

Subjective time dilation: Spatially local, object-based, or a global visual experience?

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Time can appear to slow down in certain brief real-life events—e.g. during car accidents or critical moments of athletes' performances. Such time dilation can also be produced to a smaller degree in the laboratory by 'oddballs' presented in series of otherwise identical stimuli. We explored the spatial distribution of subjective time dilation: Does time expand only for the oddball objects themselves, only for the local spatial region including the oddball, or for the entire visual field? Because real-life traumatic events provoke an apparently global visual experience of time expansion, we predicted—and observed—that a locally discrete oddball would also dilate the apparent duration of other concurrent events in other parts of the visual field. This 'dilation at a distance' was not diminished by increasing spatial separation between the oddball and target events, and was not influenced by manipulations of objecthood that drive object-based attention. In addition, behaviorally 'urgent' oddballs (looming objects) yielded time dilation, but visually similar receding objects did not. We interpret these results in terms of the influence of attention on time perception—where attention reflects general arousal and faster internal pacing rather than spatial or object-based selection, *per se*. As a result, attention influences subjective time dilation as a global visual experience.

Keywords: time perception, attention, object-based attention, attention-capture, looming

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Introduction

One of the most immutable aspects of the world, it seems, is time. Yet, our subjective impression of time is remarkably malleable. One of the most intriguing experiences of time's passage is when it subjectively appears to slow down or speed up. Such experiences are common in everyday life: time "flies" when you're having fun, but can seem to crawl by when you're bored. The same phenomenon occurs in an even more extreme fashion on a more immediate time-scale, as when time appears to slow down dramatically during highly traumatic experiences such as car collisions (Noyes & Kletti, 1977; Ursano et al., 1999). (This phenomenon is now commonly depicted cinematographically, as in the 'bullet-time' sequences in the movie *The Matrix*.) This phenomenon may be functional, allowing for more flexible actions and reactions in emergent circumstances such as are experienced in the modern world during combat situations or aircraft piloting (e.g. Hancock & Weaver, 1995).

Time dilation can also be evoked in less extreme ways in the laboratory (for a review, see Eagleman, 2008). These studies have revealed a host of factors that influence the subjective perception of time, including arousal (e.g.

Hancock & Weaver, 1995), concurrent task complexity (e.g. Macar, 1996), temporal uncertainty (e.g. Zakay, 1992), measurement methods (e.g. Block & Zakay, 1997), stimulus complexity (e.g. Schiffman & Bobko, 1974)—and even brute variables such as age (e.g. Wearden, 2005) and body temperature (e.g. Wearden & Penton-Voak, 1995).

Attention and the subjective duration of oddballs

One of the most prominent factors that has been considered in the context of time perception is *attention* (e.g. Brown, 1985; Cantor & Thomas, 1977; Casini & Macar, 1997; Enns, Brehaut, & Shore, 1999; Fraisse, 1963; Hicks, Miller, Gaes, & Bierman, 1977; Lejeune, 1998; Macar, Grondin, & Casini, 1994; Mattes & Ulrich, 1998; Pariyadath & Eagleman, 2007; Thomas & Weaver, 1975; Treisman, 1963; Tse, Intriligator, Rivest, & Cavanagh, 2004; van Wassenhove, Buonomano, Shimojo, & Shams, 2008; Yeshurun & Marom, 2008). Some of the connections between attention and time perception are theoretical: in the influential 'attenuation' model, for example, diverting attention from temporal to nontemporal

information processing (such as to a secondary task) reduces the number of temporal signals processed during an event and decreases its apparent duration (Thomas & Weaver, 1975; Treisman, 1963). Such effects may also arise due to attention driving arousal (Sokolov, 1963) which in turn accelerates the pulse rate of an internal pacemaker (Treisman, 1963). This is consistent with demonstrations that the duration of an unexpected (infrequent) object may appear longer compared to standards—especially since in some cases such dilation only appears for objects displayed for relatively long durations (e.g. for 400 ms but not 100 ms; Ulrich, Nitschke, & Rammsayer, 2006). The authors of this previous study accounted for this constraint by suggesting that arousal does not arise instantaneously, but itself requires some time to increase the speed of the internal pacemaker.

Other recent studies have tied time perception to attention in other ways by relying on ‘oddball’ manipulations. We will illustrate such effects here with a particular study that served as the inspiration for the present experiments. Observers in the experiments of Tse et al. (2004) viewed sequences of discs, presented one at a time in the center of a display. Each disc in a trial sequence was presented for the same duration (though this duration varied across trials), followed by a random interstimulus interval of roughly 1000 ms. Nearly all of the discs were simply presented as static figures (the ‘standards’), but occasionally there were ‘oddballs’, such as discs that expanded in size throughout their duration on the display. Observers simply had to report whether each oddball’s duration was longer or shorter than the duration of the ‘standards’ within that trial sequence. Across a range of ‘oddball’ durations and manipulations, observers experienced subjective time expansion: oddballs seemed to last longer than the standards. Indeed, even oddballs of considerably shorter objective durations were experienced as having appeared for a longer time than the standards. (This effect is phenomenologically salient, and can be observed as a ‘demo’ in a single trial sequence.) The authors interpreted such results in terms of the operation of attention: due to their relative salience and novelty, the oddballs captured attention, which in turn led to a greater pace of information processing, resulting in a longer subjective duration.

