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The (Dynamic) Mind in the Cave: Representational Space of Cave Paintings and Petroglyphs

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Abstract

Four experiments examined whether reported looming of cave paintings and petroglyphs was due to representational momentum. Participants viewed a target photograph of a cave painting or petroglyph, and then a probe photograph of the same cave painting or petroglyph was presented. The viewpoint in the probe was closer, the same as, or farther than the viewpoint in the target. Participants judged if the probe viewpoint was (a) the same as or different from the target viewpoint or (b) closer, the same distance as, or farther than the target viewpoint. Experiments 1, 2, 3A, and 3B presented photographs of objects and entities, and Experiments 4A and 4B presented photographs of handprints and stencils. In all experiments, responses were not consistent with representational momentum, but were consistent with boundary extension. It is suggested perception of looming arises with continued inspection and reflects a mismatch between previously perceived (displaced) and currently perceived information.

Keywords

representational momentum, boundary extension, perception of art, scene perception, dynamics

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Ever since the discovery of Paleolithic cave paintings at Lascaux, Chauvet, and Altamira, the cognitive capacity of prehistoric humanity has been debated. Some theorists suggest that characteristics of such rock art reveal the emergence of modern symbolic representation (e.g., Deacon, 1997; Mithen, 1996; but see Bednarik, 2007), and other theorists suggest that imagery in cave paintings and petroglyphs is evocative of shamanic (Clottes & Lewis-Williams, 1998), ectopic (Lewis-Williams & Pearce, 2005), or autistic (Humphrey, 1998) experience. In some interpretations, the depicted images of humans, animals, or other entities can be perceived as emerging from the rock, and the cave wall is perceived as a "membrane" between the physical world of everyday life and the spiritual realm (Lewis-Williams, 2002). Consistent with the idea of emergence, L. Dobrez (2013) and P. Dobrez (2013) suggested that entities depicted in many examples of cave art appear to loom toward the viewer, and that this looming reflects dynamic characteristics of the cognitive representational space of the observer. The experiments reported here examine the cognitive representational space of cave paintings and petroglyphs in a modern population and propose one way that perception of looming might arise out of the dynamics of the cognitive representational space. Some brief speculation regarding the role and presence of such dynamics in the Paleolithic mind is also offered.

The idea of "looming" implies motion toward an observer, but cave paintings and petroglyphs are static objects. Even so, static objects can contain information regarding motion in a specific direction (e.g., Freyd, 1993; Hubbard & Courtney, 2006) and activate motion-processing areas within the brain (e.g., Kourtzi & Kanwisher, 2000; Senior, Ward, & David, 2002; Senior et al., 2000). An example of this is found in studies of memory for "frozen-action photographs." In such studies, observers are shown a target photograph taken from within a longer motion sequence (e.g., a dancer in mid-leap). If those observers are subsequently shown a second (probe) photograph from the same motion sequence, they are more likely to judge a probe photograph from slightly later than from slightly earlier in the motion sequence to be the same as the initial target photograph (e.g., Futterweit & Beilin, 1994). This has been interpreted as suggesting that the mental representation of the location of the object or entity depicted in the target photograph has been displaced (shifted) forward in the direction of implied motion, and this displacement has been referred to as *representational momentum* (Freyd & Finke, 1984; for review, see Hubbard, 2005, 2014). In essence, a cave painting or petroglyph is equivalent to a frozen-action photograph, and L. Dobrez (2013) and P. Dobrez (2013) suggest that reports of perceived looming of rock art might reflect representational momentum.

Although representational momentum might offer a plausible explanation for looming if implied motion of a depicted object or entity is toward the observer,[1] it is not clear how representational momentum could account for looming if a depicted object or entity is depicted in profile. In the latter case, the direction of implied motion is within the picture plane, and so representational momentum-based displacement would occur within the picture plane rather than along the line-of-sight. Also, it is not always clear if frontally oriented objects or entities should be perceived as approaching or receding from the observer, but representational momentum might account for looming only if depicted objects or entities were perceived as approaching. Representational momentum operates on individual stimuli, and although displacement is usually in the direction of anticipated motion for a given stimulus, that direction would be different for objects or entities depicted to be moving in different directions (e.g., upward for upward-moving objects, rightward for rightward-moving objects, etc.; Finke & Freyd, 1985; Finke, Freyd, & Shyi, 1986; Finke & Shyi, 1988). Cave paintings and petroglyphs often involve depiction of multiple objects or entities, and it is not clear how representational momentum for individual stimuli in a scene might result in general looming of the scene. What might be more relevant is a dynamic process in cognitive representational space that operates on the level of an entire scene rather than on the level of individual stimuli within that scene.

Discussions of cave paintings and petroglyphs often assume the depicted objects or entities are part of a scene (e.g., Lewis-Williams, 2002, suggests Lascaux observers "saw through the membrane [of the rock surface] and participated in the events in the spirit realm" [p. 266]), and so characteristics of the scene within which those entities are embedded might influence representational space. Representational momentum has been observed for objects embedded in scenes (e.g., Brown & Munger, 2010; Munger et al., 2006; Munger, Owens, & Conway, 2005), but representational momentum is not the only dynamic that operates on memory of a scene. For example, memory for a scene often includes not just the information within the viewed scene, but also information that was not viewed but that would likely have been present just outside the boundaries of the initial view. This has been referred to as *boundary extension* (Intraub & Richardson, 1989; for review, see Hubbard, Hutchison, & Courtney, 2010), and in boundary extension, the space within which the entities are embedded is dynamic. This is consistent with the suggestion of L. Dobrez (2013) that we perceive the space in which objects and entities are embedded, and not just the objects and entities themselves, as dynamic (cf. Jarraya, Amorim, & Bardy, 2005). However, boundary extension is geometrically equivalent to a displacement of the viewpoint away from the scene, and this does not initially seem consistent with claims of L. Dobrez (2013) and P. Dobrez (2013) that stimuli in rock art often appear to loom toward the observer.

