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Steven Beighley & Helene Intraub

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Does inversion affect boundary extension for briefly-presented views?

Steven Beighley and Helene Intraub

Department of Psychological and Brain Sciences, University of Delaware, Newark, USA

ABSTRACT
Inverting scenes interferes with visual perception and memory on many tasks. Might scene inversion eliminate boundary extension (BE) for briefly-presented photographs? In Experiment 1, an upright or inverted photograph (133, 258, or 383 ms) was followed by a 258 ms masked interval and a test photograph showing the identical view. Test photographs were rated as "same", "closer", or "farther away" (5-point scale). BE was just as great for inverted as upright views at the 133 and 383 ms durations, but surprisingly was *greater* for inverted views at the 258 ms duration. In Experiment 2, 258-ms views yielded greater BE when the study photographs were always tested in the opposite orientation, indicating that the difference in BE was related to encoding. Results suggest that *scene construction* beyond the view boundaries occurs rapidly and is not impeded by scene inversion, but that changes in the relative quality of visual details available for upright and inverted views may sometimes yield increased BE for inverted scenes.

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Boundary extension; scene perception; frame of reference; very short-term memory

Boundary extension (BE) is false memory for the continuation of a scene just beyond the boundaries of a view. BE was originally discovered in the context of research on long-term memory for photographs (Intraub & Richardson, 1989). Subsequent research demonstrated the surprising rapidity of BE. Briefly presented study photographs (e.g., 250 ms) masked for as little as 42 ms were remembered with extended boundaries (Dickinson & Intraub, 2008; Intraub & Dickinson, 2008). This led Intraub and Dickinson (2008) to suggest that during the first fixation on a scene, *anticipatory scene construction* beyond the view boundaries begins. The construction draws on amodal continuation of surfaces (Fantoni, Hilger, Gerbino, & Kellman, 2008; McDunn, Siddiqui, & Brown, 2014) and expectations about layout and meaning based on rapid scene perception (Greene & Oliva, 2009). Moments later, participants misattribute the source of this constructed representation to vision (a source monitoring error; Johnson, Hashtroudi, & Lindsay, 1993), resulting in BE.

The purpose of this research was to gain insight into whether scene perception and anticipatory scene construction occur simultaneously or can become uncoupled. To determine if anticipatory scene construction beyond the view can be delayed relative to perceiving the content of the view, we attempted to separate these processes by increasing the demands on visual scene perception. We presented upright and inverted multi-object scenes for one of three stimulus durations (383, 258, or 133 ms) followed by a brief, masked retention interval and a boundary extension test. We sought to determine if as duration decreases, the demands of scene inversion would slow visual scene perception, thus delaying scene construction beyond the view. If so, unlike upright views, briefly-presented inverted views might not exhibit BE. Intraub and Berkowits (1996) demonstrated BE for inverted scenes (15 s and 4 s durations), but only upright views have been tested in very short-term tasks (e.g., Intraub & Dickinson, 2008).

We chose scene inversion to increase demands on scene perception because the same low-level visual information is present in both versions of the scene but, similar to faces, text, and ambiguous figures (Rock, 1974), inversion negatively impacts scene perception (Diamond & Carey, 1986; Rock, 1974; Yin, 1969). There are several different ways in which scene inversion might slow the onset of anticipatory scene construction. One possibility is that the inverted image might need to be mentally rotated to its upright position (Shepard & Cooper, 1982; Shepard & Metzler, 1971) before anticipatory scene construction can be initiated. For example, in a test of scene memory,

CONTACT Steven Beighley smbeighley@gmail.com Department of Psychological and Brain Sciences, University of Delaware, Newark, DE 19713, USA

Gaunet and Berthoz (2000) found that participants' reaction time to recognize rotated photographs of previously visited locations in Paris indicated that mental rotation was required.

Apart from mental rotation effects, inversion would be expected to affect participants' ability to perceive and encode briefly presented scenes. Recognition memory studies have found that scene inversion decreased memory for scenes tested immediately following rapid serial visual presentation (RSVP; Meng & Potter, 2008) and for scenes tested following relatively long multi-second presentations (Dallett, Wilcox, & D'Andrea, 1968; Diamond & Carey, 1986; Yin, 1969). Inversion also reduced on-line detection of named scenes (Meng & Potter, 2008) and detection of an animal in scenes (Evans & Treisman, 2005) during RSVP. In change detection tasks, scene inversion delayed (Shore & Klein, 2000) or reduced the advantage for "high interest" changes observed for upright scenes (Kelley, Chun, & Chua, 2003).