The current study: ‘Dilation at a distance’?

In the present study, we ask about the spatial scope of time dilation. When an oddball appears, just what exactly is dilated? We can distinguish four salient answers:

1. *An object*: the subjective duration of that particular oddball object (and *only* that object) is dilated.
2. *A spatial region*: the subjective duration of anything appearing in the local spatial region of the oddball is dilated.
3. *The entire visual field*: the subjective durations of all visual stimuli are dilated by the oddball. Or

4. *Everything*: the subjective durations of all perceptual experiences—in any modality—are dilated by an oddball.

In many ways, possibility #4 is the most intuitive of these answers. It is natural to think—and many models of time perception propose—that subjective durations are driven in part by an internal clock (for a review see Ivry & Schlerf, 2008). Under such conceptions, one can simply interpret time dilation in terms of speeding up or slowing down the clock in some manner. Within this intuitive framework—and its presumption of a single clock—it would be most natural to assume that the changing clock speed would alter the subjective duration of our entire perceptual experience (just as adjusting the clock speed on a CPU changes the timing for all programs). However, two recent results suggest that this answer is incorrect. First, researchers have recently adapted the methods of Tse et al. (2004) to explore intersensory effects, and in doing so they discovered that influences on the subjective durations of events in one modality needn’t similarly influence the durations of concurrent events in a different modality (van Wassenhove et al., 2008). In particular, these researchers found that visual oddballs influenced the subjective duration of concurrent auditory events, but the reverse was not true: auditory oddballs succeeded in dilating time for concurrent auditory events, but not for concurrent visual events. (This study also demonstrated that the ‘oddball’ effect was not due to unpredictability, since the oddballs in their study always occurred in the same position in every sequence, yet still reliably yielded intra-modal time dilation.) Second, in another multimodal study, researchers noted that visual oddballs underwent subjective time expansion but did not simultaneously change the perceived pitch of a concurrent auditory tone (Pariyadath & Eagleman, 2007). These results militate against option #4: the scope of subjective time dilation due to oddballs can be more constrained than all of perceptual experience.

To our knowledge, however, no previous studies have attempted to untangle options 1–3. Our goal in the present study is thus to determine whether a visual oddball dilates time for only that object, for the spatial region surrounding (and including) the oddball, or for the entire visual field. To do this, we unconfounded the oddball from the target of the duration judgment in various ways, when the target and oddball were presented in a temporally overlapping manner. In [Experiment 1](#), we simply presented them in separate spatial locations, and asked whether the oddball would dilate time for a spatially distinct object. In [Experiment 2](#), we evaluated whether the existence or magnitude of time dilation for a target object would scale with its distance from the oddball. In [Experiment 3](#), we evaluated whether time dilation would be influenced by incorporation of the target and the oddball into the same visual object. Finally, in [Experiment 4](#), we distinguished the roles of attentional capture and arousal from the

general degree of visual change, by exploring the magnitudes of time dilation for expanding vs. contracting oddballs.

Experiment 1: Oddball-specific time dilation?

In [Experiment 1](#), we examined whether the time dilation provoked by an extraneous oddball event will similarly prolong the apparent duration of another object in the display. Several previous studies have explored time dilation in response to a spatially local cue, finding subjective time expansion for spatially cued objects compared to uncued (and thus presumably less attended) objects (Enns et al., 1999; Mattes & Ulrich, 1998; Yeshurun & Marom, 2008)—but most previous studies have not directly separated the attentional cues from the targets of the duration judgments when both occurred concurrently. The possibility that oddball-induced time distortion could be specific to the oddball element itself, however, is consistent with previous psychophysical studies that observed apparent time distortions that were localized to specific locations or objects after prolonged localized adaptation to an oscillating motion pattern (Johnston, Arnold, & Nishida, 2006).

Observers in the present experiment viewed a stream of colored squares presented one at a time in the center of the display. Each square was accompanied by a gray disc presented in a randomized peripheral location that onset after the square appeared and offset before the square disappeared ([Figure 1A](#)). Less than 15% of the squares were green, and these served as the target objects: green squares could appear for varying durations, and observers simply pressed a key to indicate whether each green square's apparent duration was shorter or longer than the rest of the squares (which were all presented for the same *standard* duration). A subset of the green squares were accompanied by oddballs: instead of simply appearing and

then remaining static (as it did for all other squares), the gray disc either grew in size ([Figure 1B](#)) or was textured and rotated in place during its appearance ([Figure 1C](#)).