The experiments reported here presented photographs of cave paintings and petroglyphs. In order to address rock art perception more generally, photographs were also drawn from more recent examples of rock art as well as from Paleolithic cave art. In Experiments 1, 2, 3A, and 3B, rock art depicted frontal or profile views of animals and other entities, and in Experiments 4A and 4B, rock art consisted of hand prints or stencils (see Figure 1). In Experiments 1 and 4A,

Figure 1. An illustration of target stimuli. The top row shows two profile pictures (from Experiments 1, 2, 3A, and 3B), the middle row shows two frontal pictures (from Experiments 1, 2, 3A, and 3B), and the bottom row shows two hand pictures (from Experiments 4A and 4B).

participants viewed a target photograph of a cave painting or petroglyph and then a probe photograph of the same cave painting or petroglyph, and the probe photograph depicted a viewpoint that was slightly closer than, the same as, or slightly farther than the viewpoint in the target photograph. Participants judged whether the probe photograph was the same as or different from the target photograph. In Experiments 2 and 4B, participants viewed the same target photographs and probe photographs as in Experiments 1 and 4A, respectively, but they judged whether the viewpoint in the probe photograph was closer than, the same as, or farther than the viewpoint in the target photograph. In Experiments 3A and 3B, participants viewed a target photograph depicting a close-up or wide-angle viewpoint and a probe photograph depicting a close-up or wide-angle viewpoint, and they judged whether the viewpoint in the probe photograph was the same as or different from (Experiment 3A), or closer or farther than (Experiment 3B), the viewpoint in the target photograph.

Experiment 1

Experiment 1 adapted a methodology and response measure used in the study of representational momentum, in which observers briefly view a target (analogous to a "frozen-action photograph") and then compare a subsequently presented probe with memory for the target. More specifically, participants in Experiment 1 briefly viewed a target photograph of a cave painting or petroglyph and then viewed a probe photograph of the same cave painting or petroglyph. The viewpoint in the probe photograph was slightly closer, the same as, or slightly farther than the viewpoint in the target photograph. After the probe vanished, participants judged whether the probe photograph was from the same viewpoint as the target photograph or from a different viewpoint. If representational momentum influences perception of looming in rock art, then cave paintings or petroglyphs in which objects or entities are depicted in a frontal view should result in larger displacement toward the observer (i.e., there should be a higher probability of *same* responses for probes with closer viewpoints) than cave paintings or petroglyphs in which objects or entities are depicted in a profile view. If boundary extension influences perception of rock art, then the same level of displacement away from the observer should occur for all cave paintings and petroglyphs (i.e., there should be a higher probability of *same* responses for probes with farther viewpoints) regardless of whether objects or entities are depicted in a frontal or profile view.

Methods

Participants. The participants were 15 undergraduates from University of South Carolina Upstate, who received partial course credit and were naive to the hypotheses.

Apparatus. The stimuli were displayed upon and the data were collected with a Gateway desktop computer equipped with a 15″ color monitor with a refresh rate of 60 Hz and a resolution of 1024×768 pixels. Participants' head and eye movements were not constrained, and the average viewing distance was approximately 60 cm.

Stimuli. Target stimuli consisted of 20 photographs of cave paintings and petroglyphs, and each photograph depicted a single object (or entity) or multiple objects (or entities). Representational momentum is found with single-object displays (e.g., Hubbard, 1990) and with multi-object displays in which each object moves in a different direction (e.g., Thornton & Hayes, 2004).

Ten target photographs involved cave paintings or petroglyphs depicting a frontal view, and 10 target photographs involved cave paintings or petroglyphs depicting a profile view. Five probe stimuli were prepared for each target, and probe photographs were decreased in size by 10% or 5% from the target, the same size as the target, or increased in size by 5% or 10% from the target. A decrease in size is equivalent to a farther viewpoint, and an increase in size is equivalent to a closer viewpoint (Intraub, Bender, & Mangels, 1992; Intraub, Gottesman, & Bills, 1998; but see Bertamini, Jones, Spooner, & Hecht, 2005). In order to keep the surface area and perimeter length of the target and probe photographs constant, all targets and probes were viewed through a rectangular opening (a black surface that occluded the outer portions and edges of each photograph) 15.8 cm wide by 9.8 cm high. The targets and probes were thus all the same size and presented at the same spatial coordinates within a trial and across trials. Each participant received 100 trials (2 views [frontal, profile] × 5 probes [−10%, −5%, 0, + 5%, + 10%] × 10 replications[2]) in a different random order.

Procedure. Participants were first given a practice session that consisted of 10 trials randomly drawn from the experimental trials. Participants pressed a designated key to begin the trial. There was a 1000-ms pause, and then the target was presented for 250 ms. This target duration is consistent with target duration in previous studies of representational momentum that presented frozen-action photographs (e.g., Freyd, 1983; Futterweit & Beilin, 1994). After the target vanished, the screen remained blank for 250 ms, and then the probe was presented. Given that representational momentum peaks 250 to 300 ms after the target vanishes (for review, see Hubbard, 2005), this retention interval should reveal any representational momentum that occurs. After the probe was presented, participants pressed a key marked “S” or a key marked “D” (the M and C keys, respectively, of a standard keyboard) to indicate whether the probe was the same as or different from the target. Participants were instructed that a *same* response indicated the probe was identical in all respects to the target, including the distance of the viewpoint. Participants then initiated the next trial.

Results

Probabilities of a *same* response for each probe and view are shown in Figure 2. Two types of analysis were performed: a comparison of weighted mean estimates of displacement to zero and a comparison of the probabilities of *same* responses across conditions.

Comparison of weighted means to zero. Consistent with previous studies of representational momentum (e.g., Hayes & Freyd, 2002; Hubbard, Kumar, & Carp, 2009; Munger, Solberg, Horrocks, & Preston, 1999), estimates of direction and

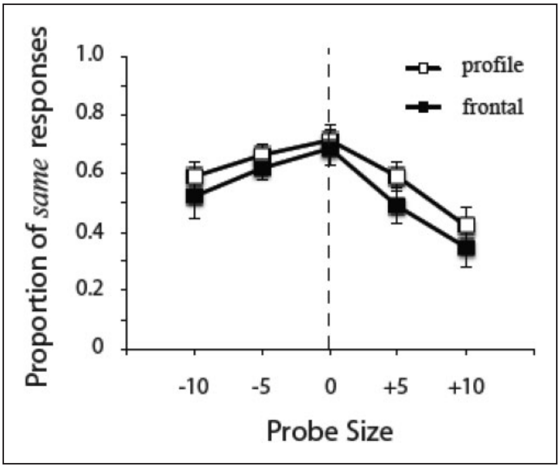

Figure 2. Proportion of *same* responses as a function of probe size in Experiment 1. Data for frontal views are shown using filled squares, and data for profile views are shown using outline squares. Error bars reflect standard error of the mean.

magnitude of any potential displacement in memory for the target were determined by calculating a weighted mean (the sum of the products of the distance of each probe from the location of the target, in pixels, and the proportion of *same* responses to that probe, divided by the sum of the proportions of *same* responses) for each participant for each condition. Weighted means significantly smaller than zero would indicate memory for the location of the target was displaced toward a farther viewpoint (inconsistent with representational momentum for frontal targets), and weighted means significantly larger than zero would indicate memory for the location of the target was displaced toward a closer viewpoint (consistent with representational momentum for frontal targets). Weighted means that did not differ from zero would indicate memory for the location of the target was not significantly displaced toward a farther viewpoint or a closer viewpoint.

