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Temporal resolution of figures and grounds

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ABSTRACT

Recent studies have demonstrated that establishing figure–ground organization influences other perceptual processes. Specifically, figures undergo perceptual processing earlier than ground regions (Lester, Hecht, & Vecera, 2009), and they are processed for longer durations relative to ground regions (Hecht & Vecera, 2011). One potential consequence of figures' extended processing is degraded temporal resolution compared to ground regions. To test this hypothesis, observers completed a modified flicker-fusion task while viewing either displays that contained well-defined figures and grounds or displays that were ambiguous. As evidenced by increased sensitivity for flickering targets on the ground regions, the current results support the claim that figures have poorer temporal resolution than ground regions.

1. Introduction

Figure–ground assignment is defined as the process by which the visual system forms or groups information together into regions and then segregates those regions into figures that fall in the foreground (i.e., occluding regions) and grounds that fall into the background (i.e., occluded regions; Palmer & Rock, 1994). Many cues and processes influence figure–ground organization. Imaged-based cues, such as smaller area, symmetric regions, convex regions, and lower-regions (e.g., Palmer, 1999, 2002; Pomerantz & Kubovy, 1986; Rock, 1975, 1995; Rubin, 1915/1958; Vecera, Vogel, & Woodman, 2002), are characteristic of figures. Similarly, higher-level perceptual processes, such as region familiarity or spatial attention, can establish a region as figure (Peterson, 1994, 1999; Peterson & Gibson, 1991, 1993, 1994; Peterson, Harvey, & Weidenbacher, 1991; Rock, 1975; Vecera, Flevaris, & Filapek, 2004; Vecera & O'Reilly, 1998; Vecera & O'Reilly, 2000).

Figure–ground organization can also be impacted by spatial and temporal factors. Klymenko, Weisstein, and colleagues (e.g., Klymenko & Weisstein, 1986, 1989a,b; Klymenko, Weisstein, Topolski, & Hsieh, 1989) determined that regions with high spatial and low temporal frequencies are typically assigned figural status whereas those with low spatial and high temporal frequencies are often treated as grounds. In alignment with these results, Wong and Weisstein (1983) also found that sharp targets were more readily detected within figures, but blurry targets were more readily detected within the background. Similarly, recent findings indicate that target detections and discriminations are faster and more accurate within figure regions. For example, (Nelson and Palmer, 2007; also see Lazareva, Castro, Vecera, & Wasserman, 2006) showed participants two-region displays containing a clear figural assignment due to the presence of a familiarity cue (e.g., the profile contour of a face). Then, they presented a target on either the figure (i.e., face region) or the ground, near the contour shared between the regions. They found that when the target fell on the figure, participants discriminated the target's identity faster and more accurately than when the target appeared on the background.

Interestingly, when attempting to explain these figural benefits (e.g., Lazareva et al., 2006; Nelson & Palmer, 2007; Wong & Weisstein, 1982, 1983), recent research has confirmed that figure–ground organization affects temporal processing (Hecht & Vecera, 2011; Lester et al., 2009). Participants made temporal order judgments (TOJs) for the onset (or offset) of target events on the figure compared with onsets (or offsets) on the ground. TOJs were more accurate when onset targets first appeared and less accurate when offset targets first disappeared on figures than on the grounds. In other words, to perceive onsets or offsets as occurring simultaneously the ground target would need to lead or follow the target on the figure, respectively. Consequently, these experiments demonstrated that perceptual processing is initiated earlier ("prior entry"; Lester et al., 2009) and is extended for a longer duration ("temporal extension"; Hecht & Vecera, 2011) on figures than on grounds.

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Given that figures are afforded extended durations of perceptual processing, a further implication of this change in temporal processing arises. Temporal extension of perceptual processing degrades temporal resolution, or the ability to resolve temporal details (e.g., Levine, 2000). As temporal resolution decreases, it can become more difficult to discriminate the duration between two closely spaced events (e.g., Reeves, 1996). Therefore, if the first of two events is processed for an extended duration of time, for example, then it would be difficult to readily perceive a second item appearing close in time at the same or a nearby spatial location. Thus, an implication of the temporal extension for figures is that the temporal resolution within grounds is higher than resolution within figures.