The question, then, is whether the duration of green target squares accompanied by spatially distinct oddballs will be subjectively prolonged or shortened compared to the targets accompanied by static gray discs. If time dilation occurs across the entire visual field, then the targets should be subjectively prolonged just as occurs for the oddball itself (Tse et al., 2004). In contrast, if the oddball captures most available attentional resources as might be expected under the attenuation model (Thomas & Weaver, 1975; Treisman, 1963), then fewer resources would be left over for the target, which should then be subjectively *shortened* compared to the non-oddball trials. Finally, if oddball-induced time dilation effects are really specific to the oddballs themselves, then the subjective duration of the target might be unaffected by the oddballs.

Method

Participants

Six naive observers were recruited from the Yale undergraduate psychology participant pool, and received course credit for their participation.

Apparatus

The stimuli were presented with custom software written using the VisionShell graphics libraries (Comtois, 2008), presented on a Macintosh computer with a 15 inch display running at 100 Hz. Observers sat approximately 50 cm from the display, which subtended 31.82° by 23.94°.

Stimuli

A 1° target square was presented at the center of a black display field for either the 'standard' duration of 1550 ms or for one of the experimental durations (950, 1150, 1350,

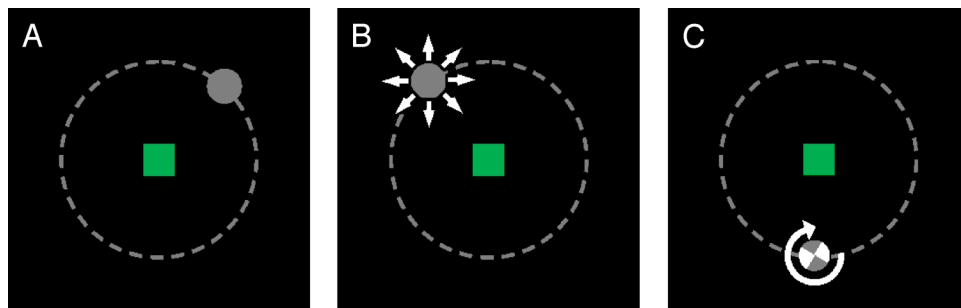


Figure 1. Display types from [Experiment 1](#). (A) Each central square was accompanied by a peripheral gray disc, which appeared at a randomized position along the dashed line (which was not visible in the actual displays). (B) Green target squares were occasionally accompanied by oddballs. In one type of oddball, the gray disc expanded in size while on the screen. (C) In the other type of oddball, the gray disc was given an internal texture, and rotated in place while on the screen.

or 1850 ms). The square was the target color green, or was chosen randomly from seven other colors. A gray 1.25° experimental disc was presented at a randomized angle 6° from the display center along with each square. The experimental disc was always presented for 700 ms, temporally centered at the midpoint of the target square's duration (± 75 ms of jitter). This event sequence ensured that the target squares and oddball discs never onset or offset together, and so could be easily temporally segregated. In practice, our participants were readily able to perceive these two durations independently, and they found it natural to provide estimates of the target squares' durations while ignoring the explicitly irrelevant peripheral discs.

Procedure

The interstimulus interval between each square varied randomly in duration between 950 and 1150 ms. Each target (green) square was preceded by 7 to 12 standard (non-green) squares (randomly chosen for each target).

Each observer responded to 100 target squares—20 for each test duration (950, 1150, 1350, 1550, and 1850 ms). Our initial pilot studies revealed that most target durations were overestimated, and so most of our test durations were shorter than the actual duration of the standard. Even though probing asymmetrically around an objective duration can inflate subjective temporal expansion, any such effect would hold constant across all conditions used here (Seifried & Ulrich, 2008). One objectively longer duration—1850 ms—was retained in order to ensure that participants would not simply adopt a strategy of always reporting that the target durations were shorter than the standards.

If observers failed to respond to the target, it was simply repeated later. Each participant thus observed a slightly different number of trials, given that the number of intervening standards was chosen randomly and that some conditions were repeated when the participants failed to make a response. Observers saw an average of 1082.5 ($SE = 10.9$) squares.

60% of the target squares for each duration were accompanied by an oddball: the gray disc either expanded in diameter from 1.25° to 2.5° (Figure 1B) or was composed of alternating gray and white quadrants that rotated clockwise at $300^\circ/\text{sec}$ (Figure 1C). For the remaining 40% of target trials, the gray disc was unchanged—appearing as a static disc throughout its duration, as was the case for nontarget squares (Figure 1A).

Observers were asked to monitor the succession of squares and report whether each target square seemed to last for a longer or shorter duration than the standard squares. The succession of squares did not pause for a response after each target, but observers were allowed up to three following standard displays to provide a response. Participants were allowed two self-timed breaks, at approximately 1/3 and 2/3 of the way through the experiment.

Results and discussion

The point of subjective equality (PSE) was estimated as the test square duration that would be reported half the time as longer than the standard duration (1550 ms). The PSE for each observer for each condition was calculated as the 50% point in a probit analysis (SPSS 11) of their responses over the tested intervals.

