Short Report

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Associated Information Increases Subjective Perception of Duration

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Richard Schweitzer
Berlin School of Mind and Brain, Humboldt-Universität zu Berlin, Berlin, Germany

Sabrina Trapp
Gonda Multidisciplinary Brain Research Center, Bar-Ilan University, Ramat-Gan, Israel; Psychology Department, Ludwig-Maximilians-University, Munich, Germany

Moshe Bar
Gonda Multidisciplinary Brain Research Center, Bar-Ilan University, Ramat-Gan, Israel

Abstract

Our sense of time is prone to various biases. For instance, one factor that can dilate an event's perceived duration is the violation of predictions; when a series of repeated stimuli is interrupted by an unpredictable *oddball*. On the other hand, when the probability of a repetition itself is manipulated, *predictabl*e conditions can also increase estimated duration. This suggests that manipulations of expectations have different or even opposing effects on time perception. In previous studies, expectations were generated because stimuli were repeated or because the likelihood of a sequence or a repetition was varied. In the natural environment, however, expectations are often built via associative processes, for example, the context of a kitchen promotes the expectation of plates, appliances, and other associated objects. Here, we manipulated such association-based expectations by using oddballs that were either contextually associated or nonassociated with the standard items. We find that duration was more strongly overestimated for contextually associated oddballs. We reason that top-down attention is biased toward associated information, and thereby dilates subjective duration for associated oddballs. Based on this finding, we propose an interplay between top-down attention and predictive processing in the perception of time.

Keywords

prediction, attention, time perception, association, context

Corresponding author:
Richard Schweitzer, Berlin School of Mind and Brain, Humboldt-Universität zu Berlin, Unter den Linden 6, 10099 Berlin, Germany.
Email: richard.schweitzer@hu-berlin.de

Introduction

Time perception is prone to distortion by various factors that may contract or dilate our subjective experience of duration. Based on findings from oddball experiments, it has been proposed that predictability is one of these factors that affect our sense of time. In the oddball paradigm, a certain stimulus—the *standard*—repeats sequentially several times until it is unexpectedly followed by a deviant—the *oddball*. It has been shown that the duration of the unpredicted oddball is overestimated (Pariyadath & Eagleman, 2007; Schindel, Rowlands, & Arnold, 2011). The common result is generally known as the temporal oddball effect. Importantly, the degree of overestimation is correlated with the amount of deviance between standard and oddball, which suggests that the violation of predictions drives the perceived dilation of duration (Pariyadath & Eagleman, 2012). In line with these findings, infrequent (and therefore, more unpredictable) oddballs were also found to be overestimated to a larger degree than frequent ones (Ulrich, Nitschke, & Rammsayer, 2006). In their neural coding efficiency hypothesis, Eagleman and Pariyadath (2009) suggested that because neural responses to a stimulus diminish after repeated presentations, standards will appear shorter in duration, and conversely, oddballs are perceived as longer.

However, expectations can be elicited by different sources. While the above-mentioned studies built upon the fact that repeated or regular exposure promotes expectations of the same stimulus, Cai, Eagleman, and Ma (2015) manipulated expectations via the probability of a certain stimulus sequence regularities within a sequence (e.g., A-B-A-B-*A* vs. A-B-A-B-*B*), as well as overlearned sequences (e.g., 1-2-3-4-*5* vs. 1-2-3-4-*6*). Interestingly, they found no evidence for a reduction of the perceived duration for more predictable stimuli. In contrast, experiments by Matthews (2015) were based on a comparison task, applying two consecutively presented pictures of faces, of which the second was either repeated or novel. However, the author did not manipulate expectations based on repetition alone, but additionally introduced higher level expectations by varying the probability of repetitions in each block. This study replicated that durations of deviations, that is, novel faces, are judged as longer than repeated ones, but the author also found an *expansion* of subjective time when repetitions were more predictable. These contradictory findings call for a more thorough investigation of different forms of expectations in the context of duration estimation.

