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The Vista Paradox: Framing or Contrast?

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The vista paradox is the illusion in which an object seen through a window appears to shrink in apparent size (and appears farther away) as the observer approaches the window. Paradoxically, the distal object appears smaller as its visual angle increases. We investigated the effect in four experiments varying object size, distance, point of fixation, and texture of the frame and of the object. In the first experiment, we tried to confirm the illusion and to test the robustness of the phenomenon. In the second experiment, we manipulated where subjects fixated (on the frame or on the object) as well as the texture of the object and the frame. Fixation was essential for the illusion: fixating the frame led to an apparent shrinking of the object, whereas fixation on the object did not. Texture of the frame intensified the apparent shrinking of the object. In a third experiment, we separated the point of fixation from the frame in a between-subjects design. Finally, in Experiment 4, we showed that the paradox does not require a frame, but it requires a fixation on a location different from the object. That is, the window or frame is dispensable for the vista paradox, but fixation is critical.

Keywords: vista paradox, illusions, frame, size perception, distance perception

The vista paradox is fascinating because it is a counterexample to size constancy. When an object is seen through an aperture, such as a window, it appears to shrink in size as the observer approaches the window. For example, the effect occurs when a rich scene is viewed through an opening, such as a garden viewed through a window in a wall. Objects in the scene appear to shrink in size and/or move farther away, even though observer and object are physically getting closer. To our knowledge, Cornish (1935) provided the first documentation of this effect when recounting his observation of a neighboring house nearly filling the breadth of a window in his room. When moving toward the window, the house appeared to shrink to about half of its initial size, whereas the retinal enlargement of the window should have made it grow in apparent size or maintain its size if a size-constancy mechanism had been at work. In his compilation of perceptual laws, Metzger (1975) makes the same observation, this time when approaching a window of an apartment facing the statue of a horseman. The statue appeared to shrink in size as he approached the window. Senders (1966) reported the related effect of the reflection of a lamp in a coffee cup. As the observer moves the cup closer to her or his eye, the reflection appears to shrink, although the retinal image of the lamp grows in size. The Taj Mahal gate illusion[1] is arguably the most famous example of the vista paradox: when walking toward the gate that visually frames the building behind it, the Taj Mahal seems to shrink as the observer approaches the gate (see, e.g., https://www.youtube.com/watch?v=eTkkqwtLLh0).

Surprisingly, despite these reports, we could only find a single study that presents an empirical study of the phenomenon. Walker, Rupich, and Powell (1989) had observers view tall flagpoles, about 60 m away, through a rectangular window. As the observers approached the window, the poles were judged to become smaller in size (by more than 20%) and to move farther away. They called this effect the vista paradox. The experiment by Walker et al. suggests that the effect may be universal but leaves many questions unanswered, in particular the perceptual basis of the illusion.

The Frame as an Agent to Isolate the Object From Its Surround

A frame can provide a specific context or change the local context in which an object finds itself. In the Ebbinghaus illusion, there is a frame (e.g., made up of small circles) acting upon an object inside the frame (e.g., making the inner circle appear larger; see, e.g., Massaro & Anderson, 1971). Most of what we know

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[1] We are grateful to James Enns for alerting us to this illusion.

about framing effects is related to simple length and size perception or to orientation perception. For instance, the judged length of a horizontal line changes when it is framed by vertical lines on either side (Yamagami, 1980). A frame can be powerful enough to induce motion in a stationary object (Duncker, 1929). An early experimental study of framing by Rock and Ebenholtz (1959) showed that size is, to a considerable extent, relationally determined. They also demonstrated that the relational effect and the taking into account of distance are both important for the perception of size at varying distances.

The frame may isolate the object and induce a direct comparison of the retinal areas covered by the object and the frame. As the observer gets closer to the frame, the target object takes up a relatively smaller portion of it (see Figure 1). Table 1 illustrates this reduction of the object's relative retinal size during approach for an initial distance of 3 m from the frame versus a final distance of 1 m from the frame, as we have used in our experiments. In the sense that the vista paradox is caused by the frame putting emphasis on this relative retinal size reduction during approach, it may be called a frame effect.

Relatedly, the frame could alter the apparent distance between observer and object. Artists and gallery visitors have known for a long time that "looking at and through the frame with one eye is a time-honored method to 'flatten' a scene" (Koenderink & van Doorn, 2003, p. 248). Thus, when a frame is between a painting and the observer, the depicted space appears to be compressed (for a quantitative study, see Eby & Braunstein, 1995). Such compression might occur because the frame truncates the visual field (see Lumsden, 1983) and isolates the object within the scene. We suspected that the frame might have different effects on a real three-dimensional scene and a two-dimensional representation. Only in the former case is the reason for the truncation perceptually given. Thus, we decided to do as Walker et al. (1989) did and use actual three-dimensional stimuli in combination with a physical frame.