To control for Type I error due to multiple comparisons, the p value required for significance was adjusted by a Bonferroni correction (.05/2 = .025 required for significance). Weighted means for profile ($M = -0.75$, $SE = 0.24$), $t(14) = -3.07$, $p < .0083$, and frontal ($M = -0.94$, $SE = 0.29$), $t(14) = -3.21$, $p < .0063$, views were significantly less than zero. Additionally, weighted means were analyzed in a one-way repeated measures analysis of variance (*ANOVA*) in which view (profile, frontal) was a within-subjects variable, and view did not approach significance, $F(1,14) = 0.25$, $MSE = 1.07$, $p = .63$.

Comparison of probabilities of same *responses.* The probabilities of *same* responses were analyzed in a 2 (view: profile, frontal) × 5 (probe: −10, −5, 0, +5, +10) repeated measures ANOVA. View was significant, $F(1,14) = 7.99$, $MSE = 0.02$, $p < .013$, such that participants were more likely to respond *same* to profile ($M = 0.59$, $SE = 0.02$) than to frontal ($M = 0.53$, $SE = 0.03$) views. Probe was significant, $F(4,56) = 11.26$, $MSE = 0.04$, $p < .001$, and least squares comparisons between the −10 ($M = 0.55$, $SE = 0.04$), −5 ($M = 0.64$, $SE = 0.04$), 0 ($M = 0.70$, $SE = 0.04$), +5 ($M = 0.54$, $SE = 0.04$), and +10 ($M = 0.38$, $SE = 0.04$) probes were significant except for comparisons between the −10 and +5 probes and between the −5 and 0 probes. A planned comparison found that participants were more likely to respond *same* to negative probes than to positive probes, $t(56) = 3.82$, $p < .0003$.

Discussion

Participants were more likely to respond *same* to probes with a farther viewpoint than to probes with a closer viewpoint, and this suggests the represented location of the depicted object or entity was displaced away from the participant. Whether the objects or entities in the paintings or petroglyphs were depicted frontally or in profile did not influence this pattern, and so it is unlikely that representational momentum accounted for the displacement, as representational momentum would have influenced memory for location along the depth axis (line-of-sight) for targets with frontal views but not for targets with profile views. Furthermore, representational momentum related to looming would have displaced the represented location of the depicted object or entity toward the participant (consistent with an emergence from the underlying rock), and this would have resulted in displacement toward a closer viewpoint. A displacement away from the participant is consistent with boundary extension, but it is not initially clear how boundary extension might contribute to reports of perceived looming. One possibility is that boundary extension occurs for the initial representation of the target, and thus, when the probe appears, the probe is perceived as closer than the target is remembered to have been. Because the probe is perceived as closer than the target, the objects or entities depicted in the target and probe would appear to have moved toward the participant (i.e., loomed). This notion will be developed further in the General Discussion section.

Even though there was no difference (as estimated by weighted means) between displacement of targets with frontal views and displacement of targets with profile views, participants were more likely to respond *same* to targets with profile views. One possibility is that movement toward or away from the participant is more likely for an object or entity depicted in a frontal view than for an object or entity depicted in a profile view (as the latter would be a less typical "sideways" movement), and so there might be greater sensitivity for or attention to position in depth with frontal views. Similar changes in the likelihood of a *same* response, but no changes in displacement, are found with changes in prior probability in a representational momentum task (Hubbard & Lange, 2010); more specifically, increases or decreases in the likelihood that a *same* response would be correct increases or decreases, respectively, the subsequent likelihood of a *same* response, but do not influence the magnitude of representational momentum. Although an equivalent examination of effects of prior probability on boundary extension has not been reported, the results of Experiment 1 are consistent with a hypothesis that changes in the prior probability a *same* response would be correct do influence the likelihood of a *same* response but not the magnitude of boundary extension. The relatively high likelihood of *same* responses to more distant probes might reflect the relatively close spacing of probes; even so, probe spacing was sensitive to the displacement of the viewpoint.

Experiment 2

The significant negative displacement in Experiment 1 suggested that memory for the target was displaced toward a more distant viewpoint (i.e., away from the participant), and such a pattern is consistent with boundary extension. The methodology and response measure of Experiment 1 were adapted from studies of representational momentum, and so to further examine whether the results of Experiment 1 were due to boundary extension, it was desirable to use a methodology and response measure typical of studies of boundary extension. Although some studies of boundary extension had participants draw a remembered target photograph, other studies (e.g., Intraub et al., 1998; Intraub, Daniels, Horowitz, & Wolfe, 2008; Munger & Multhaup, 2016) had participants view pairs of target and probe photographs as in Experiment 1. However, in these latter studies, participants typically did not judge whether the probe was the same as the target, but instead rated whether the viewpoint depicted in the probe was closer or farther than the viewpoint depicted in the target. Accordingly, participants in Experiment 2 viewed the same targets and probes as in Experiment 1, but rather than judging whether the probe was the same as or different from the target, participants rated on a 5-point scale whether the viewpoint of the probe was closer than, the same as, or farther than the viewpoint of the target. If boundary extension occurs, then the function relating ratings to probe size should be shifted downward (i.e., toward a rating of "too close").

Method

Participants. The participants were 15 undergraduates from the same participant pool used in Experiment 1, and they received partial course credit and were naive to the hypotheses. None of the participants had taken part in Experiment 1.

Apparatus. The apparatus was the same as in Experiment 1.

Stimuli. The targets and probes were the same as in Experiment 1, with the following exceptions: Rather than judging whether the viewpoint of the probe was the same as or different from the viewpoint of the target (as in Experiment 1), participants in Experiment 2 rated whether the viewpoint of the probe was closer than, the same as, or farther than the viewpoint of the target. Ratings were made using a −2 to +2 scale (in which −2 corresponded to "much too close," −1 corresponded to "slightly closer," 0 corresponded to "the same," +1 corresponded to "slightly farther," and +2 corresponded to "much too far") that was used in previous studies of boundary extension (e.g., Intraub et al., 1992; Intraub et al., 1998). It should be noted that studies in the boundary extension literature usually present targets or probes depicting only a close-up view or a wide-angle view (e.g., Intraub et al., 1992; Intraub et al., 1998, etc.), and a larger and more closely spaced set of probes for each target (as in Experiment 1) has typically not been used. However, use of such a larger set of probes has the potential advantage of offering a more sensitive measure of any potential displacement, as well as being more comparable with Experiment 1. Each participant received 100 trials (2 views [frontal, profile] × 5 probes [−10%, −5%, 0, +5%, +10%] × 10 replications) in a different random order.