Another source for expectations are associations between objects and the context in which objects appear (Bar, 2007). For example, a knife and a napkin on a table will probably not be a surprise in the context of a kitchen, but a medieval sword will be. It has been suggested that context can provide automatic coactivations of associated objects that are likely to occur in spatial or temporal proximity (Bar, 2004; Biederman, Mezzanotte, & Rabinowitz, 1982). Given this close link between context, associations, and predictions, we here ask whether the oddball overestimation is modulated as a function of relatedness to the standard, that is, *associated*: ''pizza cutter''—''pizza'' or *nonassociated*: ''pizza cutter''—''rubber duck.''

Results

Logistic psychometric functions were fitted individually for each participant and condition to model the dichotomous temporal judgment (''shorter,'' left, or ''longer,'' right) based on the predictors *oddball position* and *context*. Subsequently, descriptive values of the psychometric function (point of Subjective Equality [PSE], difference limen [DL]) were extracted (for aggregated curves see Figure 1(b)). Furthermore, the ratio of the standard duration to the

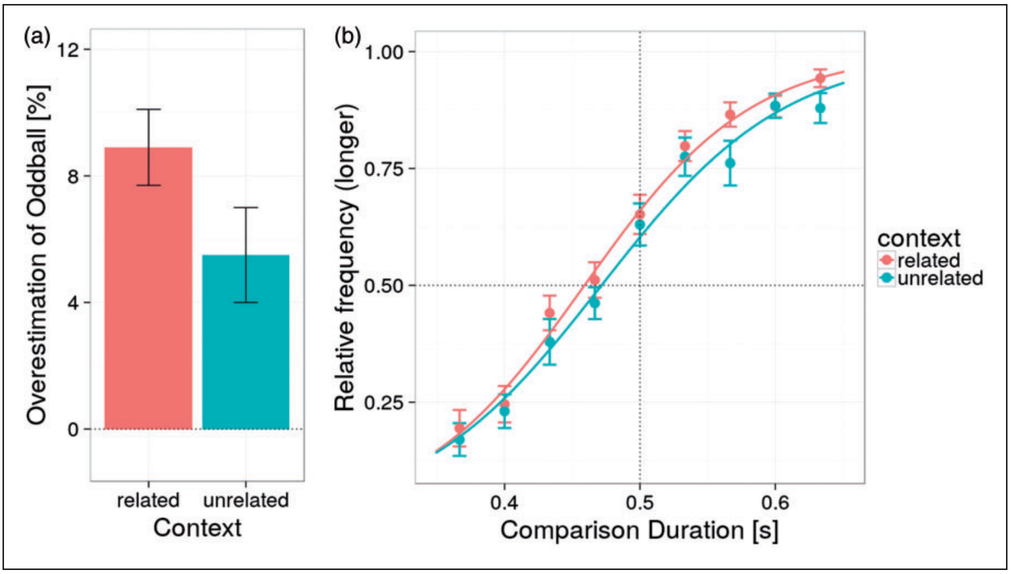

Figure 1. (a) Main effect of context. Oddballs contextually associated with the standard (red) were overestimated to a higher degree compared with nonassociated oddballs (blue). (b) Logistic fit of the mean frequencies of "longer" judgments. Separately for contextually associated and nonassociated oddballs, relative frequencies of "longer" judgments were averaged for each comparison duration over all participants and subsequently fitted by a logit model. Confidence intervals for the PSE of the two functions were estimated via bootstrapping ($\alpha = .05$, $N = 2{,}000$, $h_0 = 0.3$). The PSE for associated oddballs was 459 ms (95% CI [452, 466]) and for nonassociated oddballs 472 ms (95% CI [465, 479]). All error bars indicate one standard error.

respective PSE was computed which denotes to what percentage the oddball duration was overestimated or underestimated. Training trials, missed trials (1.44%), and trials with extremely long or short reaction times (M ± 3 SD, 2.7%) were excluded from analyses.