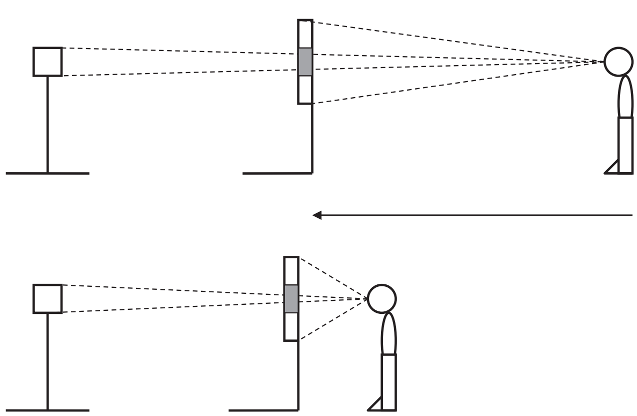

Figure 1. The framing mechanism as a potential explanation of the vista paradox. As an observer approaches an object seen through a frame, the relative retinal size of the object is accentuated. As the latter is decreasing, the object appears to shrink and/or to move farther away. Note how the proportion of the frame occupied by the object is smaller when the observer is nearer. The gray area inside the frame indicates the aperture.

Table 1
Retinal Size Change of Frame During Approach

Viewing distance from frame (m)	Retinal size of frame (°)	Retinal size of object (°)	Ratio object/frame
3	18.4	1.4	.076
1	45.0	2.2	.049

Note. As the observer approaches the frame (and object), the retinal size of the object increases, but its retinal size relative to that of the frame shrinks. The frame may make this relationship salient.

The Role of Optic Flow

Cornish (1935) and Walker et al. (1989) describe the movement of the observer toward the frame and object. Movement is an important aspect of the vista paradox because without movement, the observer would not have the impression of a continuous change in size of the target. Movement generates optic flow, that is, retinal motion that arises as the observer moves through the environment. Under normal viewing conditions, size constancy works very well when the observer is moving (Gregory & Ross, 1964a, b). The characteristic change of optic flow has been referred to as motion perspective (Gibson, 1979, p. 182f; Gibson, Olum, & Rosenblatt, 1955) for the case of an uncluttered environment and a moving point of observation (Gibson, 1979, p. 227). Gibson (1979) distinguished between outflow (magnification), specifying approach, and inflow (minimization), specifying retreat from the object. The focus or center of outflow specifies the direction of locomotion in the environment, whereas a shift of the center of outflow specifies a change in the direction of locomotion. If the center remains within the same solid angle, unchanged direction is specified (Gibson, 1979, p. 227ff; see also Wang & Cutting, 1999, for alternate invariants). Does the vista paradox scenario cause an error in the interpretation of optic outflow?

Several studies found that subjects were unable to use the center of the expanding flow pattern to judge the direction of self-motion or made heading errors when the flow structure lacked detail (e.g., Li & Cheng, 2013; Regan & Beverley, 1982). Thus, especially when the observer does not focus on the target but on some other more eccentric object, such as the frame, the ensuing difficulties judging self-motion might apply to the vista paradox. The visual impact of the frame, compared to the smaller visual angle of the object behind it, could disrupt the direction of the flow pattern. Because the maximum expansion is on the frame, we expect more outflow for the frame with magnification of the window and less behind the frame with weak magnification of the object, resulting in perceived shrinking. Fixation during locomotion may be a key for the explanation of the vista paradox and affect the magnification rates of objects when fixating the object or the frame. The maximum expansion of the flow pattern might be more associated with the point of fixation than the line of movement when they are slightly separated.

Helmholtz (1925, p. 295) noticed that for a moving observer, more distant objects glide by more slowly than closer objects. Motion parallax in the case of the vista paradox is due to locomotion, and during the approach, the expansion of the window is faster than that of the target. This may cause the impression of a shrinking target in comparison to the window frame. Note, however, that relative size of object versus frame could contribute to such motion effects. For instance, the relative retinal size decrease of the target object relative to the frame may induce illusory observer motion away from the object.

Reinhardt-Rutland (1990) tried to explain the vista paradox with the effect of induced movement, an explanation not entertained by Walker et al. (1989). They postulated induced movement akin to the example when the moon seems to move in a direction opposite to the (moving) clouds during a stormy night (see also the classic demonstration of induced motion by Duncker, 1929). The effect of induced motion depends on the assumption that a larger region of the visual field is less likely to move than the smaller regions (Ross, 1974, p. 127). In the case of the vista paradox, the frame would act as an inducer for its comparatively large retinal speed just as the clouds do in the moon example. Reinhardt-Rutland (1983, 1984) was able to show that induction was most effective when the inducing stimulus surrounded the object, as does the frame in the case of the vista paradox, and that induced movement in depth can be of sizable magnitude (see also Gogel & Griffin, 1982). Thus, if the observer approaching the vista frame sees the static object lose size and gain distance, this could be explained as induced motion in depth.