Procedure. The procedure was the same as in Experiment 1, with the following exception: After the probe appeared, participants rated on a −2 to +2 scale whether the viewpoint of the probe was closer than, the same as, or farther than the viewpoint of the target by pressing a key marked "−2," "−1," "0," "+1," or "+2" (the Z, C, B, M, and > keys, respectively, of a standard keyboard) to indicate whether the viewpoint of the probe was closer than, the same as, or farther than the viewpoint of the target. Although the 250-ms target duration and retention interval used in Experiment 1 were chosen on the basis of the time course of representational momentum, the same target duration (e.g., Intraub & Dickinson, 2008) and retention interval (e.g., Dickinson & Intraub, 2008) lead to robust boundary extension, and so these parameter values were retained in Experiment 2.

Results

Ratings for each probe and view are shown in Figure 3. Two types of analyses were performed: a comparison of ratings to zero and a comparison of ratings across conditions. Ratings significantly smaller than zero would indicate memory for the location of the target was displaced toward a farther viewpoint (consistent with boundary extension), and ratings significantly larger than zero would indicate memory for the location of the target was displaced toward a closer viewpoint (inconsistent with boundary extension, but consistent with representational momentum for frontal targets and with looming). Ratings that did not differ from zero would indicate memory for the location of the target was not significantly displaced toward a farther viewpoint or a closer viewpoint.

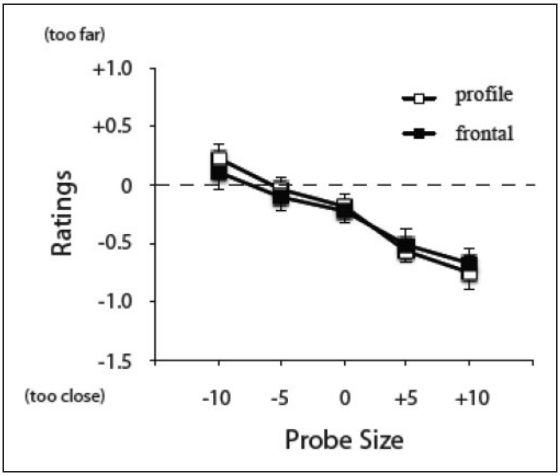

Figure 3. Ratings of distance as a function of probe size in Experiment 2. Data for frontal views are shown using filled squares, and data for profile views are shown using outline squares. Error bars reflect standard error of the mean.

Comparison of distance ratings to zero. To control for Type I error due to multiple comparisons, the p value required for significance was adjusted by a Bonferroni correction (.05/5 = .01 required for significance). Ratings for the −10 ($M = 0.17$, $SE = 0.09$), $t(14) = 1.55$, $p > .142$, and −5 ($M = -0.07$, $SE = 0.07$), $t(14) = -0.75$, $p > .46$, probes did not differ from zero. Ratings for the 0 ($M = -0.20$, $SE = 0.06$), $t(14) = -2.82$, $p < .01$, + 5 ($M = -0.54$, $SE = 0.07$), $t(14) = -5.79$, $p < .0001$, and + 10 ($M = -0.71$, $SE = 0.09$), $t(14) = -5.70$, $p < .0001$, probes were significantly less than zero.

Comparison of distance ratings across conditions. Ratings were analyzed in a 2 (view: profile, frontal) × 5 (probe: −10, −5, 0, + 5, + 10) repeated measures ANOVA. Probe was significant, $F(4,56) = 22.08$, $MSE = 0.13$, $p < .0001$, and all least squares comparisons between the −10, −5, 0, + 5, and + 10 probes were significant except for the comparisons between the + 10 and + 5 probes and between the −5 and 0 probes. Neither view, $F(1,14) = 0.08$, $MSE = 0.13$, $p > .78$, nor view × probe, $F(4,56) = 0.93$, $MSE = 0.06$, $p > .44$, approached significance.

Discussion

If there were no systematic displacement of the represented viewpoint toward or away from the participants, then the function in Figure 3 would have crossed the x-axis near the 0 probe, the −10 and −5 probes would have received significant positive ratings, and the + 5 and + 10 probes would have received significant negative ratings. However, none of the probes received a significant positive rating, and the 0, −5, and −10 probes each received a significant negative rating. Indeed, even the 0 probe, which was identical to the target, was rated as having a viewpoint significantly more distant than the viewpoint in the target. The functions in Figure 3 were generally shifted downward, corresponding to a displacement away from the participant (i.e., toward a rating of "too close"). This pattern is consistent with boundary extension, and the data support the hypothesis that displacement toward a farther viewpoint in Experiment 1 resulted from boundary extension of the representation of the target. Also, the occurrence of boundary extension in Experiments 1 and 2 regardless of whether a target depicted a single object or entity or depicted multiple objects or entities is consistent with L. Dobrez's (2013) notion that a scene does not require an interaction of two or more figures and consistent with findings that boundary extension occurs with single-figure scenes or with multi-figure scenes (Gagnier & Intraub, 2012).

Experiments 3A and 3B

The magnitude of boundary extension is influenced by the viewpoint depicted in the target, such that boundary extension is larger for close-up targets than for wide-angle targets (Intraub et al., 1998; Intraub & Richardson, 1989). If participants view a close-up target, that target is more likely to elicit boundary extension, and so participants are more likely to rate a close-up probe as too close and less likely to rate a wide-angle probe as too far. If participants view a wide-angle target, that target is less likely to elicit boundary extension, and so there is less impact of boundary extension on the rating of the probe. Accordingly, Experiments 3A and 3B presented four types of trials: a close-up target followed by a close-up probe, a close-up target followed by a wide-angle probe, a wide-angle target followed by a close-up probe, or a wide-angle target followed by a wide-angle probe. In Experiment 3A, participants judged whether the viewpoint of the probe was the same as the viewpoint of the target (as in Experiment 1), and in Experiment 3B, participants judged whether the viewpoint of the probe was closer or farther than the viewpoint of the target (as in Experiment 2). If boundary extension occurs, then in Experiment 3A, participants should be more likely to respond *same* when a close-up target is followed by a wide-angle probe than when a wide-angle target is followed by a close-up probe, and in Experiment 3B, the magnitude of a positive rating when a close-up probe is followed by a wide-angle probe should be smaller than the magnitude of a negative rating when a wide-angle target is followed by a close-up probe.

