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Inhibition of return shortens perceived duration of a brief visual event

Takayuki Osugi [a,c,*], Yuji Takeda [b], Ikuya Murakami [a]

[a] Department of Psychology, University of Tokyo, Tokyo, Japan
[b] National Institute of Advanced Industrial Science and Technology, AIST, Tsukuba, Japan
[c] Japan Society for the Promotion of Science, Tokyo, Japan

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ABSTRACT

We investigated the influence of attentional inhibition on the perceived duration of a brief visual event. Although attentional capture by an exogenous cue is known to prolong the perceived duration of an attended visual event, it remains unclear whether time perception is also affected by subsequent attentional inhibition at the location previously cued by an exogenous cue, an attentional phenomenon known as inhibition of return. In this study, we combined spatial cuing and duration judgment. After one second from the appearance of an uninformative peripheral cue either to the left or to the right, a target appeared at a cued side in one-third of the trials, which indeed yielded inhibition of return, and at the opposite side in another one-third of the trials. In the remaining trials, a cue appeared at a central box and one second later, a target appeared at either the left or right side. The target at the previously cued location was perceived to last shorter than the target presented at the opposite location, and shorter than the target presented after the central cue presentation. Therefore, attentional inhibition produced by a classical paradigm of inhibition of return decreased the perceived duration of a brief visual event.

1. Introduction

Temporal perception for events is crucial for our vision. Nonetheless, our temporal perception of briefly presented events is easily distorted depending on several factors such as physical stimulus attributes (Ono & Kawahara, 2007; Xuan, Zhang, He, & Chen, 2007), repeated exposure (Pariyadath & Eagleman, 2008; Tse, Intriligator, Rivest, & Cavanagh, 2004), and the observer's intention to perform an action (Haggard, Clark, & Kalogeras, 2002; Morrone, Ross, & Burr, 2005). Spatial attention also modulates time perception such that an attended event appears to last longer. For example, Mattes and Ulrich (1998) and Enns, Brehaut, and Shore (1999) used a spatial cuing paradigm (Posner, Nissen, & Ogden, 1978) to examine the effect of spatial endogenous attention on duration perception. When an observer was given an informative central cue to the location of an impending target, the duration of the target at the cued location was judged as lasting longer than targets presented elsewhere. A similar attentional effect occurred when an uninformative peripheral cue preceded the target (e.g., Yeshurun & Marom, 2008); the duration of the target, where exogenous attention was directed by the peripheral cue, was perceived as lasting longer even if the target was equally likely to appear at the cued and opposite locations.

Theoretically, attention can modulate the perceived time of a visual event by affecting the internal representations of three components: the beginning, end, and duration itself of the event (Gibbon, 1977; Gibbon, Church, & Meck, 1984; Kanai & Watanabe, 2006). When the duration of an event is estimated, the beginning and end of the event should be marked. Therefore, when the beginning of the event is encoded as occurring earlier or when the end of the event is encoded as occurring later, the perceived duration of the event may be lengthened if perception relies upon the time difference between the biologically marked times of the beginning and end of the event. Directing attention to a cued location speeds up the perceived onset of the stimulus presented there (known as "the law of prior entry," e.g., Shore, Spence, & Klein, 2001; Titchener, 1908), suggesting that attention leads to accelerated detection of a stimulus at the attended location so that the stimulus is allowed prior entry to perceptual processing stages. Alternatively, prior entry might be viewed as influencing internally encoded properties of objects of interest in such a way that attention does not alter the time of detection behavior per se, but rather alters the encoded representation of stimulus onset time. Similarly, recent studies have also argued that transient attention can prolong the internal response of a brief event, deferring the perceived termination of an attended stimulus (Mattes & Ulrich, 1998; Rolke,

* Corresponding author at: The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan.
E-mail address: tosugi@fechner.c.u-tokyo.ac.jp (T. Osugi).

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Ulrich, & Bausenhart, 2006; Seifried & Ulrich, 2011; Yeshurun & Marom, 2008). According to Yeshurun and Marom (2008), visual attention facilitates the activity of the sustained system (i.e., parvocellular pathway) at the attended location and inhibits the activity of the transient system (i.e., magnocellular pathway) at the same location (see also Yeshurun & Levy, 2003). Because the neurons in the parvocellular pathway generally have a sustained response profile and a longer decay time relative to the neurons in the magnocellular pathway (e.g., Derrington & Lennie, 1984), the perceived stimulus offset may be delayed if this relatively lingering response is translated into perception. However, the neural correlate of the subjective deferral of stimulus offset might also take the form of alteration of the encoded representation of stimulus-offset time.