Scene inversion has also been shown to affect perceptual organization of scenes. Holden, Curby, Newcombe, and Shipley (2010) reported that observer-defined scene-segmentation of landscapes differed for upright and inverted views. Diamond and Carey (1986) demonstrated that inversion increased the time required to detect specified geographic features (e.g., mountain, rock) in landscapes. They pointed out that inverted landscapes "looked odd" and suggested that inversion may disrupt interpretation of shaded regions, making parts of the landscape difficult to interpret. Finally, in a contextual cueing task, a task sensitive to spatial relationships within a scene across repetitions, the number of repetitions required to learn the location of a letter embedded in a scene was roughly double for inverted compared to upright views (Brockmole & Henderson, 2006). Thus, if anticipatory scene construction requires mental rotation to the upright or is slowed by perceptual demands, scene inversion might eliminate or reduce BE for briefly presented photographs. Alternatively, if anticipatory scene construction is flexible with respect to orientation and unfolds along with scene perception, then inversion may have no effect on boundary extension.

Experiment 1

The purpose of Experiment 1 was to first select photographs that could be identified whether upright or inverted given a brief (133 ms), masked presentation, and then to conduct a BE experiment at each of three different stimulus durations (133, 258, or 383 ms) to compare responses on a standard BE rating task for upright and inverted photographs. All study photographs were immediately followed by a 258 ms mask and the test photograph, which was identical to the study photograph (as in Mullally, Intraub, & Maguire, 2012). Participants rated the test photograph as being "same", "closer", or "farther away" than before on Intraub and Richardson's (1989) 5-point boundary rating scale. Intermixed with the upright and inverted photographs were "sideways-filler" photographs (±90° rotations); these were included to add uncertainly about orientation. Because of a perceptual distortion that was immediately evident during preparation for the experiment (described in "Stimulus selection"), BE test results for the sideways-filler trials could not be directly compared to the upright-inverted conditions and are therefore reported separately.

Method

Participants

Participants were 318 University of Delaware undergraduate volunteers enrolled in the Department Research Pool. Of these, 30 participated in stimulus selection, 216 in the boundary extension experiment (72 in each of three stimulus duration groups), and 72 in a replication of one stimulus duration condition.[1]

Stimulus selection

To obtain a set of 36 stimuli, we began by presenting 51 digital colour photographs of scenes that included 3–5 main objects (actors or objects) set within a natural background (580 × 580 pixels). The set included photographs taken by our lab and photographs collected from internet searches (see Figure 1 for examples). Each stimulus was presented for 133 ms (the briefest duration to be used in the experiment) followed by a 258 ms mask. The purpose of the mask was to prevent iconic persistence during the retention interval. A text box then immediately appeared in which participants typed their description of the image; they were encouraged to describe any details they could about the main objects and background. Scenes were presented in the same order, but to ensure that each scene appeared in each orientation across participants (i.e. upright, inverted, and sideways-filler [±90°-rotated]), there were three counterbalanced orders of orientation with 10 participants each. The 36 pictures associated with the best performance were selected for the BE experiment; this set was accurately described on over 99% of upright trials, 96% of inverted trials, and 96% of sideways-filler trials.[2]

While all stimuli were square, it is important to note that the 3:4 aspect ratio of the CRT monitor created the illusion of increased width for sideways stimuli; therefore, sideways performance could not be compared to upright and inverted conditions. We chose to include sideways views to increase trial-to-trial uncertainty about orientation, dissuading binary guessing and implementation of strategies such as mentally "flipping" photographs (vertically) rather than rotating them when inverted, if mental rotation processes took place.

Apparatus

Participants sat approximately 86 cm from a 21 inch (53 cm) CRT monitor in a dimly lit room. Photographs subtended a visual angle of approximately 15° × 15°. Presentation software was programmed in Microsoft Visual C 6.0 using Microsoft DirectX 9.0 and the EyeLink Windows API version 2.0, # 1997_2002 by SR Research Ltd. A computer mouse and keyboard were used to control trials and input responses.