Evidence for this consequence of temporal extension has been presented within the domain of spatial attention; attending to a spatial location can impair temporal resolution (e.g., Hein, Rolke, & Ulrich, 2006; Rolke, Ulrich, & Bausenhart, 2006; Yeshurun, 2004; Yeshurun & Hein, 2011; Yeshurun & Levy, 2003). Some of these studies have used a flicker-fusion paradigm to examine temporal resolution of spatially attended vs. unattended regions (e.g., Yeshurun, 2004; Yeshurun & Levy, 2003). In flicker-fusion tasks, two items are presented in rapid succession at the same spatial location and the delay between them (i.e., inter-stimulus interval: ISI) is varied. As the ISI approaches zero, phenomenologically only one item is perceived as being presented, rather than two. In other words at very brief delays, the two items become "fused" together and appear as a single item.

Two items are more readily fused into the percept of a single item at attended locations than at unattended locations (e.g., Yeshurun, 2004; Yeshurun & Levy, 2003). Put another way, longer delays (i.e., high flicker fusion thresholds) were required between two items presented at an attended location in order to reach equivalent discriminability to items at unattended locations. Presumably, the fusion results from extended processing of the first, attended item. This shortens the perceptibility of the delay between items because the first item's offset is not efficiently detected, degrading the ability to detect the delay and onset of the second item. Thus, a flicker-fusion procedure provides a general assessment of temporal resolution.

Applying a flicker-fusion procedure to figure–ground displays allows us to assess the temporal resolution of figure and ground regions. If two items are more readily fused (i.e., have higher fusion thresholds) on figures than on grounds, then it can be concluded that ground regions have higher temporal resolution. In the current experiment, we implemented a modified flicker-fusion task on strong figure–ground and ambiguous displays (see Fig. 1). Participants viewed one static and one flickering target on each trial and discriminated a critical feature of the flickering target. We measured the participants' accuracy for target feature discriminations using d' in accordance with other tasks examining flicker fusion (e.g., Yeshurun, 2004; Yeshurun & Levy, 2003). If backgrounds have higher temporal resolution, then accuracy should be *higher* when flickering targets appear within these *ground* regions as opposed to when these targets appear within the figure.

Fig. 1. Stimuli used in the experiment. (A) Figure–ground display in which the symmetric convex region (depicted in blue or light gray) appeared as the foreground region. (B) Two types of ambiguous displays that did not produce a strong figure–ground segregation.

2. Method

2.1. Participants

Twenty University of Iowa undergraduates with normal or corrected-to-normal vision volunteered for course credit. The participants consisted of 11 women and 10 men, and they ranged in age from 18 to 22 years old.

2.2. Stimuli & apparatus

The participants viewed figure–ground displays with strong or ambiguous assignment (see Fig. 1) used in previous experiments examining temporal processing of figures and grounds (Hecht & Vecera, 2011; Lester et al., 2009). In displays with strong figure–ground assignment, symmetry and convexity cues dictated figural status. The symmetric, convex figure subtended approximately 3.73° by 4.60° of visual angle; the concave ground region subtended approximately 3.34° by 3.73°. Both regions were equally likely to appear on either side of fixation. In comparison, ambiguous displays lacked cues for figure–ground assignment. They contained either two convex or two concave regions. Each region measured 3.58° by 4.60° in the convex display and 3.42° by 3.80° in the concave display.

The current experiment's stimuli differed from previous research in that they were not red and green in color. Temporal resolution is underestimated when stimuli are red, due to the inhibition of magnocellular pathways (see Yeshurun, 2004). In order to avoid any underestimation of temporal resolution that might occur, each of the two regions in the display was equally likely to be green (RGB = 108, 217, 152) or blue (RGB = 121, 199, 238).