Contextually associated oddballs were overestimated by 8.9% (95% CI [7.7, 10.1]) and nonassociated oddballs only by 5.5% (95% CI [4.0, 7.0]; Figure 1(a)). This seemingly small temporal oddball effect was mainly caused by trials involving oddballs at Positions 2, 3, and 4, which were not overestimated on average (0.5%, 95% CI [−2.2, 3.2]). If excluded, overestimation increased to 10.4% (95% CI [9.4, 11.4]) for contextually associated and to 7.5% (95% CI [6.0, 9.0]) for nonassociated oddballs.

A two-factorial repeated measures ANOVA with the factors context and oddball position was conducted on the parameters PSE and DL. For the PSE, results show significant main effects of context, $F(1,15) = 8.77$, $\eta^2 = .022$, $p = .001$, and oddball position, $F(4,60) = 8.34$, $\eta^2 = .187$, $p < .001$, but no interaction between them, $F(4,60) = 1.13$, $\eta^2 = .018$, $p = .352$. The intercept of the model was below the standard duration of 500 ms, $F(1,15) = 14.63$, $\eta^2 = .228$, $p < .001$. The difference limen (DL = [x.75 – x.25] / 2; see Ulrich et al., 2006) was smaller for contextually associated oddballs (DL(associated) = 39 ms, 95% CI [36.5, 41.5]) than for nonassociated oddballs (DL(nonassociated) = 58 ms, 95% CI [50, 66]). This effect of context reached significance, $F(1,15) = 4.2$, $\eta^2 = .026$, $p = .04$. However, no effect of oddball position, $F(4,60) = 1.43$, $\eta^2 = .03$, $p = .22$, or interaction between context and oddball position, $F(4,60) = 0.65$, $\eta^2 = .017$, $p = .62$, was present.

Discussion

Recently, predictability has been discussed as a variable that modulates our sense of elapsed time (for a recent review, see Matthews & Gheorghiu, 2016). However, different experimental manipulations of predictability have produced different effects on time perception, inviting a careful investigation into the role of the type of expectations and their interaction with our sense of time.

Here, we manipulated expectations by using oddballs that were either contextually associated or nonassociated with the standard and found two major effects.

First, we replicated the initial temporal oddball effect, that is, a general overestimation of oddballs as compared with standards. Other studies suggest explaining this effect by neural repetition suppression. After being exposed to a series of repetitions of the standard, the brain starts expecting the standard, the neural response is reduced, and its duration underestimated (Pariyadath & Eagleman, 2012; Summerfield, Trittschuh, Monti, Mesulam, & Egner, 2008).

Second, we found that the oddball's duration was more overestimated for contextually associated information. Importantly, as the probability of an oddball at a certain temporal position in the stream was the same for both associated and nonassociated oddballs, stimulus probability is unable to account for the difference in perceived duration of two types of oddballs. To explain the difference between associated and nonassociated oddballs, one could argue that top-down attention is more attracted by contextually associated oddballs. It is possible that objects from a specific context activate, via semantic priming, all other objects that are relevant in this context (Bar, 2004). This way, a visual search template entailing context-congruent objects could be set up. Visual search templates have been shown to bias top-down attention toward search-relevant targets (Moores, Laiti, & Chelazzi, 2003; Neider & Zenlinsky, 2006; Oliva, Wolfe, & Arsenio, 2004).

