Delayed offset detection on figures relative to backgrounds

Lauren N. Hecht
Department of Psychology, Gustavus Adolphus College, Saint Peter, MN, USA

Shaun P. Vecera
Department of Psychology, University of Iowa, Iowa City, IA, USA

Recent research suggests that perceptual processing begins earlier for figures than for background regions (B. D. Lester, L. N. Hecht, & S. P. Vecera, 2009). This “prior entry” effect begins to account for reported figural benefits. However, another difference in perceptual processing may also contribute to these observed reports: Figures may also be afforded additional perceptual processing. The current experiments examined this claim and provide evidence that targets presented on figures are perceived as offsetting later than targets appearing on grounds, suggesting extended processing of figures relative to background regions.

Keywords: perceptual organization, temporal perception


Introduction

Interpreting a visual scene places a large demand on the visual system in which a coherent representation must be constructed from a seemingly ambiguous assortment of shapes, colors, and textures. Fortunately, the visual system utilizes a wide variety of processes in order to form a coherent image of the world. One such process is figure–ground organization, during which potential objects (i.e., figures) are segregated from less relevant background details. For example, figure–ground processes can allow the image of a set of car keys to be treated as a separate object from the papers lying on the desk.

Research on figure–ground organization has focused primarily on identifying cues that are used to distinguish between foreground and background regions. Such cues include area, symmetry, convexity (see Palmer, 1999, 2002, for reviews), lower region (Vecera, Vogel, & Woodman, 2002), object familiarity (Peterson, 1994), and attention (Vecera, Fleveris, & Filapek, 2004).

Although the cues that determine figure–ground organization are well studied, much less is known about the consequences, or effects, of figure–ground organization. Discussion of the effects of figure–ground organization can be traced back to Rubin (1915/1958), who initially discussed two phenomenological consequences: increased salience and “shapeness” of the “thing-like” figure. Other researchers also claimed that figures are “more strongly structured, and more impressive” (Koffka, 1935) and appear closer to the viewer (Palmer & Rock, 1994), yet the mechanism behind these subjective perceptions and the behavioral consequences they evoke are only now being explored.

Some researchers have demonstrated behavioral effects of figure–ground organization. In particular, targets appearing on figures are discriminated faster and more accurately than those appearing on grounds (e.g., Lazareva, Castro, Vecera, & Wasserman, 2006; Nelson & Palmer, 2007; Wong & Weisstein, 1982). These behavioral effects may be attributable to differences in spatial processing between figures and grounds, since figures have higher degrees of resolution (Julesz, 1978). Still, differences in temporal processing may also be present, influencing discrimination between these regions. Specifically, two types of alterations in temporal processing could exist between figures and grounds: (1) Perceptual processing may begin earlier on figures than grounds, resulting in better onset detection for figures, and (2) perceptual processing may end later on figures than grounds, resulting in worse offset detections for figures.

The first temporal effect, in which figures receive processing ahead of grounds, was supported in a series of experiments examining a “prior entry” effect for figure–ground displays (Lester, Hecht, & Vecera, 2009). The “prior entry” effect was originally characterized by attended events being perceived before unattended events (e.g., Shore & Spence, 2005; Titchener, 1908). Using a temporal order judgment (TOJ) task, Lester et al. (2009) varied the delay between the onset of two targets. They found that targets appearing on the backgrounds needed to onset earlier than targets appearing on the foreground figures in order for the two targets to be perceived as occurring simultaneously (i.e., a “prior-entry-like” effect).
These results imply that figure targets were perceived to lead ground targets, suggesting that figures are afforded early perceptual processing over grounds. Although figures are available for perceptual processing earlier than grounds, another temporal effect could contribute to previously observed figural benefits: later termination of perceptual processing of figures compared to grounds. We hypothesized that figure–ground organization would exhibit a shift in perceptual processing of offsets whereby figures undergo longer perceptual processing than grounds. If this is the case, then detecting the offset of a target would be more difficult when it is located on a figure than on a ground, producing a ground advantage for target offsets.