Method

Participants. The participants were 32 undergraduates from the same participant pool used in Experiment 1, and they received partial course credit and were naive to the hypotheses. None of the participants had taken part in Experiments 1 or 2. Sixteen participants completed Experiment 3A, and 16 participants completed Experiment 3B.

Apparatus. The apparatus was the same as in Experiment 1.

Stimuli. The targets and probes were the same as in Experiments 1 and 2, with the following exceptions: In Experiments 1 and 2, the target photograph of a given cave painting or petroglyph always depicted the same viewpoint distance, and there were five different viewpoint distances across the probes for that target. In Experiments 3A and 3B, the two most extreme (i.e., the closest [scaled by + 10%, resulting in a close-up view] and farthest [scaled by -10%, resulting in a wide-angle view]) versions of the probes for each target were used as targets and as probes. Consistent with previous studies of boundary extension (e.g., Gottesman & Intraub, 2002; Intraub et al., 1998; Intraub et al., 2008), there were thus four types of trials: CC (close-up/close-up; in which the target and probe were both + 10%), CW (close-up/wide-angle; in which the target was + 10% and the probe was -10%), WC (wide-angle/close-up; in which the target was −10% and the probe was + 10%), and WW (wide-angle/wide-angle; in which the target and the probe were both −10%). Each participant received 80 trials (4 comparisons [CC, CW, WC, WW] x 2 views [frontal, profile] x 10 replications) in a different random order.

Procedure. The procedure for Experiment 3A was the same as in Experiment 1, and the procedure for Experiment 3B was the same as in Experiment 2.

Results

Probabilities of a *same* response for each probe and view in Experiment 3A are shown in the top panel of Figure 4, and ratings for each probe and view in Experiment 3B are shown in the bottom panel of Figure 4. Two types of analyses analogous to those of Experiment 1 were performed on judgments in Experiment 3A: a comparison of probabilities of *same* responses to a chance level of 50% and a comparison of the probabilities of *same* responses across conditions. Two types of analyses analogous to those in Experiment 2 were performed on ratings from Experiment 3B: a comparison of ratings to zero and a comparison of across types of comparisons.

Experiment 3A: Comparison of probabilities of same *responses to chance.* Probabilities of *same* responses for each type of comparison were compared with chance (50%). Probabilities of *same* responses significantly higher than chance when the target and probe were the same (CC, WW), and probabilities of *same* responses significantly lower than chance when the target and probe were different (CW, WC), would indicate participants were generally correct in their

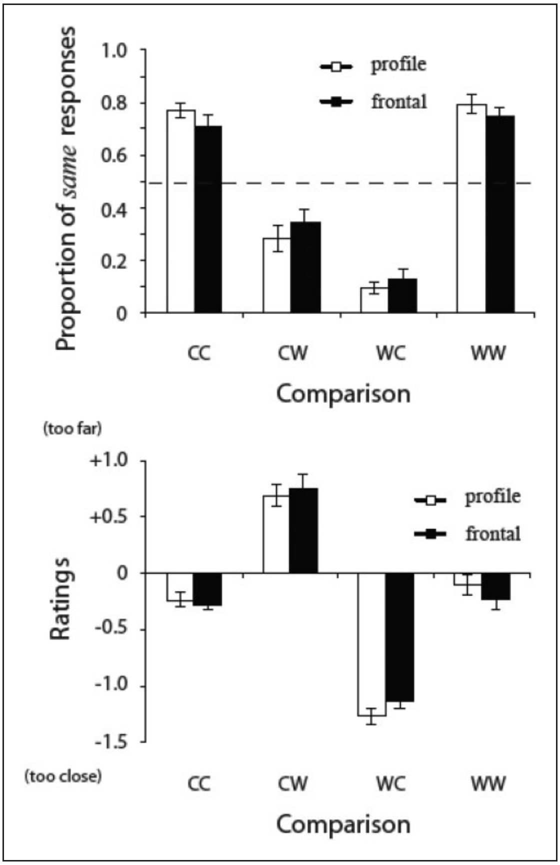

Figure 4. Proportion of *same* responses as a function of comparison in Experiment 3A (top panel) and ratings as a function of comparison in Experiment 3B (bottom panel). Data for frontal views are shown using filled columns, and data for profile views are shown using outline columns. Error bars reflect standard error of the mean.

judgments. Probabilities of *same* responses that did not differ from chance would suggest participants could not discriminate between the target and the probe or did not understand the experimental task. To control for Type I error due to multiple comparisons, the p value required for significance was adjusted by a Bonferroni correction (.05/4 = .012 required for significance). Probabilities of a *same* response for CC ($M = 0.73$, $SE = 0.03$), $t(15) = 7.80$, $p < .0001$, and WW ($M = 0.77$, $SE = 0.03$), $t(15) = 9.44$, $p < .0001$, were significantly higher than chance. Probabilities of a *same* response for CW ($M = 0.32$, $SE = 0.04$), $t(15) = -13.84$, $p < .0001$, and WC ($M = 0.11$, $SE = 0.02$), $t(15) = -13.33$, $p < .0001$, were significantly lower than chance.

Experiment 3A: Comparison of same *responses across conditions.* Probabilities of *same* responses were analyzed in a 2 (view: profile, frontal) × 4 (comparison: CC, CW, WC, WW) repeated measures ANOVA. As shown in the top panel of Figure 4, comparison was significant, $F(3,45) = 88.62$, $MSE = 0.04$, $p < .0001$, and all least squared comparisons between CC, CW, WC, and WW were significant except for the comparison between CC and WW. View was not significant, $F(1,15) = 0.07$, $MSE = 0.02$, $p > .79$. View × Comparison was marginally significant, $F(3,45) = 2.32$, $MSE = 0.01$, $p < .10$, and there was a trend for the effect of comparison to be larger for targets with profile views than for targets with frontal views.