As depicted in Figure 2, the mean PSE for test squares accompanied by oddballs (1266 ms, $SE = 71$ ms) was significantly shorter than the mean PSE of test squares accompanied by a static disc (1462 ms, $SE = 37$ ms), $t(5) = 2.85$, $p = .04$. Therefore, central targets accompanied by peripheral oddballs were perceived to last considerably longer than their true durations. Time dilation caused by oddballs is not constrained to the oddballs themselves, but occurs for other simultaneously presented objects in the display.

As depicted in Figure 2, there was also apparent time dilation beyond the oddball effect: the apparent durations of targets accompanied even by static discs were generally estimated to be longer than their objective durations (something that is also true in the following experiments). This may be due to the arousal associated with detection of the targets alone. This possibility is entirely consistent with the present idea that time dilation accompanies events requiring some behavioral response (here, an estimate of the targets' durations). In principle, however, such an effect could also have resulted from the participants using an internal "standard" duration that was constructed from the duration of the target squares themselves (Penney, Gibbon, & Meck, 2000; Wearden, Todd, & Jones, 2006). (The average duration of the green target squares across all probe duration conditions was

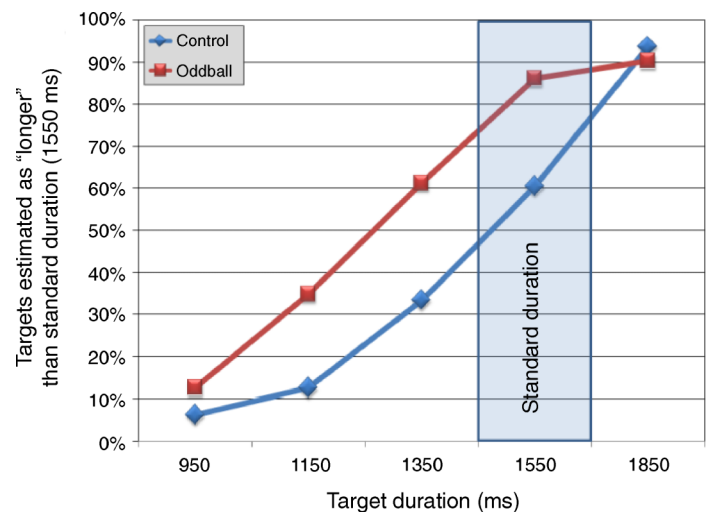


Figure 2. Results of Experiment 1. The percentage of times a target square shown at each duration was reported as having lasted "longer" than the standard duration. When accompanied by a spatially distinct oddball, targets were judged to have lasted systematically longer than when unaccompanied by an oddball.

1370 ms.) Indeed, observers can adopt a criterion for bisecting the durations of sets of events even without explicitly identified standard or anchoring durations (Wearden & Ferrara, 1995), and in some cases they may actually rely more on such ‘constructed’ criteria than on the given concrete standards (Allan & Gerhardt, 2001). The use of such a potential alternative “standard” duration, though, would only account for the baseline time dilation for the targets themselves, and *not* for the even greater dilation associated with the peripheral occurrence of the dynamic oddballs.

Experiment 2: Spatially graded time dilation?

Though oddball-induced time dilation is not specific to the oddballs themselves, it could still be spatially graded, such that targets nearer to the oddball are diluted to a greater degree than more distal targets. (Yeshurun and Marom (2008) did not observe an effect of eccentricity on time dilation in their study of exogenously cued attention, but their valid cues and targets appeared in the same location, whereas the oddballs and targets in these experiments are separated.) This would be consistent with some of the known properties of visual attention, which may often be distributed in a spatially graded manner—and it would also be consistent with the spatially local time distortion that may result from local adaptation (Johnston et al., 2006). Should spatially graded attention mediate time dilation in the same way that it mediates cue detection (e.g. Downing & Pinker, 1985), then dilation might diminish with distance. We explored this possibility here by simply comparing ‘dilation at a distance’ (as in Experiment 1) for two target-oddball distances.

Method

This experiment was identical to Experiment 1 except as noted here. Seven naive observers participated. The gray disc was presented at a randomized angle at either 6.96° or 11.6° from the central square. Each target (green) square was preceded by 5 to 9 standard (non-green) squares (randomly chosen for each target). Each observer responded to 140 target squares—14 for each of the 5 test durations, for each of the two disc eccentricities. 57% of the target squares were accompanied by an oddball. The participants observed an average of 1176.3 ($SE = 26.0$) squares.