Rolke, Ulrich, and Bausenhart (2006) have demonstrated that modifying the TOJ procedure to offset, rather than onset, detections provides a relative comparison of the duration of time an item is processed; thus, we used a TOJ task where offset was detected to test our hypothesis. Participants viewed bipartite figure–ground displays containing two regions (Figures 1A and 1C), each with a target protruding from its surface. The interval between the targets' offset varied at one of four stimulus offset asynchronies (SOAs), and participants reported which target offset first (Experiment 1A) or which offset second (Experiment 1B). Any bias in responding first to targets on figures or on grounds should be eliminated by including these report order conditions (see Shore, Spence, & Klein, 2001). For instance, a participant preferentially responding to the figure would be less accurate when the ground target offsets first, especially at short SOAs; this same result is taken to suggest that figure targets were perceived to offset earlier than ground targets. However, if participants have this response bias, it would be evident when reporting which target offset second; their reports would now be opposite of those found when reporting which offset first. Increased responses to the figure would suggest that it was perceived as offsetting second more often than the ground; in other words, the ground target was perceived to lead the figure target, conflicting with the earlier result.

We assessed temporal discrimination by calculating the point of subjective simultaneity (PSS). The PSS reflects the temporal delay between target offsets that produces the most uncertainty for participants, resulting in 50% discrimination accuracy; that is, the PSS is the point at which participants perceive the stimuli as offsetting simultaneously. If perceptual processing is extended for figures relative to grounds, then a target appearing on the figure would be perceived as offsetting later than a target on the ground. Thus, the target on the figure would need to offset before the target on the ground for the two targets to be perceived as offsetting at the same time, shifting the PSS away from zero. Alternatively, if no extension in processing exists, then the PSS should fall at zero, indicating that the events must occur at the same time to be perceived as simultaneous.

### Experiments 1A and 1B

#### Methods

**Participants**

Thirty-two University of Iowa undergraduates with normal or corrected-to-normal vision volunteered for course credit.

**Stimuli**

Figure 1 depicts the two different display types: strong figure–ground assignment (Figure 1A) and ambiguous figure–ground assignment (Figure 1C). There were two types of ambiguous displays: two convex regions and two concave regions. Each display contained a green region (RGB = 0, 132, 0) and a red–orange region (RGB = 238, 83, 15) displayed against a black background. Both regions were equally likely to appear on either side of fixation, and each color occurred equally often on the left and right regions. Consequently, there were 12 stimulus displays: 3 display types (figure–ground, ambiguous: convex, ambiguous: concave) × 2 orientations (“figure” on the left, “figure” on the right) × 2 colors (left region is red–orange, left region is green).

In figure–ground displays, the symmetric, convex figure subtended approximately 3.73° by 4.60° of visual angle; the concave, shaded ground region subtended approximately 3.34° by 3.73°. Each region in a convex ambiguous display measured 3.58° by 4.60°, and each region in a concave ambiguous display measured 3.42° by 3.80°. The ambiguous displays lacked the depth cues present in the figure–ground displays, thereby eliminating strong figure–ground assignment.

Two targets, a small “x” and “o” that subtended approximately 0.40° by 0.40° of visual angle, were

![Figure 1. Stimuli used in the experiments. (A) Figure–ground display in which the symmetric convex region (depicted in red-orange) appeared as the foreground region. (B) Separated figure–ground displays that do not contain a strong figural assignment. (C) Two types of ambiguous displays that did not produce a strong figure–ground segregation.](https://jov.arvojournals.org/pdfaccess.ashx?url=/data/journals/jov/932792/)

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present in each display, with one target on each shape. The targets were the same color as the region on which they were presented, thereby eliminating the appearance of the targets being superimposed over the displays (see Richard, Lee, & Vecera, 2008, for discussion). Targets were drawn and rendered on the convex and concave regions using Google Earth (2006). As a result, targets are identifiable primarily by shadow cues created by the light sources in this three-dimensional space. Several images were captured with the targets protruding varying lengths from the surface of the figure and ground regions. During the trials, these images were displayed sequentially to create apparent movement of the target. Across trials, each target appeared equally often on each region of the display and appeared 1.80° from fixation.

