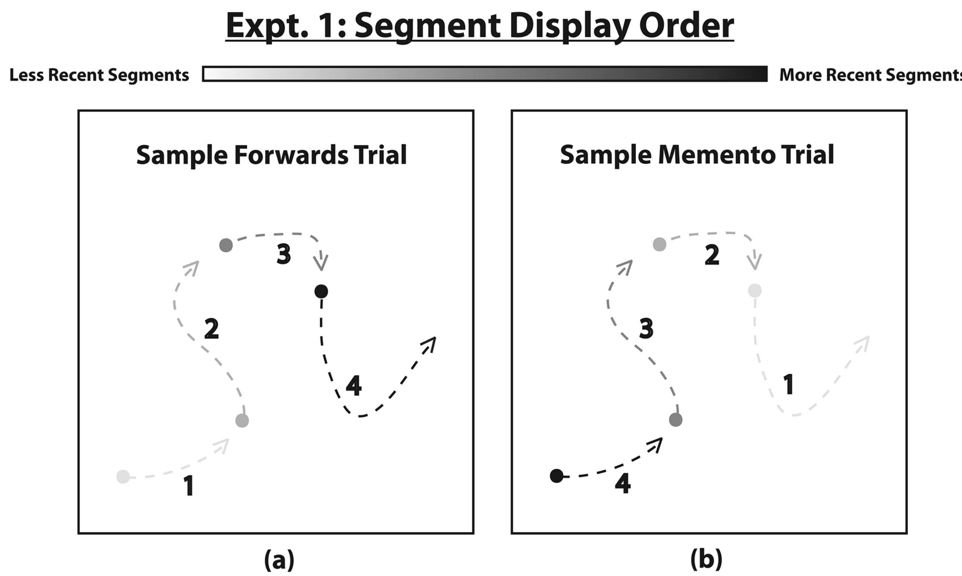

Figure 2. A cartoon illustration of the path shuffling manipulation in Experiment 1. Circles depict the starting positions of the disc on each path segment, and dashed arrows depict the direction of motion along each segment. In each panel, the temporal order of the disc's motion along four segments is depicted via shading: as in a phosphor trace, the darkest lines represent the most recently "played" segments, and the lightest lines represent the segments played first. The associated numbers also indicate the order in which the segments are played in each condition: (a) In Forwards trials, the disc simply followed the linear path from start to finish. (b) In Memento trials, the disc traversed each segment in order, but the segments themselves were played in a reversed order. See the online demonstrations for dynamic animations, at http://www.yale.edu/perception/memento/

central point monitored with an eyetracker while viewing the animations.[2]

Given that spatiotemporal continuity is one of the most powerful cues that drives object persistence and segmentation in dynamic scenes (see Scholl, 2007), it seemed likely to do so in our simple displays. To confirm this, though, we presented 20 new observers with a single Forwards or Memento animation (between subjects), and asked them whether it was best described in terms of "a single object" or "several distinct moving objects." Nine of 10 Forwards subjects chose the former option, while 10 of 10 Memento subjects chose the latter option, a significant difference, $\chi^2(1, N = 20) = 16.36$, $p < .0001$.

These findings suggest that event segmentation influences subjective time, independently of previously studied factors such as stimulus energy, attention, and predictability. Indeed, even beyond the controls in our experimental design, it would surely be Memento trials that were otherwise more visually salient, attention-grabbing, and unpredictable—but these factors all yield time *dilation* (for a review see Eagleman, 2008), which is the opposite pattern to that observed here.

Experiment 2: Attentional Shifting

The distance between subsequent disappearances and reappearances was greater for Memento trials than for Forwards trials in Experiment 1. This was a necessary feature of the design, as this greater distance was part of what disrupted spatiotemporal continuity in Memento trials, yielding multiple events. To ensure that this differential "gap-distance" could not explain the results of Experiment 1 (perhaps because attentional shifts for larger gaps took longer; cf. Brown, 1985), we directly tested whether greater offset/onset distances lead to shorter subjective durations in the present experiment. We did so by contrasting shorter and longer intersegment distances in a context where there was no spatiotemporal continuity in any trials, due to the addition of severe intersegment changes in motion direction (see Figures 3 and 4).

Method

This experiment was identical to Experiment 1 unless noted here. Twelve new observers participated. The disk always appeared in an initial random location, and then proceeded to move (without luminance probes) with the segment durations and offset/onset distances perfectly matched across trials to each of the 120 trials in Experiment 1. However, the path segments were reconfigured as follows. First, following a gap, the disk onset in a random direction relative to the previous offset point, but still separated by the same distance as in Experiment 1. Second, the entire segment was rotated such that the angle formed by the object's average direction of motion for the 83 ms pre- and postdisappearance was always at least 90° (see Figure 3). To make

[2] Eye movements were monitored with an ISCAN eyetracker at 60 Hz. Matched pairs of trials were excluded from analysis if participants fixated more than 1° beyond the fixation point for more than 10% of all samples in either trial. For remaining trials, the mean Memento–Forwards error differential was −2.5%, which differed significantly from chance [$t(18) = 2.172$, $p = 0.043$, $d = 0.50$].