Results and discussion

Each participant’s PSE was calculated for each cell of a 2×2 within-subjects ANOVA (oddball vs. no-oddball

target; near vs. far oddball) in the same fashion as in Experiment 1. As depicted in Figure 3, the results for each eccentricity qualitatively replicated Experiment 1: peripheral oddballs prolonged the apparent duration of central targets, but this phenomenon was unaffected by target-oddball distance. Target squares accompanied by an oddball had a PSE (1370 ms, $SE = 50$ ms) that was significantly shorter than when accompanied by a static disc (1445 ms, $SE = 40$), $F(1, 6) = 6.30$, $p = .046$. The PSE of target squares was unaffected by the proximity of the peripheral disc (1397 ms vs. 1418 ms), $F(1, 6) < 1$. More importantly, there was no interaction between the presence or absence of the oddball and the target-disc

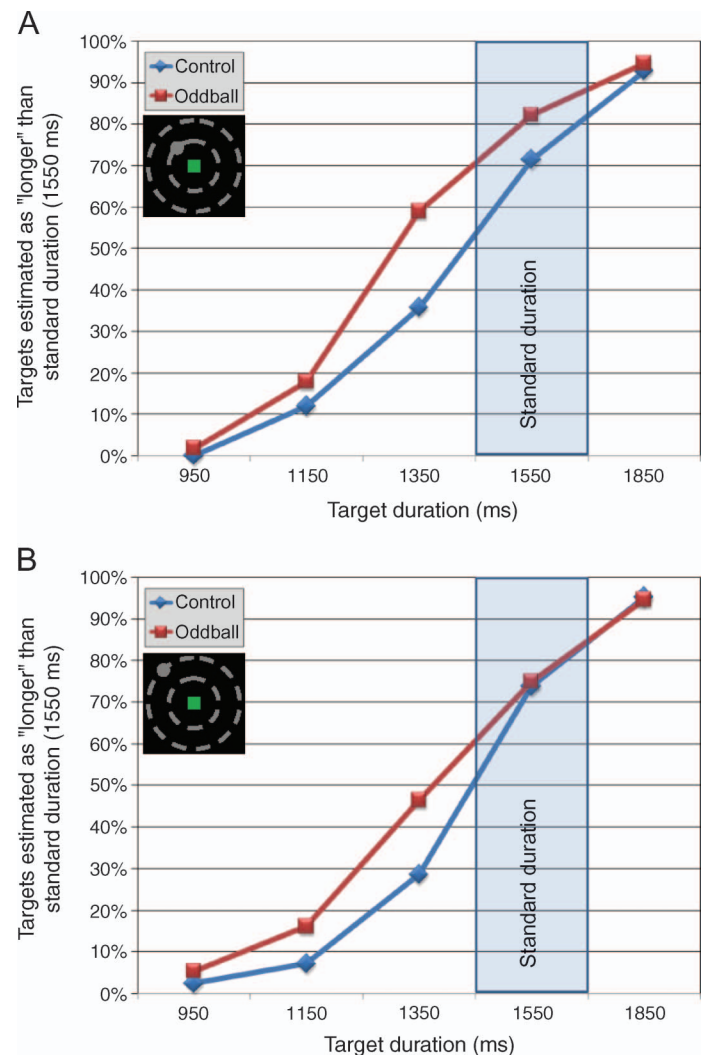


Figure 3. Results of Experiment 2. The percentage of times a target square shown at each duration was reported as having lasted “longer” than the standard duration, for (A) the smaller oddball-target distance, and (B) the larger oddball-target distance. When accompanied by a spatially distinct oddball, targets were judged to have lasted systematically longer than when unaccompanied by an oddball—but this effect did not interact with the oddball-target distance.

distance, $F(1, 6) < 1$. Therefore, central targets accompanied by peripheral oddballs were perceived to last longer than their true durations, regardless of their distance from the oddball. Time dilation caused by oddballs is not constrained to the spatial region near the oddball, but occurs even for relatively distant objects in the display.

Experiment 3: Object-based time dilation?

Though oddball-induced time dilation does not appear to be spatially graded, it could still be affected by the structure of the display—such that dilation would be greater when the oddball and the target were incorporated into the same visual object. (In contrast, the displays in Experiments 1 and 2 had no salient structure: the oddball and the target were simply presented as distinct objects.) This would be consistent with some of the known properties of visual attention, which may often be allocated to displays in an object-based manner (e.g. Egly, Driver, & Rafal, 1994; see Scholl, 2001, for a review), such that attention to one part of an object (say, the oddball part) would result in the automatic selection of another part of that same object (say, the target part), compared to equidistant locations not on that object. Should object-based attention mediate time dilation in the same way that it mediates most other perceptual processes (such as cue detection and discrimination, multiple object tracking, and visual memory), then dilation might be greater when the target and oddball are joined into the same visual object. Only one previous study of temporal perception (Chen & O’Neill, 2001) has included any sort of object-based manipulation, and they did not find any effect of object-based attention. However, that study was aimed at exploring the influence of spatial cueing on time

perception, and so their cue and target never appeared at the same time. We explored the possibility that object structure could mediate time dilation in the oddball paradigm by comparing time dilation in displays with a single target-oddball distance, varying whether they appeared as parts of the same ‘dumbbell’ object (as in Figure 4A) or as distinct objects (as in Figure 4B). This type of ‘dumbbell’ manipulation has previously been found to effectively drive object-based attention (Scholl, Pylyshyn, & Feldman, 2001; Watson & Kramer, 1999).