Experiment 3B: Comparison of distance ratings to zero. To control for Type I error due to multiple comparisons, the *p* value required for significance was adjusted by a Bonferroni correction (.05/4 = .012 required for significance). Ratings for CC ($M = -0.25$, $SE = 0.04$), $t(15) = -5.16$, $p < .0001$, and WC ($M = -1.20$, $SE = 0.05$), $t(15) = -21.42$, were significantly less than zero. Ratings of CW ($M = 0.72$, $SE = 0.09$), $t(15) = 6.65$, $p < .0001$, were significantly greater than zero. Ratings for WW ($M = -0.17$, $SE = 0.06$), $t(15) = -1.92$, $p < .08$, did not differ from zero.

Experiment 3B: Comparison of distance ratings across conditions. Ratings were analyzed in a 2 (view: profile, frontal) × 4 (comparison: CC, CW, WC, WW) repeated measures ANOVA. View, $F(1,15) = 0.03$, $MSE = 0.05$, $p > .86$, and view × comparison, $F(3,45) = 1.87$, $MSE = 0.05$, $p > .14$, were not significant. As shown in the bottom panel of Figure 4, comparison was significant, $F(3,45) = 119.82$, $MSE = 0.16$, $p < .0001$, and all least squared comparisons between CC, CW, WC, and WW were significant except for the comparison between CC and WW.

Discussion

The greater likelihood of a *same* response in CW trials than in WC trials in Experiment 3A is consistent with previous findings that boundary extension is larger if participants view a close-up target than a wide-angle target (as boundary extension for a close-up target makes it more similar to a wide-angle probe, but any boundary extension for a wide-angle target makes it more dissimilar to a close-up probe). The lack of a significant difference in the probabilities of a *same* response in CC trials and in WW trials in Experiment 3A is consistent with the lack of a significant difference in the probabilities of a *same* response in those conditions reported by Intraub et al. (1998); this might reflect that a response of *different* did not afford an opportunity to indicate in which direction the probe differed. The asymmetry in ratings in CW trials and ratings in WC trials in Experiment 3B matches previous studies of boundary extension (e.g., Intraub et al., 1998; Intraub et al., 2008). Ratings in CC trials usually indicate more boundary extension than do ratings in WW trials (e.g., Intraub et al., 2008; but see Munger & Multhaup, 2016). In Experiment 3B, CC trials, but not WW trials, were rated as too close, and there was a trend for ratings in CC trials to be more negative than ratings in WW trials. Experiments 3A and 3B used a CC, CW, WC, and WW design common in studies of boundary extension; the probabilities of *same* judgment in Experiment 3A, and ratings of viewpoint distance in Experiment 3B, were consistent with previous boundary extension literature.

The effect of view was significant in Experiment 1 but not in Experiment 3A, and this might reflect the difference between the narrow probe spacing in Experiment 1 and the coarse spacing of close-up views and wide-angle views in Experiment 3A. The lack of an effect of view in Experiment 3B is consistent with the lack of an effect of view in Experiment 2. The literature on boundary extension has not generally considered the potential effect of orientations of objects within scenes. However, if one purpose of boundary extension is to prepare an observer for what might be seen in the next fixation (cf. Intraub & Dickinson, 2008), then boundary extension should be larger in the direction of anticipated motion within a scene. Consistent with this, Intraub, Hoffman, Wetherhold, and Stoehs (2006) found that boundary extension occurred for the side of a picture in the direction of an eye movement but not for the opposite side of the picture, and Courtney (2006) found that if a photograph showed an object moving toward one side (e.g., a galloping horse), then memory for that side of the photograph exhibited more boundary extension than did memory for the other side of the photograph. In such examples, though, it is not clear if the asymmetry in boundary extension reflected just boundary extension or a combination of boundary extension for the scene and representational momentum for the object (for a related asymmetry in representational momentum, see Munger et al., 2006). Regardless, results of Experiments 1, 2, 3A, and 3B suggest observers exhibit boundary extension for target scenes of cave paintings and petroglyphs.

Experiments 4A and 4B

P. Dobrez (2013) suggested depictions of hands in rock art are perceived as approaching (reaching toward) the observer and that representational momentum for such hand prints and stencils results in looming. Dobrez proposed an experiment in which two hand images were successively shown to an observer. If the second image was slightly larger than the first, but the observer judged the two to be the same, then that would suggest memory for the first image had been displaced toward the observer (cf. representational momentum for hand movements in Wilson, Lancaster, & Emmorey, 2010). The method of Experiment 1 was similar to this, although non-hand stimuli were presented. However, results of Experiment 1 indicated memory for the target was displaced away from, rather than toward, the observer.

Experiments 4A and 4B explicitly tested Dobrez's notion regarding hand stimuli in rock art, and photographs of hand prints and stencils drawn from Dobrez's article were used as target and probe stimuli. In Experiment 4A, participants judged whether the viewpoint in the probe was the same as the viewpoint in the target (as in Experiment 1), and in Experiment 4B, participants judged whether the viewpoint in the probe was closer or farther than the viewpoint in the target (as in Experiment 2). If hand prints and stencils are perceived as reaching toward the observer, then in Experiment 4A, participants should be more likely to respond *same* to probes that depict a closer viewpoint, and in Experiment 4B, the function relating ratings to probe size should be shifted upward (toward a rating of "too far").

Method

Participants. The participants were 29 undergraduates from the same participant pool used in Experiment 1, and they received partial course credit and were naive to the hypotheses. None of the participants had taken part in Experiments 1, 2, 3A, or 3B. Fifteen participants completed Experiment 4A, and 14 participants completed Experiment 4B.

Apparatus. The apparatus was the same as in Experiment 1.

Stimuli. The targets and probes were drawn from photographs of hand prints and stencils in P. Dobrez (2013). There were 10 target photographs. Five probe stimuli were prepared for each target, and as in Experiments 1 and 2, probe photographs were decreased in size by 10% or 5% from the target, the same size as the target, or increased in size by 5% or 10% from the target. Targets and probes were viewed through the same rectangular opening, and appeared the same perimeter size, as targets and probes in Experiments 1, 2, 3A, and 3B. Each participant received 50 trials (5 probes [−10%, −5%, 0, +5%, +10%] × 10 replications) in a different random order.

Procedure. The procedure for Experiment 4A was the same as in Experiment 1, and the procedure for Experiment 4B was the same as in Experiment 2.