Why should more top-down attention increase subjective duration? Matthews (2015) argued that increased expectation of repetition boosts perceptual in-depth analysis of the stimuli that appear in such repetitions, which he hypothesizes is the mechanism that increases subjective duration. Top-down attention could boost in-depth analysis of stimuli, too. Such perceptual processing of contextually associated information would also be in line with higher temporal discrimination performance in our study, as indicated by the DL. Another possible explanation for increased duration with putatively more deployment of top-down attention may come from some models of time perception, such as the attentional-gate model (Zakay & Block, 1995) or the attentional two-processors models (e.g., Hicks, Miller, Gaes, & Bierman, 1977; Lejeune, 1998; Thomas & Weaver, 1975). These models propose that prospective temporal judgments require attention to the passage of time (Fraisse, 1963; Herbst, van der Meer, & Busch, 2012), and that there is a trade-off between temporal and nontemporal processing performance. In other words, the *less* attention paid to a nontemporal task, such as identifying object form, color, or category, the *more* attentional resources can be allocated to a temporal task, for example, a duration judgment. Attention to the temporal dimension of a stimulus presumably enables the temporal processor to pick up more and more accurate temporal cues (Coull et al., 2004). Indeed, there is evidence from other experimental paradigms (e.g., spatial cueing) that attention allocation to an event can lead to a dilatation of its perceived duration (Enns, Brehaut, & Shore, 1999; Mattes & Ulrich, 1998; Tse, Intriligator, Rivest, & Cavanagh, 2004). This explanation aligns with the idea of enhanced perceptual analysis of stimuli. The involvement of top-down attention could explain both the stronger overestimation and increased temporal discrimination performance in our study. Certainly, explanations based on these time models remain speculations, and whether resources are indeed more or less allocated to the associated stimulus must be thoroughly investigated in future work.

Methods

Participants

Sixteen Bar-Ilan University students with normal or corrected-to-normal vision acuity and color vision (13 female, age range 18 to 32) participated in the experiment. The sample size was predetermined based on Experiment 3 by Pariyadath and Eagleman (2007). The experimental protocol was approved by the University of Bar-Ilan Brain Research Ethics Committee.

Apparatus

The experiment took place in a dimly lit and sound-attenuated room and was programmed using PsychoPy (Peirce, 2007). Stimuli were presented on a HP Pavilion 2311 x LED monitor (VGA connected) with a frame refresh rate of 60 Hz. The screen had a size of 50.9 cm × 28.6 cm and a resolution of 1920 × 1080. Participants' distance to the screen was approximately 60 cm.

Stimuli

We used 252 triples of pictures of neutral objects. Each triple was composed of a standard stimulus, an oddball stimulus contextually associated with the standard, and an oddball stimulus not associated with the standard. Of the 252 stimulus triples, 172 were selected from the POPORO database (Kovalenko, Chaumon, & Busch, 2012). The selection was based on the largest differences in relatedness of contextually associated and nonassociated oddballs with their respective standard. To avoid potential effects of low-level properties on subjective duration, associated and nonassociated stimulus pairs were also tested for differences in luminance, spectral power, and shape. Differences in shape were checked using the inner-distance shape classification algorithm by Ling and Jacobs (2007). In addition, 80 images were provided by Cheung, Gagnon, Panichello, and Bar (2014). Post hoc tests revealed no significant differences in luminance, M(associated) = 0.74; M(nonassociated) = 0.77; $t(158) = -1.53$, $p = .13$, and shape dissimilarity, M(associated) = 63.4; M(nonassociated) = 66.8; $t(152) = -1.57$, $p = .12$, between associated and nonassociated pairs either. The relatedness of all possible stimulus pairs was surveyed in separate pilot studies by Kovalenko et al. (2012) and Cheung et al. (2014), respectively. Every stimulus—both standard and oddball—was only presented in a single trial and did never reappear again in the experiment. That was done to avoid repetition effects between trials.

Procedure

The task structure is displayed in Figure 2. Every standard stimulus was presented on the screen for a fixed duration of 500 ms. The oddball, on the other hand, had nine different durations, which were symmetrically jittered around the standard duration (366.7, 400, 433.3, 466.7, 500, 533.3, 566.7, 600, and 633.3 ms), and could be either contextually associated or nonassociated with the standard. All pictures were presented with a physical size of 3.1 cm × 3.1 cm. Each trial involved nine stimulus presentations, including the oddball, which could appear at all positions except for the first and last position of the sequence. After all presentations, a response screen appeared and participants had 3 s to compare the