Methods

This experiment was identical to Experiment 1 except as noted here. Seven naive observers participated. Each target (green) square was preceded by 5 to 9 standard (non-green) squares (randomly chosen for each target). Each observer responded to 140 target squares—14 for each of the 5 test durations, for both the Same-Object and Different-Object conditions. 57% of the target squares were accompanied by an oddball. The participants observed an average of 1151.7 ($SE = 5.9$) squares. The square and disc were always each enclosed in separate 1.75° or 2° light gray disc, respectively (as depicted in Figure 4). In the Same-Object condition, these discs were joined by a central $.5^\circ$ -thick light gray line segment, giving the appearance of a single dumbbell object (as depicted in Figure 4A). Half of the target squares for each duration (and half of the nontarget squares for the standard duration) were connected to the disc via the dumbbell manipulation.

Results and discussion

Each participant’s PSE was calculated for each cell of a 2×2 within-subjects ANOVA (oddball vs. no-oddball target; Same-Object vs. Different-Object) in the same

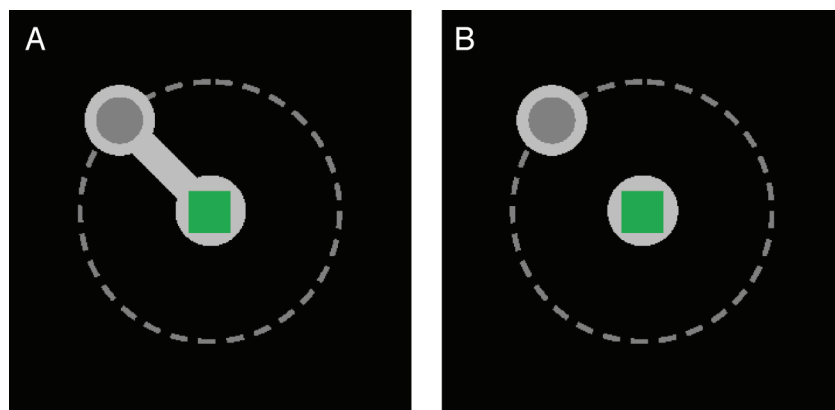


Figure 4. Display types from Experiment 3. (A) In the *Same-Object* condition, the central target square and the disc appeared as parts of the same light-gray ‘dumbbell’ object. (B) In the *Different-Object condition*, the square and the disc appeared on light gray discs, but were not joined into a single object representation. The gray disc appeared at a randomized position along the dashed circle, which was not visible in the actual displays.

fashion as in [Experiment 2](#). As depicted in [Figure 5](#), the results for both the Same-Object and Different-Object conditions qualitatively replicated [Experiment 1](#): peripheral oddballs prolonged the apparent duration of central targets, but this phenomenon was unaffected by the manipulation of object structure. Target squares accompanied by an oddball had a PSE (1292 ms, $SE = 95$ ms) that was significantly shorter than those accompanied by a static disc (1481 ms, $SE = 62$), $F(1, 6) = 6.77$, $p = .04$. The PSE of target squares was unaffected by the Same-Object vs. Different-Object manipulation (1388 vs. 1385 ms), $F(1, 6) < 1$. More importantly, there was no interaction

between the presence or absence of the oddball and the objecthood manipulation, $F(1, 6) < 1$. (In fact, an examination of [Figure 5](#) reveals that the magnitude of the dilation effect for oddball trials relative to control trials was actually more extreme for the Different-Object condition for several of the target durations. This indicates that the failure to find a greater degree of time dilation for the same-object condition could not simply have been due to a lack of statistical power). Therefore, central targets accompanied by peripheral oddballs were perceived to last longer than their true durations, regardless of whether they appeared as part of the same object as the oddball. Time dilation caused by oddballs is not an object-based process.