Design and procedure

Participants were randomly assigned to the 133, 258, or 383 ms study duration group ($n = 72$ in each). The 36 scenes resulting from stimulus selection were always presented in the same order with an equal number of upright, inverted, and sideways-filler views. Photograph orientation was counterbalanced across participants in each of the three study duration groups, such that each scene appeared equally often in upright, inverted, and sideways-filler trials. Orientation was randomly intermixed throughout each sequence with the constraint that there be no more than two of the same orientation in succession. For the sideways-filler photographs, half were rotated clockwise and half were rotated counterclockwise, but direction was not counterbalanced across scenes, as there was no associated theoretical question.

Participants were instructed to try to remember each study photograph in as much detail as possible, including the objects, their placement, and the background. On each self-initiated trial, they fixated a centrally-located red cross on a black screen. The study photograph appeared for 133, 258, or 383 ms (depending on study duration group) followed by a dynamic pattern mask (Dickinson & Intraub, 2008) for 258 ms. The mask consisted of a black and white pattern (580 × 580 pixel) with a "happy face" (170 pixel diameter) in the centre that changed colour and expression 150 ms after onset. The study photograph then reappeared (unchanged) and remained onscreen, serving as the test photograph. Participants provided a boundary rating by indicating if the camera that took the test photograph was *much closer* (−2), *a little closer* (−1), *same* (0), *a little farther away* (+1), or *much farther away* (+2) than earlier, then provided a confidence rating (*Sure* [3], *Pretty Sure* [2], or *Not Sure* [1]). If they missed a picture (e.g., they blinked during presentation), instead of the confidence rating, they indicated that they missed the trial.

Results and discussion

Participants reported missing the upright, inverted, and sideways-filler photographs on less than 2% of trials at each orientation; these trials were excluded. Mean confidence rating for upright, inverted, and sideways-filler trials was 1.9, 1.8, and 1.9, respectively (a rating of "2" signified *Pretty Sure*).

Upright and inverted photographs

The mean boundary rating for upright and inverted study photographs in each study duration group is shown in Figure 2. As .95 confidence intervals around each mean excluded the rating of zero ("same") and single-mean tests comparing each mean to zero were all significant ($p < .01$ each).

A 2 (Orientation) × 3 (Duration) mixed measures ANOVA on the mean boundary ratings showed that BE was *greater* for inverted than upright views, $F(1, 213) = 7.09$, $p < .01$, $\eta_p^2 = .032$. As shown in Figure 2, mean BE tended to decrease as study duration increased; this effect of duration approached, but did not reach, significance, $F(2, 213) = 2.93$, $p = .06$. There was a significant Orientation × Duration interaction, $F(2, 213) = 3.47$, $p < .05$, $\eta_p^2 = .031$. Post-hoc tests of the effect of inversion at each duration were conducted using Bonferroni adjusted alpha levels of .0167 per test (.05/3): inverted views yielded greater BE than upright views solely at the 258 ms duration

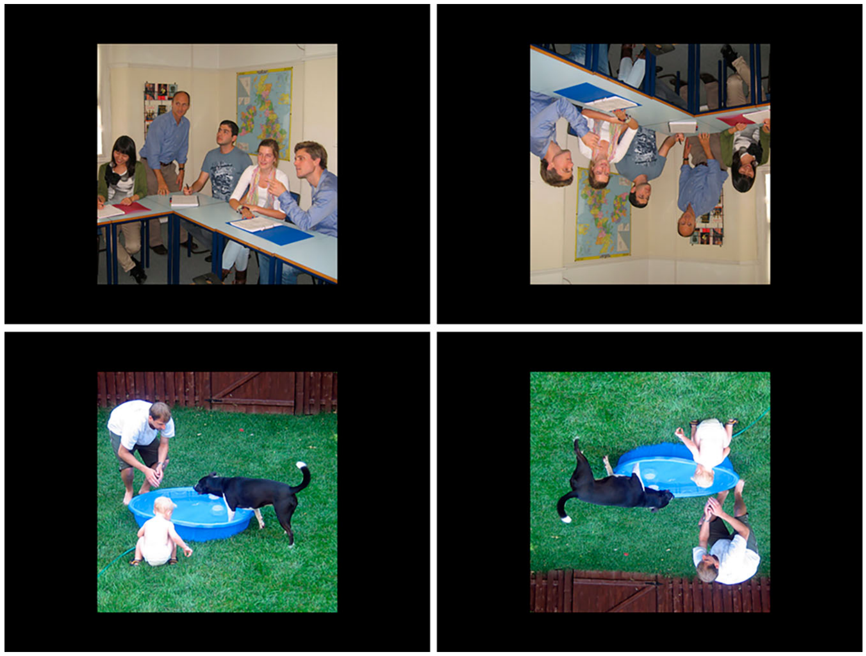

Figure 1. Example of two stimuli in both upright and inverted orientations. All stimuli contained 3–5 main objects and/or actors against a natural background. The photograph in the top panels was obtained online ("Classroom Photograph", n.d.); the photograph in the bottom panels is from a set taken by members of our lab.