In addition to the biological registration/representation of the beginning and end of the event, it is likely that the event duration is independently estimated from the time evolution of a visual input rather than from the difference between the onset and offset. Indeed, psychophysical investigations have unequivocally demonstrated that perceived duration can be altered without perceptual alteration of onset and offset times (e.g., Johnston, Arnold, & Nishida, 2006; Kaneko & Murakami, 2009). Several models have attempted to account for these attention-induced distortions of perceived duration within the hypothetical scheme that the visual system has a "pacemaker-accumulator" architecture that keeps track of the number of temporal units (Thomas & Weaver, 1975; Treisman, 1963; Tse et al., 2004). Such a scheme dictates that if attention is allocated to process the duration of a brief event, the number of accumulated temporal units becomes greater because fewer temporal units are missed by the accumulator or because the rate of the pacemaker is boosted.

Previous studies have focused on the effects of endogenous attention on perceived duration by an informative cue to the location of an impending target, or effects of exogenous attention on perceived duration by an uninformative peripheral cue for only brief cue-target intervals (e.g., Yeshurun & Marom, 2008); therefore, potential effects of exogenous attention with longer cue-target intervals remain unclear. This is an important point to consider because reaction times for a speeded button-pressing response to a target onset typically show an early facilitation at the cued location, where exogenous attention is automatically allocated, relative to the "uncued" location (the location opposite to the cued location about a central fixation point), followed by a late decrease in attentional performance at the same cued location (e.g., Posner & Cohen, 1984). More specifically, when the interval between an uninformative peripheral cue and a target is as short as 0–100 ms, reaction will be faster for the target appearing at the cued location than at the uncued location; however, when the cue-target interval exceeds 300 ms, reaction will be slower for the target appearing at the cued location (this location, where exogenous attention was automatically directed some while before, but stays no longer, is hereafter called "previously cued location"). It has been suggested that attention is hard to be directed again to the same location where exogenous attention has recently been directed by a cue and then already withdrawn (e.g., Klein, 2000; Posner & Cohen, 1984).

Although attentional capture by an exogenous cue is known to prolong the perceived duration of an attended visual event, it remains unclear whether time perception is also affected by subsequent attentional inhibition at the location previously cued by an exogenous cue, an attentional phenomenon known as inhibition of return. This study examined how duration perception was affected in the presence of this inhibition of return. To test the hypothesis that this type of attentional inhibition affects some aspect of temporal processing at the previously cued location in addition to the lengthening of reaction time, we combined spatial cuing and duration judgment that naturally involves something more than the detection of stimulus onset. We measured the perceived duration of a target presented at cued, uncued, and neutral locations using a duration matching method, and recorded reaction times for target onset as is done in a typical spatial cuing paradigm (e.g., Posner & Cohen, 1984).

2. Methods

2.1. Participants

Twelve observers (aged 21–32 years, mean age, 25.8 years, SD = 3.8, 8 females) who were unaware of the study's purpose participated. All participants had normal or corrected-to-normal visual acuity. Our study followed the Declaration of Helsinki guidelines and it was approved by the institutional ethics committee of the Graduate School of Humanities and Sociology at the University of Tokyo. Written informed consent was obtained from all participants.

2.2. Stimuli and apparatus

The stimuli were displayed on a CRT monitor (Iiyama HM204DA, 1024×768 pixels, mean luminance of 19.62 cd/m^2, grey background) via a stimulus processor (Bits#, Cambridge Research Systems, Kent, UK) controlled by a computer by using Matlab and the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997). The refresh rate of the monitor was 60 Hz. The viewing distance was 57 cm. The monitor was gamma-corrected to achieve linear output.

The stimulus display consisted of three vacant boxes with black contours (<0.01 cd/m^2) subtending 2.5° in height and width. The width of each line segment was 0.16°. One box was presented at the center of the display and the other two were displayed 7.5° to the left and to the right of the central box (Fig. 1). The target stimulus (47.5 cd/m^2) was a filled white square subtending 1.25° in height and width. A spatial cue was given by transiently (150 ms) thickening the line width of one of the three boxes to 0.48°.

2.3. Design and procedure

Participants completed five sessions: a training session of duration judgment, a reaction-time session, and three duration-judgment sessions. These sessions were conducted on different days; therefore, five days were needed for each participant to complete the experiment. Half of the observers performed the reaction-time session on the first day, whereas the remaining half performed it on the last day.

Each trial of the duration-judgment session consisted of a "constant" stimulus sequence and a "test" stimulus sequence presented consecutively in random order (Fig. 1). Each sequence began with a blank display for 200–600 ms, followed by three boxes presented for 750 ms. The cue then appeared and blinked twice during 150 ms (on-off-on; stayed for 50 ms, disappeared for 50 ms, and reappeared for 50 ms). In the "constant" stimulus sequence, the cue was presented at one of the three boxes at equal likelihoods, whereas the cue of the "test" stimulus sequence always appeared at the central box. A fixation cue — abrupt thickening of the line width of the central box to 0.48° with no blinking — was presented 350 ms after the cue offset and stayed for 250 ms, followed by a continuing display of the three vacant boxes for 250 ms. The target stimulus then appeared at the right or left box at equal likelihoods. That is, the three boxes could be cued with equal likelihoods and the target either could appear at the right or left box with equal likelihoods. Therefore, the cue location