Color and Contrast

Weale (1975) described the effect of an optical illusion in which judgments of size can vary with contrast: a white figure on a black background appears larger than a black figure on a white background. This contrast effect should be taken into consideration for size estimation. It is essential that frame and object vary as little as possible in color and luminance. Objects in bright colors (white, red, or yellow) are perceived as nearer than darker objects (Allekseenko, 1989). For example, after rain and when the sun is bright, the wet roofs can show vivid colors ordinarily not seen at that range ("How to train your eye to judge distance," (1973) p. 46). This means that color, contrast, and illumination can influence the estimations of distances and sizes. In the case of the vista paradox, such effects might influence not the shrinking itself but perhaps the shrinking rate for several object-background differences. In a more straightforward manner, the vista paradox could be driven by the change in relative size contrast between the object and the frame as illustrated above (see Figure 1 and Table 1). If the retinal size increase is overshadowed by this size contrast, then the illusory shrinking of the object during approach could be understood as a simple contrast effect.

Experimental Hypotheses

On the basis of these insights, we entertain three mechanisms that might explain why size constancy breaks down in the case of the vista paradox: (1) Fixation hypothesis: the frame induces observers to fixate the frame rather than the object, possibly via an attention shift. When fixating the frame, the optic flow field during an approach would place the object toward the periphery and induce different and asymmetric flow on the object compared to the case where the object is the region of fixation. (2) Enclosure hypothesis: the presence of a frame perceptually isolates the object from its background and thus emphasizes the differences between frame and object in terms of their retinal sizes. Enclosure is required for this process, and thus the frame is indispensable for the illusion. (3) Retinal reference hypothesis: the isolation process described in Hypothesis 2 is able to work by mere juxtaposition and does not require enclosure. Note that Hypothesis 3 is a more general version of the same mechanism. In this case, any reference object similar in size and distance to the frame should produce a vista paradox effect. Also note, all three hypotheses spell out necessary but not sufficient conditions for the illusion. In this sense, they are not mutually exclusive.

Overview of Experiments

We report four experiments conducted in a physical environment and designed to differentiate among the three hypotheses. In Experiment 1, we tried to replicate the vista paradox in a controlled laboratory setting using a physical frame. The object behind the frame was a small cube. Surprisingly, most observers did not experience the paradox. In the second experiment, we tested the fixation hypothesis. Fixation of the frame turned out to be crucial for the illusion. In Experiment 3, we varied the shape of the frame to test Hypotheses 2 and 3. Even a small reference object was able to produce the illusion. Finally, Experiment 4 tested the robustness of the fixation hypothesis.

General Method

There are some shared aspects to all four experiments, including the experimental materials (frame, fixation ball) and methods (questionnaire for verbal and size gauge for haptic answering mode). Moreover, we focused on a set of related variables (observer's position, targets, distances, experimental room). Therefore, we introduce the general method and provide an overview of the experimental conditions.

Apparatus. The vista frame is a moveable wooden structure, 240 cm high and 100 cm wide. It has a convertible aperture of 20×20 cm width. The center of the aperture was 175 cm above the ground (see Figure 2). It was covered with black cardboard (above and below the aperture) and a black opaque curtain on both sides (85 cm), extending from the ceiling to the floor and thus occluding the backstage floor and the walls of the corridor.

The experiments were conducted in the Psychology Department of Johannes Gutenberg-Universität Mainz, Germany. The corridor had a length of 1,500 cm and a width of 270 cm. A white curtain was placed in the background at a distance of 410 cm (see Figure 3).

Observer position. The participants were naive to the purpose of the experiments. Each observer was positioned 3 m from the frame at one end of the corridor. After the instructions were given, they walked 2 m in the direction of the frame and stopped 1 m in front of the frame. All participants freely viewed the scene binocularly and were allowed unlimited time for their judgments. They were also allowed to repeat a trial if necessary before answering the questions.

Targets. The targets were presented as textured or as black cardboard cubes of two sizes: 10×10 cm (small) and 14×14 cm (large). The cubes were placed on wooden poles of different heights so that the respective cube was centered in the window of the vista frame (170 cm and 168 cm; see Figure 4).