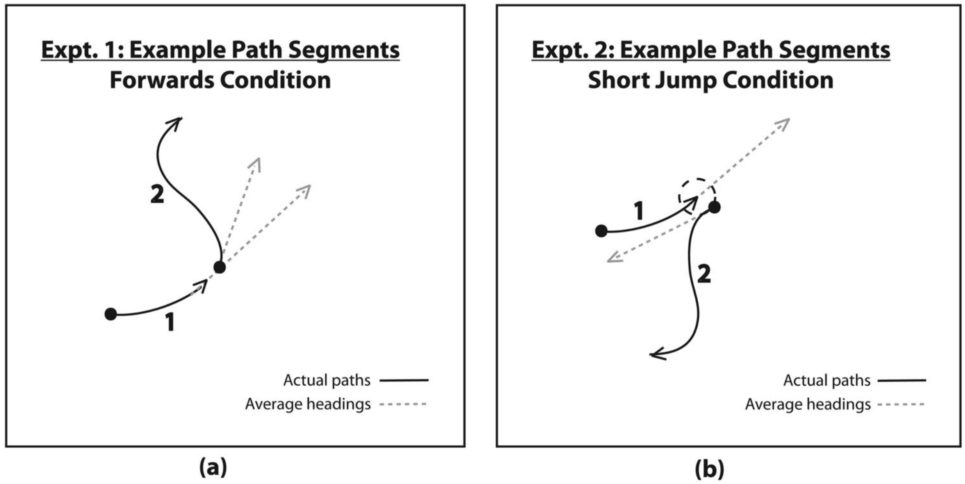

Figure 3. A depiction of how path segments were reconfigured in Experiment 2 to produce the Short Jumps paths. (a) The solid bars represent the two subsequent path segments from a Forwards trial of Experiment 1. The dashed lines represent the average headings for the last 83 ms of the first segment, and the first 83 ms of the second segment. (b) Each successive pair of segments was then transformed as follows to create a matched Short Jumps trial for Experiment 2. The first segment is presented as in the previous experiment's Forwards trial. The second segment is then transformed in two ways. First, it can begin at any position equidistant from the final position of the first segment—i.e. anywhere along the dashed black circle. Second, the second path segment's orientation was adjusted so that the angle between the average start and end trajectories was at least 90 degrees.

reappearance points predictable (as with the "nodes" in Experiment 1), a 1.52° white "preview" ring appeared for 1s at the reappearance location 500ms before the disk disappeared. Observers completed 120 trials, each matched for offset/onset distances and path segments to one of the trials of Experiment 1—now separated into Short Jumps trials (based on Forwards trials) and Long Jumps trials (based on Memento trials). (Critically, the preview ring was added to both types of trials, so that its presence could not account for any of the results.)

Results and Discussion

Signed reproduction errors were calculated as in Experiment 1 (now eliminating 1.7% of trials as outliers). Difference scores were calculated as Long Jumps minus matched Short Jumps signed error. The mean differential error was + 1.9%, but this did not differ from chance, $t(11) = 1.577$, $p = .143$, $d = 0.46$—demonstrating that the subjective durations of Long Jumps and Short Jumps trials did not differ.

These results rule out the possibility that the differences observed in Experiment 1 were due to differences in the offset/onset distances across conditions. Indeed, given that the present numerical difference is in the opposite direction of that observed in Experiment 1, our design may have actually underestimated the magnitude of the true effect of segmentation on subjective duration.

General Discussion

Although time seems intuitively more fundamental than events, here we found a clear influence of event segmentation on the subjective durations of simple dynamic animations: sequences that were segmented into distinct objects over time (appearing/disappearing sequentially) were perceived as subjectively shorter than those with only a single perceived object (undergoing occasional occlusion). Though segmentation and time perception have been theoretically related on at least one previous occasion (Poynter, 1989), this is to our knowledge the first experimental demonstration of such a connection.

This pattern runs counter to what would be predicted by many other types of effects. In particular, we would have expected *longer* reproductions for Memento trials on the basis of change-based models (which would treat event boundaries as salient changes; e.g., Brown, 1995), accounts of attention-based time dilation (since the appearance of new objects captures attention; see Hollingworth, Simons, & Franconeri, 2010; Tse et al., 2004), or appeals to complexity and coherence (since time dilation is typically observed for more complex and/or less coherent stimuli; e.g., Block, 1978; Boltz, 1995; Brown & Boltz, 2002). These contrasts serve to bolster the idea that the current effects are due to event segmentation per se, rather than to these previously studied factors.