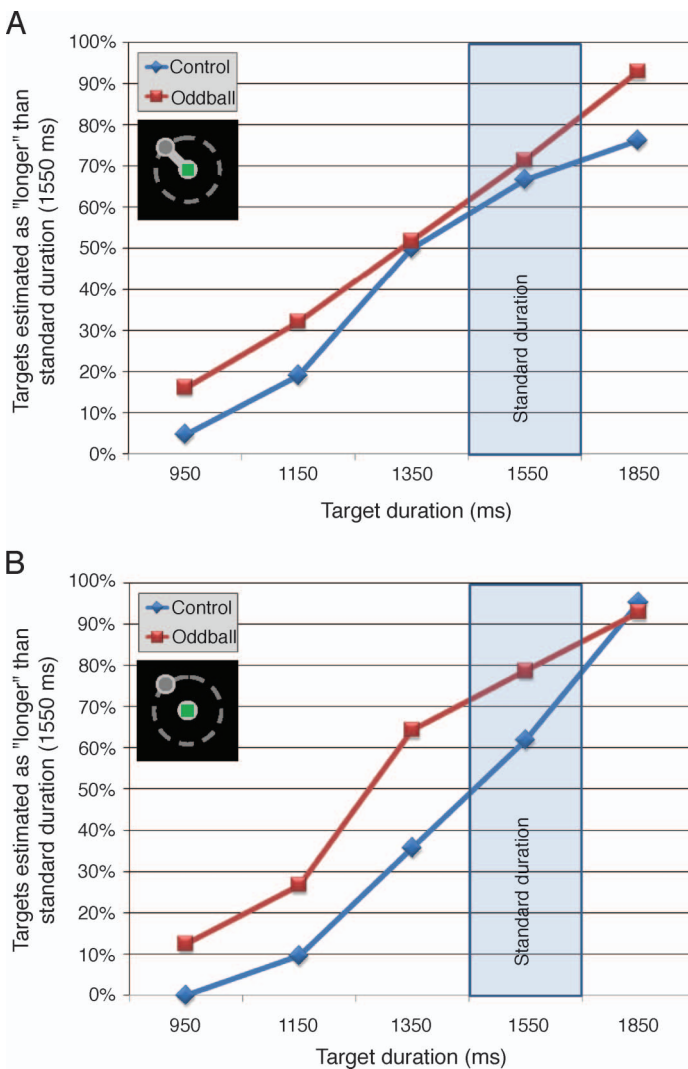


Figure 5. Results of [Experiment 3](#). The percentage of times a target square shown at each duration was reported as having lasted “longer” than the standard duration, for (A) targets and oddballs presented as parts of the same visual object, and (B) targets and oddballs presented as different objects. When accompanied by a spatially distinct oddball, targets were judged to have lasted systematically longer than when unaccompanied by an oddball—but this effect did not interact with the manipulation of objecthood.

Experiment 4: Capture-specific time dilation?

[Experiments 1–3](#) were motivated in part by (1) the role of attention in oddball-induced time dilation, reported by Tse et al. (2004), and (2) the fact that attention can be spatially graded (as explored in [Experiment 2](#)) and object-based (as explored in [Experiment 3](#)). However, there is an alternative explanation for the time dilation we have observed that does not appeal to attention at all. The storage-size model of time perception (Ornstein, 1969) suggests that apparent event durations are a function of the “memory space” required to encode events. Hence, events involving more numerous or complex changes may require more memory and are therefore seen as lasting longer (Poynter & Homa, 1983). If the entire display used in the present experiments could be considered as a “unit of analysis”, however (as is suggested by the null effects of spatial distance and objecthood), then the memory-space model would also predict that the greater complexity of the dynamic oddball displays would lead to a longer perceived duration (especially considering the fact that only the oddball displays involved motion; Brown, 1995).

In this experiment we provided a critical test of this alternative account, by contrasting oddballs that were or were not expected to capture attention, while controlling for the overall amount of motion. In particular, we contrasted expanding oddballs (as in [Experiment 1](#)) with contracting oddballs. The contracting oddballs involved identical animations as the expanding oddballs, but played in reverse. As such, the memory-storage account would predict that these oddballs would yield the same manner and magnitude of time dilation. However, if the time dilation in the previous experiments (and in Tse et al., 2004) was mediated via attention, these two displays should have markedly different effects. Looming objects may represent more behaviorally urgent events that are privileged for visual attention relative to receding objects. Indeed, expanding discs of the type we used in these studies are interpreted in terms of looming, and thus

reliably capture attention in an automatic fashion, whereas contracting (receding) discs do not (Franconeri & Simons, 2003, 2005; von Mühlenen & Lleras, 2007). Thus, if the time dilation observed in the previous experiments is due to attentional effects, then it should occur for expanding but not contracting oddballs.¹

Methods

This experiment was identical to [Experiment 1](#) except as noted here. Twelve naive observers participated in exchange for a monetary payment. Each target (green) square was preceded by 5 to 9 standard (non-green) squares (randomly chosen for each target). Half of the oddballs for each target duration were expanding (as in [Experiment 1](#)), and half were contracting: the gray disc contracted in diameter from 2.5° to 1.25°. The participants observed an average of 760.4 ($SE = 22.4$) squares.

Results and discussion

Each participant's PSE was calculated for each condition of a one-way repeated-measures ANOVA with the variable of oddball type (none vs. expanding vs. contracting). As depicted in [Figure 6](#), time dilation occurred for expanding oddballs but not for contracting oddballs. This impression was verified via the statistical analyses. There was a main effect of oddball type, $F(2, 10) = 4.191$, $p = .048$. Follow-up t -tests revealed that the PSEs for targets accompanied by expanding oddballs (1347 ms, $SE = 51$) were significantly shorter than those accompanied by no oddballs (1507 ms, $SE = 61$), $t(11) = 2.888$, $p = .02$. However, PSEs for targets accompanied by contracting