**Procedure**

Each trial began with a 500-ms central fixation point that participants were instructed to fixate throughout the trial. The fixation point appeared at a location that was later occupied by the contour between the two regions. Either a figure–ground or ambiguous display was then presented for 400 ms; this display contained two targets (x and o) each protruding from one region (figure and ground). Following this display, and after a variable amount of time (35–75 ms), these targets began receding at different times into their respective regions over a duration of 110 ms; varying the shadow lengths cast by the targets reinforced this movement. Once the first target began to offset (i.e., once the shadow began to recede), the second target began to offset after one of four randomly selected SOAs: 26, 50, 100, and 150 ms. The target on the figure moved ahead of that on the ground on half of trials (negative SOAs) and conversely on the other half of trials (positive SOAs). Following the recession of the targets, the figure–ground display remained on screen until participants responded. Figure 2 illustrates the order of events in a trial. Half of the participants indicated which target began to offset first (Experiment 1A) and the other half indicated which offset second (Experiment 1B); they responded via key press. Participants completed a total of 512 trials, divided equally across 16 conditions: 2 display types (figure–ground, ambiguous) × 8 SOAs (+150 ms, ±100 ms, ±50 ms, ±26 ms).

**Results and discussion**

The proportion of time the ground’s target was perceived as moving first or second, averaged across all participants, is plotted in Figure 3. The curves plotted in Figure 3 represent the best-fitting logistic function to the averaged data. However, all statistical analyses were based on the best-fitting logistic curves fitted to each individual participant’s data. All curve fits converged to a tolerance of $R^2 \geq 0.92$.

As shown in Figures 3A and 3B, the proportion of trials in which the ground target was perceived as offsetting first (or second) increased as SOA increased. Critically, the PSS was shifted leftward for figure–ground displays relative to the ambiguous displays such that the figure target needed to offset earlier than the ground target in order to be perceived as offsetting simultaneously. This pattern was observed in a majority (75%) of participants as can be seen in their individual data and curve fits, plotted in Supplementary Figures I and II. The two types of ambiguous displays, convex (Experiment 1A: 85.8%; Experiment 1B: 80.2%) and concave (Experiment 1A: 84.9%; Experiment 1B: 79.9%), did not yield differences in accuracy of reports (Experiment 1A: $t(15) = 1.10, p > 0.20$; Experiment 1B: $t(15) < 1, ns$); thus, we averaged results across these displays for the remaining analyses.

Analysis of the PSSs indicated that the PSS for the figure–ground displays shifted significantly leftward, demonstrating that the figure’s target needed to offset ahead of the ground’s target. The PSS in Experiment 1A was −10.1 ms, and the PSS in Experiment 1B was −9.9 ms. Both of these PSS values differed significantly.
from zero, $t(15) = 3.02, p < 0.05$ for Experiment 1A and $t(15) = 2.67, p < 0.05$ for Experiment 1B. Since a similar result was obtained in Experiments 1A and 1B, a response bias does not readily account for this result. Consequently, these data were combined to obtain a PSS of $-10.0$ ms for the figure–ground displays, which differed significantly from zero, $t(31) = 4.07, p < 0.05$. This negative PSS indicates that deletion of targets on figures must occur, on average, $10$ ms ahead of those on grounds for the two targets to be perceived as occurring simultaneously.

In contrast, the PSSs for ambiguous displays did not exhibit significant, systematic shifts from zero. The PSS for ambiguous displays in Experiment 1A was $-1.3$ ms, $t(15) < 1$, ns, and in Experiment 1B, it was $-1.6$ ms, $t(15) < 1$, ns. Again, because a response bias was ruled out, the results were averaged across Experiments 1A and 1B, yielding a PSS of $-1.5$ ms, which did not differ significantly from zero, $t(31) = 1.01, p > 0.30$, indicating that the targets in neither of the regions in these displays had an advantage over the other region.

Moreover, the PSS for the figure–ground displays was significantly larger than the PSS for ambiguous displays, $t(31) = 3.22, p < 0.05$. A similar result was obtained when examining the data for Experiments 1A and 1B individually: a significant difference in Experiment 1A, $t(15) = 2.46, p < 0.05$, and a marginally significant difference in Experiment 1B, $t(15) = 2.06, p = 0.06$.