Event segmentation (as in Memento trials here) may have led to shorter duration reproductions as a result of temporal representations becoming coarser or degraded. Several studies have shown that crossing an event boundary leads to poorer recall of the details of past events (Radvansky & Copeland, 2006; Swallow et al., 2009), perhaps due to the automatic "flushing" of an event-based memory buffer (Kurby & Zacks, 2008). If observers rely in part on the perceptual detail within event representations stored in memory when estimating the amount of time that has passed, then such subjective estimates should be influenced by any factor that impacts the quality of those memories.

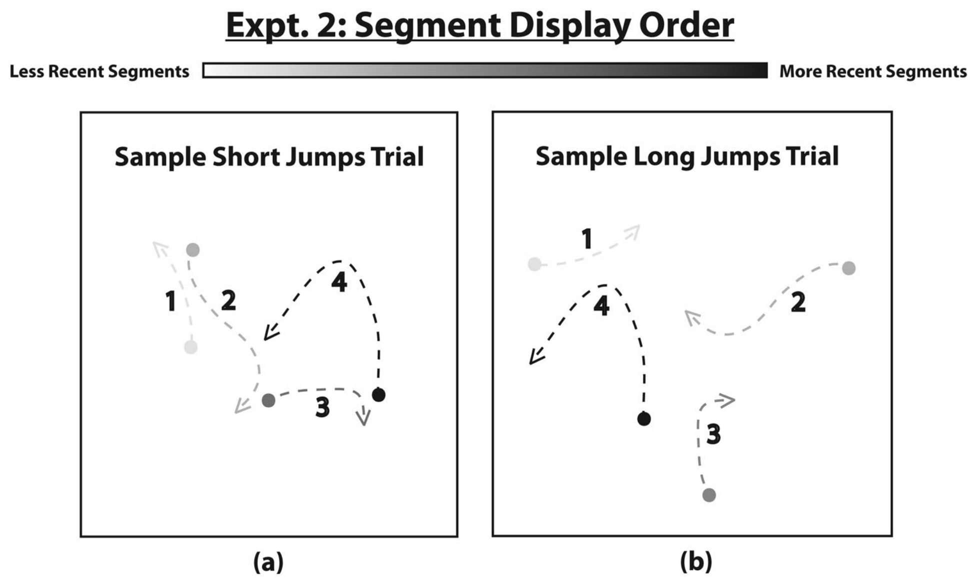

Figure 4. Cartoon depiction of a Short Jumps and Long Jumps trial from Experiment 2, using the same path segments as depicted in Figure 2. Circles depict the starting positions of the disc on each path segment, and the arrows depict the direction of motion along each segment. In each panel, the temporal order of the disc's motion along four segments is depicted via shading: as in a phosphor trace, the darkest lines represent the most recently "played" segments, and the lightest lines represent the segments played first. The associated numbers also indicate the order in which the segments are played in each condition: (a) In Short Jumps trials, the subsequent path segments are positioned to start a short distance away from the final position of the preceding segments. (b) In Long Jumps trials, these intersegment distances are longer, corresponding the offset/onset distances in Memento trials in Experiment 1.

Thus, if event segmentation leads to the flushing of such details from memory, then estimates of time will similarly be compromised. Such flushing effects could be implemented in terms of several possible underlying architectures. For example, if memory for time is represented in an independent, amodal format (e.g., "ticks" on pacemaker-accumulator models of time perception; e.g., Treisman, 1963), then crossing event boundaries might simply result in the loss of some of these ticks. In either case, the less proximate events from the Memento trials would be remembered with less perceptual or temporal detail during their subjective "playback" at the time of duration reproduction, which would lead to shorter estimates of time on those trials, relative to matched Forwards trials. One currently unresolved question is whether Path Shuffling typically leads to incrementally degraded representations of all prior events or to the complete loss of individual discrete events, which should be a target for future research.

In order to maintain careful control over other features such as attention and predictability, our displays involved simple objects and animations. However, the same dynamics may be at work in time perception for naturalistic events in real-world experience: a period of relatively high event segmentation may lead to coarser representations for the earlier events themselves. This might help to explain why time seems to have flown by after an exciting day filled with multiple events (say, at an amusement park), while time seems to have dragged on after a day spent largely doing one thing (say, while standing in line).