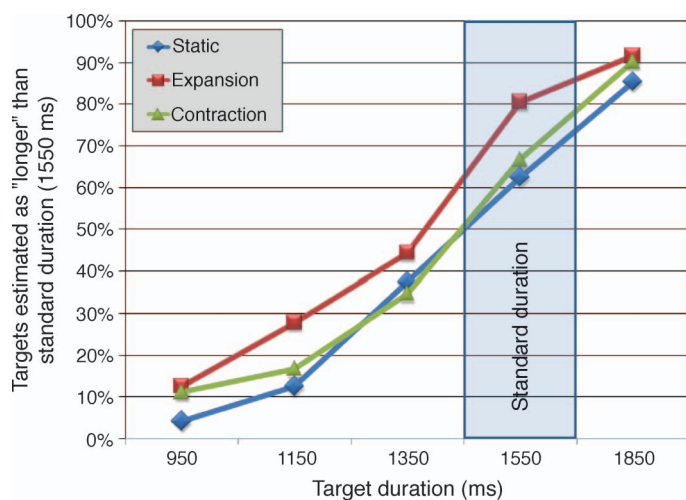


Figure 6. Results of [Experiment 4](#). The percentage of times a target square shown at each target duration was reported as “longer” than the standard duration oddball disc when accompanied by a static, expanding, or contracting oddball disc.

oddballs (1482 ms, $SE = 77$ ms) did not differ from those accompanied by no oddballs (1507 ms, $SE = 61$), $t(11) = .646$, $p = .53$.

These results thus replicate the ‘dilation at a distance’ results of the previous experiments, and demonstrate (contra the memory-space model) that these effects are driven by the attention-capturing nature of the oddballs, rather than by the amount of overall motion in the display.

Conclusions

In these studies of the spatial scope of subjective time dilation, we began by asking about just what was dilated by oddballs. Previous research had left open three options:

1. the oddball and *only* the oddball could be dilated;
2. the local spatial region around (and including) the oddball could be dilated; or
3. the entire visual field could be dilated.

(Previous research had already ruled out an even more extreme example wherein the subjective duration of *all* perceptual experiences—in any modality—are dilated.)

The current experiments are clearly most consistent with one answer to this question: subjective time-dilation applies to the entire visual field. In particular, in each of the four experiments we consistently observed time dilation when the target and the oddball were spatially separated. [Experiment 2](#) directly ruled out option #2, since the existence and magnitude of this ‘dilation at a distance’ was unaffected by the target-oddball distance. And [Experiment 3](#) directly ruled out option #1, since the existence and magnitude of subjective time dilation was unaffected by whether the target and the oddball were presented as parts of the same visual object.

These experiments thus collectively suggest that subjective time dilation is a global visual experience. This is consistent with anecdotal reports of the more extreme time dilation that occurs in real-life traumatic events (Noyes & Kletti, 1977; Ursano et al., 1999), when time appears to slow *globally*, and not just for the provoking object or event. (We also note in passing that the increasingly common ‘bullet-time’ sequences in movies such as *The Matrix* slow down the entire scene, not just the bullets themselves.)

We interpret the effects of time dilation in this paper in terms of the influence of attention, consistent with previous research that has ruled out unpredictability as the driving force of dilation in oddball paradigms (van Wassenhove et al., 2008). As noted above, many previous studies have explored attentional effects on time dilation, but they have not always distinguished between different senses of attention. Of particular relevance, Chen and O’Neill (2001) found that objects displayed at a cued spatial location appeared longer in duration during a

concurrent nontemporal task but shorter without an accompanying task. Further, such time dilation was unmediated via any object-based attentional effect.

Here we suggest that the sense of attention most connected to time dilation is not that of *selective* attention, since selective attention is inherently both object-based and spatially graded (often at the same time; e.g. see Alvarez & Scholl, 2005). Instead, the influence of attention on time dilation is perhaps better characterized simply in terms of *arousal* and the increased information processing that it enables. Oddballs increase arousal on a local time scale, yielding a greater rate of information processing, and consequently expanding the display's subjective duration via the associated faster internal clock pacing. This interpretation is also consistent with the findings of Ulrich et al. (2006), who suggested that arousal itself may take some time to influence perceived durations, such that time dilation of this sort only arises for objects whose actual durations are relatively long. Critically, all of our target durations well exceeded the threshold which previous studies have identified for such effects (which lies somewhere within 100–400 ms; Ulrich et al., 2006).

Contrary to the attentional allocation model, which might predict that greater attention to nontemporal information (such as the looming behavior of an oddball) decreases attention to temporal information and thus contracts subjective time, the present results suggest that the oddball captures attention, increasing arousal, and thus expanding the subjective duration of the entire visual display.

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Footnote

¹Another study that contrasted expanding vs. contracting discs in multimodal displays appeared during the preparation of this article (van Wassenhove et al., 2008). They found effects of expansion but not contraction, but their procedures were different from those used in these studies:

in particular, they divorced attentional effects from effects of predictability by always presenting the ‘oddball’ in a way that was fully expected, and in the same position of constant-length sequences. In contrast, the oddballs in the present experiments were always unpredictable.

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