$F(1, 213) = 13.36$, $p < .001$, and there was no effect at either of the other durations, $F < 1$, n.s. for each. It is interesting to note that this difference appeared to reflect a step-like change in BE at the 258 ms study duration. At the 133 ms duration, BE was relatively high for both orientations; moving to the 258 ms duration, BE remained relatively high for the inverted scenes but decreased for the upright scenes (yielding a significant difference). Then as duration increased to 383 ms, the inverted scenes appeared to "catch up" to the upright scenes (showing less BE than before), and again there was no effect of orientation.

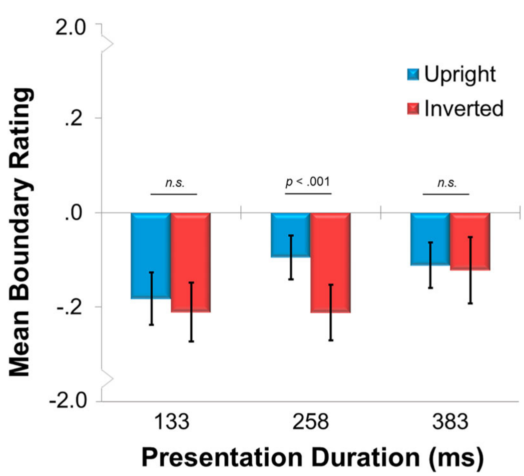

Figure 2. Mean boundary rating for upright and inverted study-photographs in each study duration group (Experiment 1). Error bars show the .95 confidence interval around each mean. Negative values indicate boundary extension. Significance bars indicate results of Bonferroni adjusted post-hoc *t*-tests comparing upright and inverted pictures within each study duration group.

Sideways-filler photographs

The mean BE rating for the 133, 258, and 383 ms groups was −.30 ($SD = .31$), −.14 ($SD = .23$) and −.11 ($SD = .26$), respectively. Single-mean *t*-tests comparing each mean BE rating with 0 (*same*) revealed significant BE at each duration: $t(71) = 8.23$, 5.19, and 8.23, $p < .001$ each, for the 133, 258, and 383 ms groups, respectively. A one-way ANOVA demonstrated a significant decrease in boundary extension as stimulus duration increased, $F(2, 213) = 10.35$, $p < .001$, $\eta_p^2 = .089$.

Replication with new participants (258 ms duration)

The observation of *greater* (rather than reduced) BE for inverted photographs at any duration was surprising. To determine if the unexpected increase in BE for inverted as compared with upright pictures at the 258 ms duration was a spurious effect, we repeated this condition with a new group of 72 participants. Results replicated the earlier findings. Participants reported missing the upright and inverted photographs on less than 1% of trials; these were excluded. Mean confidence for upright and inverted trials was 2.1 and 2.0, respectively.

Figure 3 shows the mean BE rating for each orientation. As shown in Figure 3, BE occurred for both orientations: again, BE was significantly *greater* on inverted than upright trials, $t(71) = 2.79$, $p < .05$, $d = .53$. In the case of the sideways-filler photographs, participants reported missing the photograph on less than 1% of all trials, and these trials were excluded from analysis. The mean confidence rating on sideways-filler trials was 2.0. Sideways-filler photographs yielded a mean boundary rating of −.12 ($SD = .28$) and, as in the main experiment, a single-mean *t*-test found significant boundary extension, $t(71) = 3.54$, $p < .001$, $d = .84$.

Experiment 2

The results of Experiment 1 showed that boundary extension occurred for inverted views when stimulus duration was as brief as 133 ms. The observation that inverted views led to at least as much BE as upright views underscores the rapidity of anticipatory scene construction and its flexibility with respect to orientation. The purpose of Experiment 2 was to explore the reason for greater BE on inverted trials when photographs were presented for 258 ms (an effect that was found and subsequently replicated in Experiment 1). To determine if greater BE for inverted views at this duration was due to encoding differences (e.g., differences in the quality of the visual representation in memory) or instead to decision differences at test (e.g., inverted test photographs might receive greater boundary extension ratings irrespective of study photograph orientation), participants were presented with the same 258 ms study photographs as in Experiment 1, but test photographs were *always* shown in the *alternate* orientation.