References

Aurelius, M. A. (1909–1914). The meditations of Marcus Aurelius (G. Long, Trans.). In C. W. Eliot (Ed.), The Harvard Classics (Vol. II, part 3). New York, NY: P. F. Collier & Son. Retrieved from http://www.bartleby.com/2/3/

Block, R. A. (1978). Remembered duration: Effects of event and sequence complexity. *Memory & Cognition, 6,* 320–326. doi:10.3758/BF03197462

Boltz, M. G. (1995). Effects of event structure on retrospective duration judgments. *Perception & Psychophysics, 57,* 1080–1096. doi:10.3758/BF03205466

Brainard, D. H. (1997). The psychophysics toolbox. *Spatial Vision, 10,* 433–436. doi:10.1163/156856897X00357

Brown, S. W. (1985). Time perception and attention: The effects of prospective versus retrospective paradigms and task demands on perceived duration. *Perception & Psychophysics, 38,* 115–124. doi:10.3758/BF03198848

Brown, S. W. (1995). Time, change, and motion: The effects of stimulus movement on temporal perception. *Perception & Psychophysics, 57,* 105–116. doi:10.3758/BF03211853

Brown, S. W., & Boltz, M. G. (2002). Attentional processes in time perception: Effects of mental workload and event structure. *Journal of Experimental Psychology: Human Perception & Performance, 28,* 600–615. doi:10.1037/0096-1523.28.3.600

Carroll, S. (2010). *From eternity to here: The quest for the ultimate theory of time.* New York: Dutton.

Eagleman, D. M. (2008). Human time perception and its illusions. *Current Opinion in Neurobiology, 18,* 131–136. doi:10.1016/j.conb.2008.06.002

Fortin, C., & Massé, N. (2000). Expecting a break in time estimation:

Attentional time-sharing without concurrent processing. *Journal of Experimental Psychology: Human Perception & Performance, 26,* 1788–1796. doi:10.1037/0096-1523.26.6.1788

Hollingworth, A., Simons, D. J., & Franconeri, S. L. (2010). New objects do not capture attention without a sensory transient. *Attention, Perception, & Psychophysics, 72,* 1298–1310. doi:10.3758/APP.72.5.1298

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

Levin, D. T., & Varakin, D. A. (2004). No pause for a brief disruption: Failures of visual awareness during ongoing events. *Consciousness & Cognition, 13,* 363–372. doi:10.1016/j.concog.2003.12.001

Liverence, B. M., & Scholl, B. J. (2011). Selective attention warps spatial representation: Parallel but opposing effects on attended versus inhibited objects. *Psychological Science, 22,* 1600–1608. doi:10.1177/0956797611422543

Luck, S. J., & Vogel, E. K. (1997). The capacity of visual working memory for features and conjunctions. *Nature, 390,* 279–281. doi:10.1038/36846

Morrone, M. C., Ross, J., & Burr, D. (2005). Saccadic eye movements cause compression of time as well as space. *Nature Neuroscience, 8,* 950–954.

Nolan, C. (Director). (2000). *Memento* [Motion Picture]. United States: Newmarket Films.

Pariyadath, V., & Eagleman, D. (2007). The effect of predictability on subjective duration. *PLoS ONE, 2,* Article e1264. Retrieved from http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0001264

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision, 10,* 437–442. doi:10.1163/156856897X00366

Poynter, W. D. (1989). Judging the duration of time intervals: A process of remembering segments of experience. In I. Levin & D. Zakay (Eds.), *Time and human cognition: A lifespan perspective* (pp. 305–330). Amsterdam, The Netherlands: Elsevier. doi:10.1016/S0166-4115(08)61045-6

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

Scholl, B. J. (2001). Objects and attention: The state of the art. *Cognition, 80,* 1–46. doi:10.1016/S0010-0277(00)00152-9

Scholl, B. J. (2007). Object persistence in philosophy and psychology. *Mind & Language, 22,* 563–591. doi:10.1111/j.1468-0017.2007.00321.x

Swallow, K. M., Zacks, J. M., & Abrams, R. A. (2009). Event boundaries in perception affect memory encoding and updating. *Journal of Experimental Psychology: General, 138,* 236–257. doi:10.1037/a0015631

Treisman, M. (1963). Temporal discrimination and the indifference interval: Implications for a model of the "internal clock." *Psychological Monographs, 77,* 1–31. doi:10.1037/h0093864

Tse, P. U., Intriligator, J., Rivest, J., & Cavanagh, P. (2004). Attention and the subjective expansion of time. *Perception & Psychophysics, 66,* 1171–1189. doi:10.3758/BF03196844

Vickery, T. J., & Chun, M. M. (2010). Object-based warping: An illusory distortion of space within objects. *Psychological Science, 21,* 1759–1764. doi:10.1177/0956797610388046

Zacks, J. M. (2004). Using movement and intentions to understand simple events. *Cognitive Science, 28,* 979–1008. doi:10.1207/s15516709cog2806_5

Zacks, J. M., Speer, N. K., & Reynolds, J. R. (2009). Segmentation in reading and film comprehension. *Journal of Experimental Psychology: General, 138,* 307–327. doi:10.1037/a0015305

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