The participants viewed targets consisting of Landolt squares, embossed onto the surface of the figure and ground regions in order to promote the sensation of targets that bulge from the surface of the region (see Fig. 2). These squares subtended 0.90° by 0.90° of visual angle, and each contained a 0.16° gap on its top or bottom.

2.3. Procedure

Fig. 2 illustrates the sequence of events in a trial. The participants viewed a white central fixation point (500 ms) on a black background and were instructed not to move their eyes from this location. Next, the figure–ground display was presented for 40–60 ms, followed by the presentation of two targets. In each trial, only one target appeared in each region (figure and ground), and one target had a gap on its top while the other had a gap on its bottom. For ambiguous trials, one region was randomly designated 'figure' and the other 'ground'.

The targets were presented for 40 ms before one of the targets (i.e., the flicker target) was removed for an inter-stimulus interval (ISI) of 10, 20, or 30 ms, while the other target remained visible. After this ISI, the flicker target reappeared, and both targets remain visible for an additional 40 ms. Finally, the targets were removed and the figure–ground display remained visible until the participants responded which target (gap on top or on bottom) was the target that flickered. The participants completed 384 trials and responded via key press.

3. Results

The participants' accuracy (d') was calculated using the following formula (Macmillan & Creelman, 1991): $d' = z(\text{hit rate}) - z(\text{false alarm rate})$. Table 1 portrays the mean d' value for each condition.

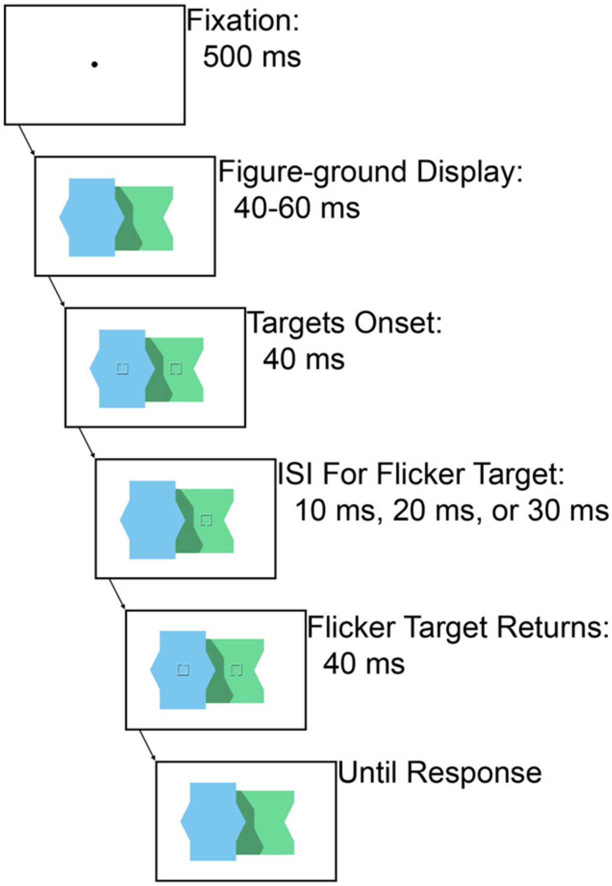

Fig. 2. Events and their durations for a single trial.