If greater BE for inverted study photographs reflects encoding differences between orientations, then the inverted study photographs should still yield greater BE, even though the test photographs are upright. If it reflects differences at test, then the upright study pictures should now yield greater BE because the test photographs are inverted.

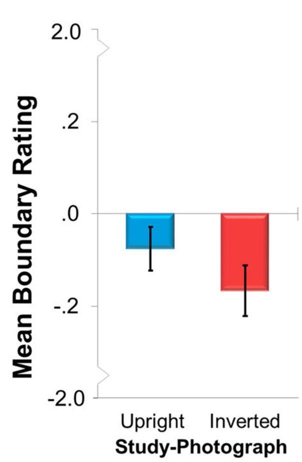

Figure 3. Mean boundary rating for upright and inverted study photographs (Experiment 1: "Replication with new participants (258 ms duration)"). Error bars show the .95 confidence interval around each mean. Negative values indicate boundary extension.

Method

Participants, stimuli, and apparatus

Participants were 72 undergraduates from the same population as in Experiment 1. Stimuli and apparatus were the same as in Experiment 1.

Design and procedure

The presentation procedure was the same as in the 258 ms study duration group in Experiment 1. The only difference occurred at test, when test photographs were always presented in the opposite orientation.

Results and discussion

Participants reported missing the upright, inverted, or sideways-filler study photograph on less than 1% of trials each and these trials were excluded. Mean confidence on upright, inverted, and sideways-filler presentation trials was 1.9, 2.0, and 1.9, respectively.

Upright and inverted photographs

The mean boundary rating for upright and inverted study photographs are shown in Figure 4. As indicated by the .95 confidence intervals in Figure 4, significant BE occurred for inverted study photographs (tested upright), but BE was not significant for the upright study photographs (tested inverted), although the mean was suggestive of BE; single-mean *t*-tests verified these comparisons, $t(71) = 6.68$, $p < .001$, and $t(71) = 1.70$, $p = .09$, respectively. Critically, the mean boundary rating for inverted study photographs was farther from zero than for upright study photographs,

$t(71) = 3.64$, $p < .05$, $d = .63$. This indicates that the orientation difference at the 258 ms condition was caused by differences in encoding the visual information rather than in decision processes associated with inverted test photographs.

Inspection of Figures 3 and 4 (Experiment 1 and 2, respectively) shows similar mean performance for upright views presented at 258 ms, but suggests greater variance in Experiment 2 (see error bars, showing the .95 confidence interval for each). To test this apparent difference, we calculated the standard deviation for each participant's upright and inverted trials and used this to conduct a 2 (Presentation Orientation) × 2 (Experiment) ANOVA. The main effect of presentation orientation across experiments was not significant, $F(1, 142) = 2.73$, $p = .10$. However, Experiment 2 yielded significantly greater mean variance, $F(1, 142) = 18.31$, $p < .001$, and there was a significant Presentation Orientation × Experiment interaction, $F(1, 142) = 8.52$, $p = .004$. Post-hoc tests using Bonferroni adjusted alpha levels of .025 per test (.05/2) show that upright study photographs (tested upright) in Experiment 1 ($M = .63$, $SD = .23$) yielded a significantly smaller mean standard deviation than upright study photographs (tested inverted) in Experiment 2 ($M = .83$, $SD = .23$), $t(142) = 5.14$, $p < .001$; the same comparison of the inverted-study photograph conditions between Experiments 1 and 2 ($M = .72$, $SD = .24$ and $M = .80$, $SD = .23$, respectively) found no significant difference, $t(142) = 2.21$, $p = .028$. These results suggest that comparing memory to a test picture that is presented in the opposite orientation (Experiment 2) led to greater variance, and this increased variance likely washed out boundary extension for the upright presentation condition in Experiment 2.