These results support our hypothesis that figures are subject to shifts in perceptual processing that delay one’s ability to detect offsets on a figure’s surface relative to offsets on a background. Importantly, the PSS was shifted leftward for displays containing strong figure–ground assignment but not for ambiguous assignment: A figure target must begin to offset prior to a ground target in order for the offsets to be perceived as simultaneous.

Importantly, our procedures employed both reports of “which offset first” and “which offset second.” Assessment of such complimentary reports is a technique that has been used in previous research (e.g., Carrasco, Ling, & Read, 2004; Shore et al., 2001) to rule response bias accounts (see Pashler, 1998). If a response bias were present in the current experiments, then the PSS would have been shifted in opposite directions for each experiment; the PSS may have shifted leftward in Experiment 1A (i.e., figures

Figure 3. (A) Results from Experiment 1A in which participants determined the target that was perceived to offset first and (B) Experiment 1B in which participants determined the target that was perceived to offset second. The figure–ground displays produced a leftward shift in the PSS (black arrow) compared to ambiguous regions in which either region could be perceived as figure (gray arrow). No such shift appears in (C) Experiment 2, in which the regions are separated spatially. The graphs plot the proportion of trials in which the target on the ground was judged to offset first as a function of SOA. Negative SOAs are for targets on figures that move first and positive SOAs are for targets on grounds that move first.
must offset before grounds) and rightward in Experiment 1B (i.e., grounds must offset before figures), or vice versa. Because neither outcome was present, response biases cannot account for our results.

The results of Experiments 1A and 1B are straightforward: Figures are processed for extended durations. However, a question remains as to the mechanism underlying this result. Previous research has demonstrated that attended locations often undergo processing for extended durations relative to unattended locations (e.g., Enns, Brehaut, & Shore, 1999; Hein, Rolke, & Ulrich, 2006), delaying the perceived offset for items at the attended locations (Rolke et al., 2006). Therefore, the temporal consequences observed in Experiments 1A and 1B may reflect a mechanism that is similar to or is exactly the same as the one producing the spatial attention effects.

The current results, along with those of previous research (e.g., Lester et al., 2009), demonstrate that the consequences of figure–ground assignment on temporal perception parallel those found in the spatial attention research (e.g., Hein et al., 2006; Rolke et al., 2006; Shore & Spence, 2005; Shore et al., 2001; Yeshurun, 2004; Yeshurun & Levy, 2003). This raises the question of whether the prior-entry-like effect and the current temporal effect (i.e., delayed offset detection) for figures are a corollary of figure–ground processes or simply reflect a shift of spatial attention, in which attention is drawn to figural regions. Figure–ground organization is known to have a tightly linked interaction with attention (e.g., Qiu, Sugihara, & von der Heydt, 2007; Vecera et al., 2004). The figures may have acted as an attentional cue and attracted attention, causing a shift in the PSS in the figure–ground displays. Moreover, the ambiguous displays would not have attracted attention to either region, allowing these displays to act as a “neutral” attention cue.

In sum, a spatial attention mechanism may mediate the effects of figure–ground organization on temporal perception. However, before considering this interpretation, we must first demonstrate that figure–ground organization, not convexity, produced this attention-like shift. In other words, any convex region may yield impaired detection of offsets. To address this concern, participants in Experiment 2 performed the TOJ task used in Experiment 1A with displays that separated the two regions of the figure–ground displays.

By separating the two regions of the figure–ground displays, the convex and concave regions no longer compete with one another for figural status; both regions may now be assigned figural status. If our results were produced by attention being directed to convex regions, then separating the regions should not impact offset judgments, and we should replicate the results of Experiment 1A. Attention would still be drawn to the “figure” (i.e., convex region), and targets offsetting from this region should still be perceived as offsetting later than targets on the “ground” (i.e., concave region). In contrast, if our results depend on figure–ground organization, then the temporal perception of the offsets should be accurate and unbiased. That is, the PSS for the convex region should not be shifted negatively away from zero because figure–ground organization has been weakened or eliminated between these regions via their separation.

### Experiment 2

#### Methods

**Participants**

Sixteen University of Iowa undergraduates with normal or corrected-to-normal vision volunteered for course credit.