Results

Probabilities of a *same* response for each probe in Experiment 4A are shown in the top panel of Figure 5, and ratings for each probe in Experiment 4B are shown in the bottom panel of Figure 5. Two types of analyses analogous to those in Experiment 1 were performed on judgments from Experiment 4A: a comparison of estimated displacement based on weighted means to zero and a comparison of the probabilities of *same* responses across probes. Two types of analyses

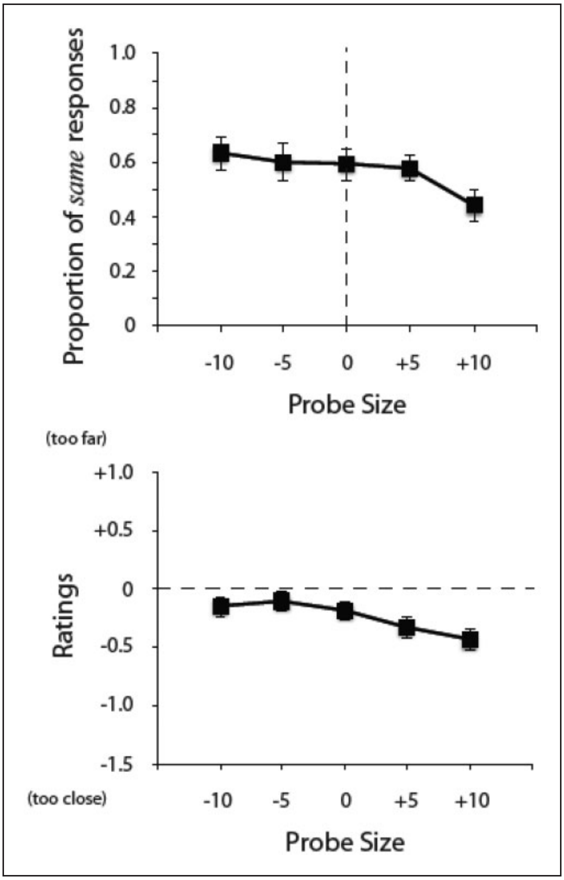

Figure 5. Proportion of *same* responses as a function of probe size in Experiment 4A (top panel) and ratings of distance as a function of probe size in Experiment 4B (bottom panel). Error bars reflect standard error of the mean.

analogous to those in Experiment 2 were performed on ratings from Experiment 4B: a comparison of ratings to zero and a comparison of ratings across probes.

Experiment 4A: Comparison of weighted means to zero. Weighted means for hand stimuli ($M = -0.92$, $SE = 0.29$), $t(14) = -3.17$, $p < .0068$, were significantly less than zero.

Experiment 4A: Comparison of probabilities of same *responses.* The probabilities of *same* responses were analyzed in a one-way (probe: −10, −5, 0, +5, +10) repeated measures ANOVA. As shown in the top panel of Figure 5, probe was significant, $F(4,56) = 3.43$, $MSE = 0.03$, $p < .02$, and least squares comparisons between the -10 ($M = 0.63$, $SE = 0.06$), -5 ($M = 0.60$, $SE = 0.07$), 0 ($M = 0.59$, $SE = 0.06$), $+5$ ($M = 0.58$, $SE = 0.04$), and $+10$ ($M = 0.44$, $SE = 0.06$) probes found that ratings for the $+10$ probe were significantly different than ratings for the -10, -5, 0, and $+5$ probes, and so this effect was driven by the $+10$ probe. Even so, a planned comparison found that participants were more likely to respond *same* to negative probes than to positive probes, $t(56) = 2.64$, $p < .02$.

Experiment 4B: Comparison of distance ratings to zero. To control for Type I error due to multiple comparisons, the p value required for significance was adjusted by a Bonferroni correction (.05/5 = .01 required for significance). Ratings for the -10 ($M = -0.15$, $SE = 0.06$), $t(13) = -1.76$, $p > .10$, and -5 ($M = -0.11$, $SE = 0.06$), $t(13) = -1.35$, $p > .20$, probes did not differ from zero. Ratings for the 0 ($M = -0.19$, $SE = 0.06$), $t(14) = -2.27$, $p < .05$, probe were marginally less than zero. Ratings for the $+5$ ($M = -0.33$, $SE = 0.07$), $t(13) = -3.76$, $p < .003$, and $+10$ ($M = -0.43$, $SE = 0.09$), $t(13) = -4.71$, $p < .0005$, probes were significantly less than zero.

Experiment 4B: Comparison of distance ratings across conditions. Ratings were analyzed in a one-way (probe: -10, -5, 0, $+5$, $+10$) repeated measures ANOVA. As shown in the bottom panel of Figure 5, probe was significant, $F(4,52) = 5.77$, $MSE = 0.04$, $p < .0006$, and all least squares comparisons between the -10, -5, 0, $+5$, and $+10$ probes were significant except for the comparisons between the -10 and -5, -10 and 0, -5 and 0, and $+5$ and $+10$ probes.

Discussion

Representational momentum for hand prints and stencils did not occur in Experiments 4A and 4B. Instead, the results of Experiments 4A and 4B were consistent with the results of Experiments 1 and 2 in suggesting that boundary extension occurred. However, the response ranges in Experiments 4A and 4B were reduced relative to the response ranges in Experiments 1 and 2, and boundary extension in Experiments 4A and 4B was weaker than boundary extension in Experiments 1 and 2.[3] Relatedly, the effect of probe size in Experiments 4A and 4B was weaker than the effect of probe size in Experiments 1 and 2. One possibility is that hand stimuli in Experiments 4A and 4B were perceived as less scene-like than were frontal stimuli and profile stimuli in Experiments 1, 2, 3A, and 3B. Boundary extension usually does not occur for isolated objects and only occurs when objects are embedded in a scene (e.g., Gottesman & Intraub, 2002, 2003). It is possible that viewing only a portion of the body (e.g., hand) in Experiments 4A and 4B might have been less successful in evoking a scene than were the generally full-body views in Experiments 1, 2, 3A, and 3B. Regardless, Experiments 4A and 4B suggest that the primary dynamic in cognitive representational space for rock art depicting hand prints and stencils is boundary extension rather than representational momentum. It is possible, of course, that representational momentum might occur with rock art stimuli, but it would be limited to extrapolation in the direction a stimulus is clearly depicted as moving or pointing, and it would not provide a mechanism for a generalized looming effect.