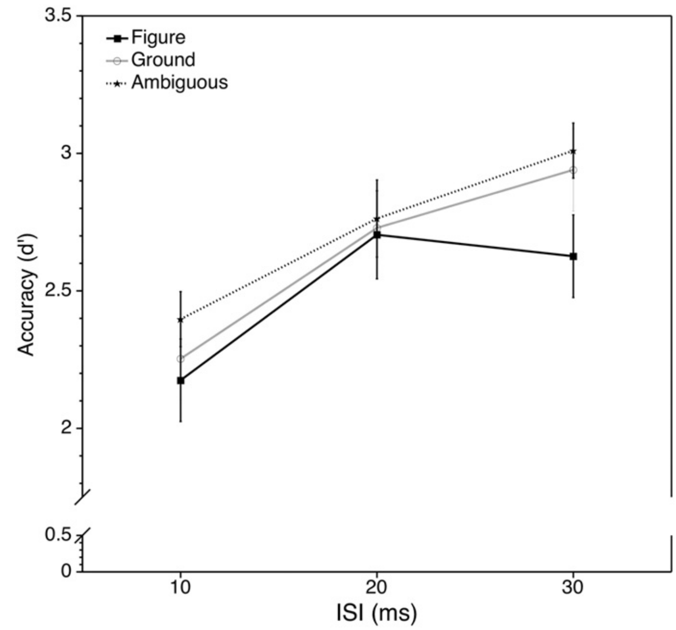

Fig. 3. Results plotting accuracy (d') in reporting the feature (gap on top or bottom) of the flicker target for each trial type across ISIs. All error bars indicate the within-subject 95% confidence intervals for the pairwise comparisons of the figure vs. ground trials (for the figure and ground lines) and of the ambiguous vs. figure trials (for the ambiguous line).

For ambiguous displays, a two-factor ANOVA between shape (convex, concave) and ISI (10, 20, 30 ms) revealed a significant main effect of ISI, $F(2, 38) = 10.96$, $p < .05$, partial-$\eta^2 = .37$, in which accuracy increased as ISI increased. However, there was no difference in accuracy for targets on convex and concave shapes, $F(2, 38) < 1$, *ns*, and no interaction between shape and ISI, $F(1, 19) = 2.50$, $p = .10$, partial-$\eta^2 = .12$. Hence, accuracy for both shapes was combined for the remaining analyses.

We used a two-factor ANOVA on trial type (figure, ground, ambiguous) and ISI (10, 20, 30) to analyze the d' data. The mean d' values across these conditions appear in Fig. 3. The main effect of trial type was significant, $F(2, 38) = 5.92$, $p < .05$, partial-η^2 =.24, with lowest sensitivity when the flicker target appeared on the figure ($d' = 2.50$) than on either the ground ($d' = 2.64$) or the ambiguous displays ($d' = 2.72$). The main effect of ISI was also significant, $F(2, 38) = 17.10$, $p < .05$, partial-$\eta^2 = .43$, with an increase in d' as the ISI increased (see Table 1). Finally, the interaction between trial type and ISI was not significant, $F(4, 76) = 1.06$, $p > .30$.

We used planned pairwise comparisons to investigate flicker fusion performance across the different trial types. The d' values were lower when the flickering target appeared on the figure than on the ground, $t(19) = 1.92$, $p = .07$, $d = 0.43$, and significantly lower when the flickering target appeared on the figure than on the ambiguous regions, $t(19) = 3.60$, $p < .05$, $d = 0.81$. The d' values did not differ when the flickering target appeared on the ground from when it appeared on the ambiguous regions, $t(19) = 1.36$, $p > .10$, $d = 0.30$.

Table 1
Mean Sensitivity (d′) For Trial Type X ISI.

Trial Type	ISI			
	10 ms	20 ms	30 ms	Total
Figure	2.18	2.70	2.63	2.50
Ground	2.25	2.73	2.94	2.64
Ambiguous	2.40	2.76	3.01	2.72
Total	2.28	2.73	2.86	

These findings suggest that there is a heightened sensitivity to flickering targets appearing within ground regions, compared to figure regions. In other words, these results support the temporal extension hypothesis, which proposes that figures hold processing longer than grounds. One consequence of this extended figural processing is that figures have poorer temporal resolution than grounds.

4. Discussion

Temporal processing is modified based on the perceptual organization of the scene, where figures receive extended durations (i.e., temporal extension) of perceptual processing. The current experiment tested a strong prediction generated from this temporal extension account: figures should be less sensitive to, and thus worse at detecting, a flickering target appearing within its borders. In a modified flicker-fusion task, reports were more accurate at discriminating a target's feature when the flickering target was on the ground rather than the figure, suggesting that there was an increased temporal resolution within the ground allowing the flicker to be perceived more accurately. In other words, the results of this experiment further support the extended processing of figures.