**Stimuli and procedure**

The stimuli and procedure were identical to Experiment 1A, with the following exceptions. First, participants only viewed figure–ground displays; ambiguous displays were not presented. Second, the regions in these displays were separated by 0.50° of visual angle and did not share an edge (see Figure 1B). To compensate for the fact that the targets appeared further in the periphery than those in Experiment 1A, the targets in the current experiment were increased in size to 0.50° by 0.50° in accordance with the cortical magnification factor (Rovamo & Virsu, 1979) previously used in discrimination tasks (e.g., Carrasco & Frieder, 1997; Carrasco, McLean, Katz, & Frieder, 1998; Wolfe, O’Neill, & Bennett, 1998).

This separation of the regions removes competition for edge assignment. Consequently, there is no motivation for participants to attend to one region over the other. Still, to maintain consistency in referencing the convex and concave regions also present in the figure–ground displays of Experiments 1A and 1B, here the convex region is treated as “figure” and the concave as “ground.”

#### Results and discussion

The best-fitting logistic function of the averaged data is plotted in Figure 3C. Logistic functions were fit to each individual’s data (see Supplementary Figure III) and were used to compute a PSS for each participant. Analysis of the averaged PSSs revealed a PSS of 1.8 ms, which did not differ significantly from zero, t(15) < 1, ns. Additionally, the magnitude of the PSS was significantly different from the PSS in Experiment 1A, t(30) = 1.74, p < 0.05. These findings suggest that competition for figural status, which is increased when the two regions share a contour, was important in determining temporal perception differences between the two regions (Experiments 1A and 1B). When regions do not compete with one another for figural
status, temporal perception does not differ significantly between the two regions (Experiment 2). Simply put, convexity is not sufficient to extend temporal processing.

**General discussion**

Perceptual processing ends later on figures relative to grounds, requiring more lead time for targets that offset on the figure to be perceived as offsetting simultaneously as those that offset on the ground, as was found in Experiments 1A and 1B. An offsetting target on a foreground figure could not be detected as readily as targets on other regions. Thus, a greater delay was needed between the offset of the lingering target (i.e., the figure target) and the other target (i.e., the ground target). Moreover, this temporal effect is a consequence of figure–ground organization, as evidenced by accurate temporal perception of events on separated “figure” and “ground” regions (Experiment 2).

The current results, in combination with those of Lester et al. (2009), demonstrate an effect of figure–ground assignment on temporal perception that suggests that figures undergo longer durations of processing; however, one caveat for this interpretation is that the onset and offset judgment may arise from separate mechanisms (see Enns et al., 1999, for discussion). Moreover, we cannot determine whether this effect is a direct consequence of figure–ground assignment or if it is modulated by an effect of figure–ground assignment on attention. Recent evidence suggests that figure–ground organization and attention can be dissociated (e.g., Kimchi & Peterson, 2008; Vecera & Behrmann, 1997), supporting the idea of a direct influence of figure–ground processes over offset detection. However, given the tight linkages between figure–ground assignment and attention (Qiu et al., 2007; Vecera et al., 2004), it is difficult to disentangle these two processes.

Regardless of the relationship between these processes, neuronal processing differences between figures (or attended locations) and grounds (or unattended locations) may explain both the prior entry and temporal extension effects. 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). This increased activation for figures (or attended locations) may allow for increased sensitivity to targets’ onsets and account for delayed offset detections that may result from a temporal extension effect. We are currently exploring a computational model to simulate our behavioral data, which will allow us to examine the plausibility of such a mechanism.

In addition to examining the mechanism driving these effects, we are also exploring the consequences of this temporal extension for figures. If figures undergo temporal extension (i.e., processed for longer durations), perceiving other items occurring close in time at the same or a nearby location should be more difficult. In other words, a consequence of temporal extension is poor temporal resolution—the ability to discriminate the duration between two closely spaced temporal events (e.g., Enns et al., 1999; Hein et al., 2006; Rolke et al., 2006; Yeshurun, 2004; Yeshurun & Levy, 2003).