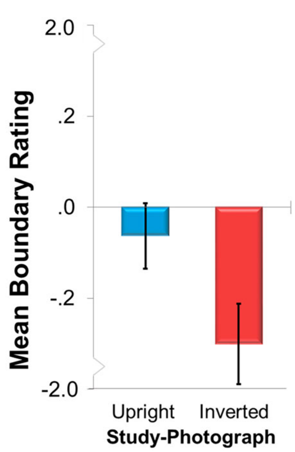

Figure 4. Mean boundary rating for upright and inverted study photographs (258 ms) when test pictures were always in the alternate orientation (Experiment 2). Negative values indicate boundary extension. Error bars show the .95 confidence interval around each mean.

Sideways-filler photographs

When counterclockwise study photographs were tested with clockwise photographs (and vice versa), the mean boundary rating was −.11 ($SD = .24$) and a single-mean *t*-test showed significant boundary extension, $t(71) = 3.88$, $p < .001$, $d = .92$. The reader is reminded that for the sideway-fillers, direction of rotation was not counterbalanced across scenes, as there was no associated theoretical question, so no comparison was made (see Design section of Experiment 1).

General discussion

These experiments provide new support for the rapid construction of anticipatory scene representation and demonstrate that this process is not inhibited when atypical view orientations are presented. Boundary extension (BE) was at *least* as great for inverted views as for upright views when study photographs were presented for as little as 133 ms. Boundary ratings provided no evidence to suggest that either mental rotation or any of the other deleterious effects associated with scene inversion had delayed or eliminated anticipatory scene construction. However, reduction in the quality of the visual representation, an effect of inversion demonstrated in prior research, provides a possible explanation of the surprising *increase* in BE for inverted scenes observed *only* at the 258 ms duration. This effect was observed and then replicated with a new group of participants in Experiment 1, and was again observed when test pictures were always presented in the opposite orientation in Experiment 2.

It is not clear why the 258 ms duration *alone* led to greater BE for inverted views, but the step-like pattern of results observed in Experiment 1 provides a tentative explanation. It may be that the quality of memory for the visual content of the view increased with duration (leading to the trend toward less BE), as shown in Figure 2. However, as may be observed in Figure 2, at the 258 ms duration this improvement in quality lagged behind for the inverted scenes, "catching up" again in the 383 ms condition. Note that BE for the sideways-filler trials showed a significant decrease in BE with increasing stimulus presentation durations (Experiment 1), supporting the idea that visual memory likely improves with increased viewing time, causing participants to misattribute less constructed space to having been seen.

According to the multisource model (Intraub, 2010; 2012), if the quality or resolution of visual memory is reduced, this would serve to decrease the difference between memory for the information just inside the view boundary (memory with a visual source) and memory for constructed information just outside the view boundary (memory based on top-down sources of information), resulting in more BE. Indeed, factors thought to compromise visual memory, such as dividing visual attention during presentation (Intraub, Daniels, Horowitz, & Wolfe, 2008) or placing demands on object perception by changing an object's colours to be non-diagnostic (e.g., blue bananas; Hale, Brown, & McDunn, 2016) have been shown to increase BE. Thus, in Experiment 1, it may be that the 258 ms duration captured a time-point at which visual memory for inverted views was sufficiently reduced compared to upright views to lead to a difference in BE. However, at present we consider this to be a speculation that would require further research.

What these experiments clearly demonstrate, however, is that anticipatory representation of surrounding context occurs very rapidly in visual scene processing, even when scenes are inverted (or, as shown in sideways-filler trials, rotated 90°). This flexibility with regard to orientation may be beneficial when observers take a viewpoint that breaks the alignment between head position and the orientation of surrounding objects and surfaces (e.g., as when lying down). Considering that observers must sample the world around them one fixation at a time, we suggest that this flexible and rapid implementation of scene construction beyond the view may support our ability to quickly perceive and interact with the surrounding world.

Notes

1. Number of participants for each stimulus duration group was based on prior brief boundary extension research with similar designs (Dickinson & Intraub, 2008; Intraub & Dickinson, 2008).
2. Among photographs that were rejected, a small number showed that inversion can preserve layout while compromising visual details in a way that changes participant's interpretation of the scene. For example, one photograph showed chefs (wearing typical chef's garb) around a preparation table. Upright, all participants correctly identified the people as "chefs" or "cooks"; however, inverted, the chefs were variously described as "doctors", "scientists", or "people in white". This observation is similar to Dickerson and Humphreys's (1999) observation that object rotation slows identification at the subordinate-level more than at the basic-level and has no effect on superordinate-level identification.

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCiD

Steven Beighley http://orcid.org/0000-0003-1009-4904

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