Although the current results support temporal extension for figures, we may have underestimated differences in the degree of temporal resolution between figure and ground regions. In our modified flicker-fusion task, participants searched for a flickering target and performed a discrimination task that required spatial processing. As described earlier, spatial and temporal factors have complementing, inverse relationships within figure and ground regions: high spatial and low temporal processing in figures, low spatial and high temporal processing in grounds (e.g., Klymenko & Weisstein, 1986, 1989a,b; Klymenko et al., 1989; Wong & Weisstein, 1983). Detecting the flickering target is more accurate in the ground region, but the spatial discrimination task is more accurate in the figure region. Thus, the conflict between these processes may have resulted in diminished differences between the temporal resolution of figures and grounds.

The current results also address an alternative explanation for the results of the experiments first demonstrating temporal extension (Hecht & Vecera, 2011): participants may have made eye movements and fixated on one of the regions in the display during the trial. In this previous work, the figure–ground displays were visible for 400 ms before the targets appeared in order to allow the regions to be fully segregated. Because figures may be more likely to be fixated, a change in fixation position is particularly problematic because peripheral targets are processed faster than central targets (e.g., Carrasco, McElree, Denisova, & Giordano, 2003). Thus, preferential eye fixation of the figure can result in a temporal advantage for grounds. However, the current experiment addresses this concern. The figure–ground displays and targets were presented for up to 180 ms, at which point the figure–ground displays remained visible until response. The participants would not have had time to fixate on either region prior to the presentation of the targets. Therefore, the differences found here indicate that Hecht and Vecera's (2011) results were not due to preferential eye fixation by providing converging evidence for extended processing of figures.

One account for the effects of figure–ground assignment on temporal processing is that processing figures enhances the activation of neurons relative to those processing grounds. Some researchers have predicted higher amounts of activation for the neural representations of figures than for the neural representations of grounds (see Vecera & O'Reilly, 1998, 2000; see also Peterson, 1999; Peterson & Skow, 2008). These predictions are supported by neurophysiological studies demonstrating that neuronal firing in response to the perception of figures is increased relative to firing in response to the perception of grounds (e.g., Lamme, 1995; Marcus & Van Essen, 2002; Qiu, Sugihara, & von der Heydt, 2007). This increased activation for figures may allow for increased sensitivity to targets' onsets and account for the temporal extension of figures that decreases sensitivity to targets' offsets.

We have created a computational model to examine the plausibility of such a mechanism (Hecht, Spencer, & Vecera, in preparation). The model utilizes dynamic field theory (Simmering, Schutte, & Spencer, 2007; Spencer, Perone, & Johnson, 2009; Spencer, Simmering, Schutte, & Schöner, 2007), which employs a neural architecture reflective of the visual cortex (Amari, 1977; see also Wilson & Cowan, 1972) in order to portray an organism's behavior as an autonomous system that receives and processes inputs and generates responses. It posits that neural populations processing the figure are more active due to completion of figure–ground assignment, resulting in a peak of activation that builds and pierces the threshold earlier than a peak of activation in response to the ground. Consequently, judgments for onsets are faster and more accurate within figure regions. However, this same enhanced activation for figures is sustained when the target is present, impairing accuracy when determining its offset. Because levels of activation for the figure's target are already above threshold, they must first decrease and drop below threshold (i.e., destabilize) before newly generated activation to the target's offset can re-pierce threshold and generate a response. This latter result is directly relevant to the current study: the prolonged activation for a figure's target delays detection of the target's offset, leading to less accurate performance at identifying targets flickering on figures.

In conclusion, the experiment presented here provides additional evidence that figure–ground assignment influences temporal processing. In particular, it exhibits *ground* benefits for temporal resolution (see also Hecht & Vecera, 2011). Several directions for future research exist, especially further understanding the interaction between figure–ground organization and the temporal process, as well as examining the neurophysiological hypotheses that have been proposed to account for temporal processing effects.

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