An initial assessment of individuals’ resolution, and thus sensitivity to temporal differences, in the current data revealed a difference between figure–ground and ambiguous displays in Experiments 1A and 1B. Calculating the just noticeable difference (JND) for the figure–ground and ambiguous displays provided an indication of the least amount of separation in time between two events (i.e., SOA) that is required to order the events with 75% accuracy. For this study, the JND was defined as half of the temporal interval between the SOA values at 75% and 25% accuracy on the best-fitting logistic function. This value shares a monotonic relationship with the slope of the functions, providing an assessment of the sensitivity of observers’ perceptions (see Shore & Spence, 2005, for discussion). Thus, as the JND decreased (i.e., shorter SOAs) for figure–ground displays (38.5 ms), less time was required between target offsets to reliably order the events relative to ambiguous displays (46.3 ms), $t(31) = 2.33, p < 0.05$. In other words, the slope of the function became steeper (i.e., increased more rapidly). Hence, the smaller JND indicated a higher sensitivity to temporal differences in the offset of events on figure–ground displays.

Although our results suggest higher sensitivity for figure–ground displays relative to ambiguous displays, this does not provide an assessment of the resolution within each region. Consequently, we are currently conducting experiments examining the temporal resolution of figures and grounds using multiple methodologies. Preliminary findings support this implication of temporal extension: Figures have poorer temporal resolution relative to grounds in a flicker fusion task. These initial results complement previous findings that perceptual grouping (Nicol & Shore, 2007) and object-based processes (e.g., Nicol, Watter, Gray, & Shore, 2009) impact temporal perception. For example, temporal resolution is degraded when targets are part of a single perceptual group (Nicol & Shore, 2007), provided the targets are similar (Nicol et al., 2009). However, if the targets remain distinct from one another (e.g., as parts of separate perceptual groups), then temporal resolution remains accurate. Interestingly, the current results present a caveat to this result: The perceptual groups must not be in direct competition for figural assignment in order to maintain temporal resolution.

In support of this conclusion, verification of the figure–ground assignment in the current displays demonstrates the presence of this competition when the convex and concave regions shared an edge. In their third experiment, Lester et al.’s (2009) participants discriminated targets...
appearing on the figure and ground regions. In accordance with previous research (e.g., Lazarova et al., 2006; Nelson & Palmer, 2007), discrimination performance was sensitive to figure–ground assignment: Targets on figures in figure–ground displays in which the regions shared an edge and competed for edge assignment were discriminated faster than targets appearing on grounds, whereas targets on all other regions in both ambiguous displays and separated figure–ground displays were discriminated relatively slowly due to the absence of a strong figure–ground interpretation.

Additionally, the current results help extend future research beyond temporal perception. Other research has demonstrated additional consequences of figure–ground assignment, such as perceptual enhancement of figures compared to grounds in tasks requiring fine discriminations (Hecht, Cosman, & Vecera, under revision). Interestingly, this figural benefit suggests better spatial resolution for figures relative to grounds, contrary to the predicted poor temporal resolution resulting from temporal extension of figures. A similar trade-off between spatial and temporal processing has been demonstrated in relation to completing figure–ground assignment. Regions consisting of high spatial frequency, low temporal frequency, or both are typically perceived as figures (e.g., Klymenko & Weisstein, 1989; Weisstein, Maguire, & Brannan, 1992). Weisstein et al. (1992) proposed that spatial and temporal frequency channels interact to produce these trade-offs, which then impact assignment in a bottom-up fashion. However, these interactions appear bidirectional as there is now evidence that figure–ground assignment can impact spatial and temporal perception in a top-down fashion.

**Conclusion**

Several studies have reported figural advantages consisting of faster and more accurate discrimination and detection of targets (e.g., Lazarova et al., 2006; Nelson & Palmer, 2007; Wong & Weisstein, 1982) that may reflect differential processing within other domains such as spatial and temporal perception. Specifically, figures enhance spatial perception (Hecht et al., under revision) and enter into perceptual processing earlier than grounds (Lester et al., 2009). The current results indicate that another source of the figural advantages is an extended duration of perceptual processing afforded by figures.

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Corresponding author: Lauren N. Hecht.
Email: lhecht@gustavus.edu.
Address: Department of Psychology, Gustavus Adolphus College, 800 West College Ave., Saint Peter, MN 56082, USA.

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