General Discussion

Participants who viewed target photographs of cave paintings or petroglyphs were more likely to remember those cave paintings or petroglyphs as having been viewed from a slightly more distant viewpoint, and this occurred for cave paintings and petroglyphs involving either a frontal view or a profile view of animals or other entities or a view of hand prints and stencils. Participants could more easily reject probes depicting a closer viewpoint than probes depicting a farther viewpoint. Both L. Dobrez (2013) and P. Dobrez (2013) suggested the cognitive representational space of rock art was influenced by representational momentum, but the similarity of displacement for targets depicted in a profile view and for targets depicted in a frontal view, as well as displacement toward a farther viewpoint, is not consistent with representational momentum. Displacement toward a farther viewpoint is consistent with a hypothesis that the cognitive representational space of rock art is influenced by boundary extension. Boundary extension is a common dynamic of scene perception, and depictions in cave paintings and in petroglyphs are often discussed as scenes. As boundary extension has been shown for many different types of scenes, the occurrence of boundary extension for cave paintings and petroglyphs is not surprising. Interestingly, the occurrence of boundary extension in the cognitive representational space of rock art suggests that other dynamics related to cognitive representational space might also occur (e.g., representational momentum might be observed if displacement along the picture plane was measured for targets depicted in profile).

Why might boundary extension occur? Boundary extension has been hypothesized to help connect discrete fixations into a representation of a continuous environment, and to thus enhance the ability to anticipate and prime processing for what might be perceived in the next fixation (Intraub & Dickinson, 2008). Such an ability would have been useful in helping Paleolithic humans anticipate what might be next encountered. Similarly, representational momentum has been hypothesized to compensate for delays in perception due to neural processing time (Hubbard, 2005), and such compensation would have been useful in helping Paleolithic humans anticipate where a predator or prey animal might be in the next moment of time. Of course, the existence of cognitive dynamics such as boundary extension (and a likely representational momentum in the picture plane for targets viewed in profile) in contemporary humans who observe cave paintings and petroglyphs does not address whether Paleolithic observers of cave paintings and petroglyphs experienced similar dynamics; even so, such dynamics are potentially highly adaptive and a case could be made that such dynamics would have been selected for. The potential presence of such dynamics in ancient hunter-gatherers is consistent with hypothesized similarities in brain structures of contemporary humans and Paleolithic humans and with existence of an intuitive physics in Paleolithic humans (cf. Mithen, 1996).

As noted in the discussion of Experiment 1, displacement toward a more distant viewpoint might initially appear inconsistent with reports of looming by L. Dobrez (2013) and P. Dobrez (2013). However, such a notion ignores temporal aspects of the dynamic nature of the mental representation, as an initial increase in the depicted distance could be part of a larger mechanism that resulted in subsequent looming. The scene as initially viewed has specific boundaries,[4] and once an observer fixates on a specific region of the scene, that information is encoded into the representation of the scene. When the observer shifts his or her gaze to another location in a scene, memory for the initially fixated location undergoes boundary extension. If the observer then shifts his or her gaze back to the initially fixated location, there is a mismatch between the remembered information (which has been displaced) and the current perceptual information. The depicted object or entity is remembered as being more distant in the initial perception (because of boundary extension), and so the current (subsequent) perceptual information suggests a closer location (and so the object or entity appears to loom). Looming thus "emerges" with subsequent inspection, and in the presence of flicking torches and possible psychoactive substances speculated to have accompanied viewing or creation of cave art, this might be interpreted as a depicted object or entity "emerging" from behind the surface of the rock. Such an account is consistent with the existence of boundary extension with brief target displays (Intraub & Dickinson, 2008) and retention intervals (Dickinson & Intraub, 2008) corresponding to the latency between saccades.

Although the experiments reported here focused on a prediction regarding the source of looming in cave paintings and petroglyphs, the proposed mechanism seems relevant to perception of visual art more generally (e.g., other genres of painting, sculpture, architecture). Interestingly, at least a portion of the aesthetic experience of cave paintings and petroglyphs might result from a mismatch of current perceptual information with previously remembered (displaced) information similar to the mismatch suggested here; indeed, several theories of aesthetic response posit a role for violation of expectancies similar to the mismatch between perceived and expected (displaced) information suggested here (e.g., Berlyne, 1971; Huron, 2006; Meyer, 1956). A mismatch between previously remembered information displaced by representational momentum and current perceptual information as a basis for aesthetic response has been previously discussed (Freyd, 1993; Hubbard & Courtney, 2006), and the mismatch between previously remembered information displaced by boundary extension and current perceptual information suggested here as a basis for looming (and aesthetic response) is similar. Whether such dynamics might have been explicitly or implicitly exploited by Paleolithic artists and observers is not clear, of course, but a consideration of cognitive dynamics discovered by studies of cognition in contemporary humans offers potentially useful ideas about the dynamics that might have been present in the mind in the cave.

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Notes

1. There have been relatively few studies of representational momentum for objects moving in implied depth, and the data are not entirely consistent. Hubbard (1996) attempted to indicate implied depth by changes in the size of a square on an otherwise blank display and instructing participants to interpret the stimulus as approaching or receding, and he found that representational momentum only occurred with faster target velocities. Nagai, Kazai, and Yagi (2002) had experimental participants wear stereoscopic goggles while observing a square target that appeared to approach or recede, and they found representational momentum was stronger for receding motion. Munger, Owens, and Conway (2005) presented stimuli that implied motion of the self into a scene along the line of sight. In trials designed to specifically test for representational momentum, they found representational momentum. However, in the trials designed to test whether boundary extension or representational momentum would occur, they found evidence for boundary extension (i.e., participants rated close-up test views that were identical to the final view in the stimulus sequence as too close-up) but not for representational momentum. DeLucia and Maldia (2006) presented motion along the line of sight toward a target, and they reported that memory for the final view was not consistent with representational momentum. However, both Munger et al. and DeLucia and Maldia, as well as Hubbard, relied on pictorial depth cues and instruction rather the actual changes in perceived depth. Although studies involving linear motion are most relevant to claims of looming, it should be noted that Munger et al. (1999) found robust representational momentum for the remembered orientation of a target that rotated in depth.
2. "Replications" normally refers to repeated presentations of the same stimulus. In order to sample a wider range of cave paintings and petroglyphs in the current experiment, replications involve presentations of additional but different stimuli in that same condition (e.g., the 10 replications of the frontal condition involved 10 different exemplars of frontal view rock art).

3. The height of the function in Experiment 4A is still increasing at the −10 probe size, and this suggests the weighted mean might underestimate the extent of the displacement. Even so, the weighted mean is still significantly less than zero, and so the hypothesis that the representation of the hand is shifted toward the observer can be rejected.
4. In the target and probe stimuli, the borders were specified by the edges of the photographs. As Intraub and others have discussed (e.g., Daniels & Intraub, 2006; Intraub, 2010), the borders specified by a photograph are analogous to the natural borders specified by the limits of the visual field. Thus, boundary extension is not merely an artifact of perception of photographs, but is a more general bias involving the multidimensional representation of scenes.

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