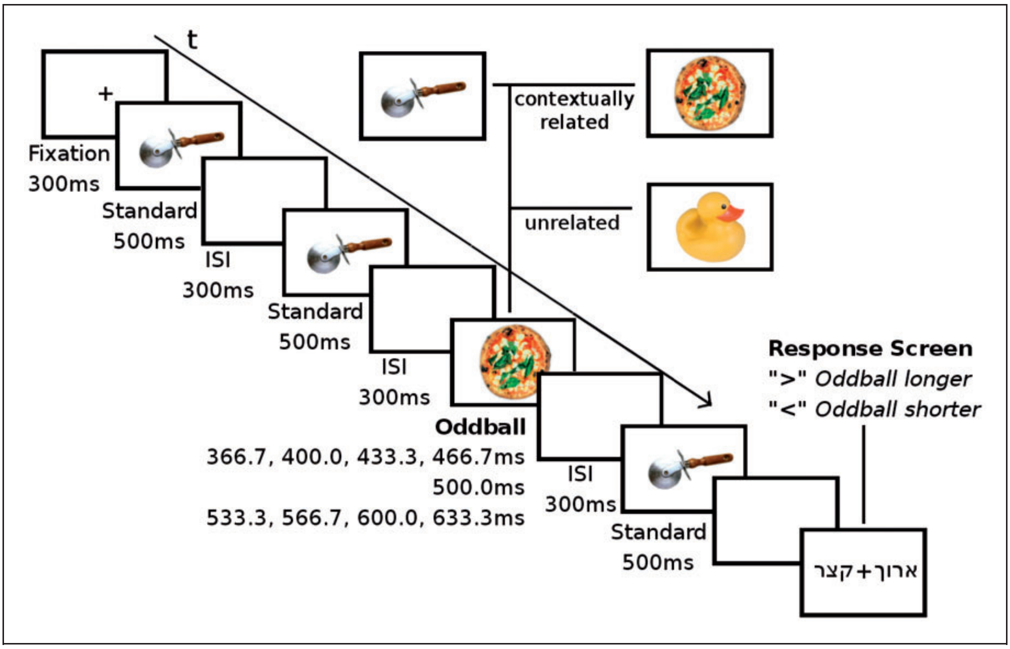

Figure 2. Illustration of a trial. The task structure was based on Pariyadath and Eagleman (2007). Participants were asked to judge whether oddball's duration, symmetrically arranged around 500 ms, was longer or shorter than the standards, which all had the same constant physical duration of 500 ms. Oddball stimuli varied in their duration, were either contextually associated (e.g., pizza cutter—pizza) or nonassociated (e.g., pizza cutter—rubber duck), and appeared at systematically varying positions in a sequence of nine stimulus presentations.

duration of the oddball to the duration of the repeated stimulus by pressing “<” (shorter) or “>” (longer) on a standard U.S.-English keyboard.

The experiment began with nine training trials and was then structured in three blocks, each containing 81 trials. After each of those three blocks, participants were informed about their mean accuracy. Matching the number of stimulus triples, there were 252 trials altogether, so that each picture was only presented in a single trial. In each block, 72 oddballs (50% associated and 50% nonassociated) could appear at Positions 5, 6, 7, and 8, based on the trial design proposed by Pariyadath and Eagleman (2007). To minimize the possibility that participants learned to expect the oddball stimuli at later positions, nine distractor trials per block were introduced, where oddballs appeared at Positions 2, 3, and 4. The distractor trials to the context condition had to be assigned randomly, but still led to an equal distribution of associated and nonassociated oddballs among them, $\chi^2(15) = 9.4$, $p = .85$. All conditions—context, position, and duration of oddball—were interleaved in each block.

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Authors Contribution

Richard Schweitzer and Sabrina Trapp contributed equally to this work. R.S. developed the study concept and all authors contributed to the study design. The implementation of the experiment, data collection, and analysis were performed by R.S. under M.B.'s and S.T.'s supervision. S.T. drafted the manuscript, and R.S. and M.B. provided critical revisions.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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