Texture. Depending on the condition, the frame was either painted black or textured with a black-and-white checkerboard

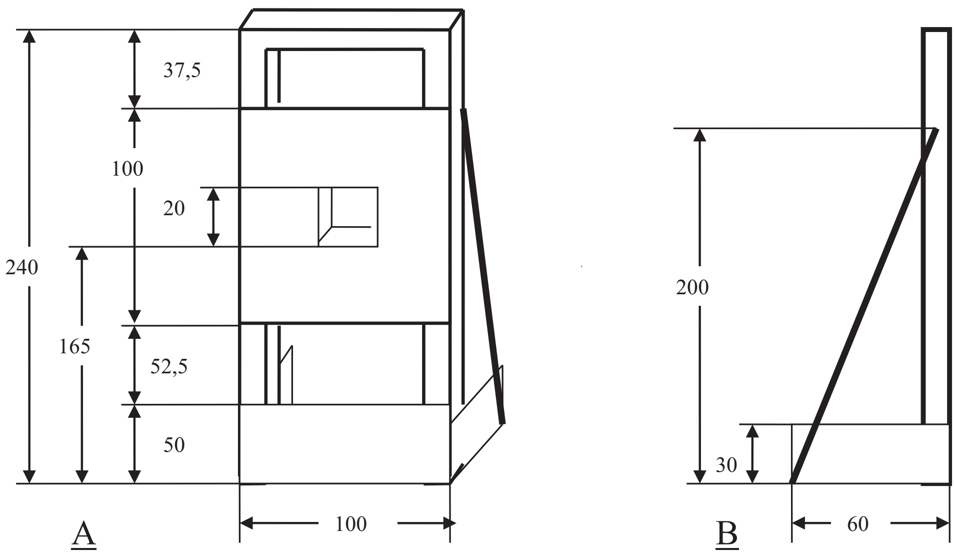

Figure 2. The frame (A: front, B: side view) used to study the vista paradox. All measurements are in centimeters.

pattern (squares of 10 × 10 cm). In the latter case, the 100-cm × 100-cm frame was covered with 96 squares. The cubes were covered with a random dot pattern with 50% black and 50% white squares generated by Microsoft Excel 2010 (a total of 3,969 squares in 63 × 63 rows).

Fixation. Fixation was only relevant for the perceived change estimation when the subject was approaching the frame. For the size and distance estimations of the actual objects, observers always fixated the objects directly. For the direct fixation on the object when approaching the frame, we used no further devices. When the task was to fixate the frame, a small red cardboard triangle was attached to the frame, centered at the bottom of the window. The triangle was attached to the backside of the frame such that merely its tip was visible through the window. The visible part of the triangle in the window was an equilateral triangle with a side length of 1.0 cm, 9.5 cm away from the left and right window sides. Subjects fixated the top of the triangle while approaching. The triangle was removed for object fixation trials. In Experiment 3, when no frame was present, a small sphere served as fixation. It was 2.30 cm in diameter and mounted on top of a pole (height 165 cm), corresponding in position to the middle of the frame in the other experiments.

Distances. The distances of the cubes for all experiments were 135 cm, 270 cm, and 405 cm behind the frame. Salient landmarks were avoided.

Procedure. The subjects were placed 3 m in front of the frame and had to estimate the size and distance (distance estimation: Experiments 1, 3, and 4) of the target verbally and by adjusting the

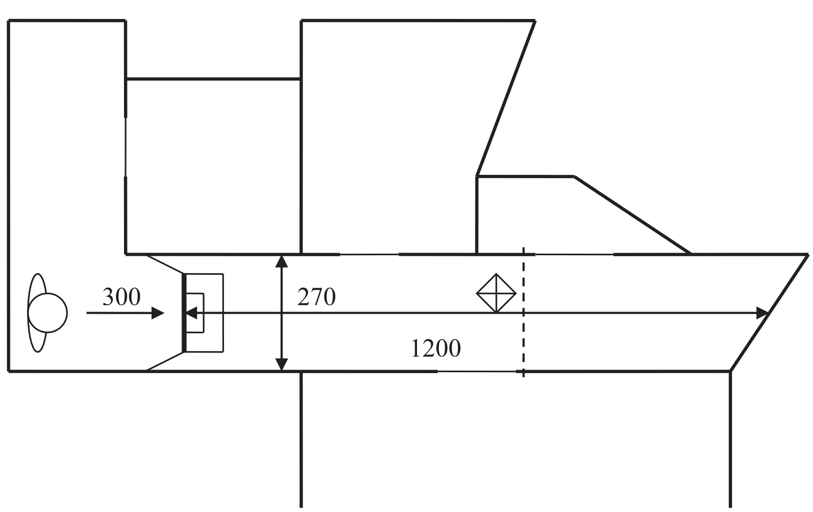

Figure 3. A plan showing the physical environment in which we studied the vista paradox (all measurements are in centimeters).

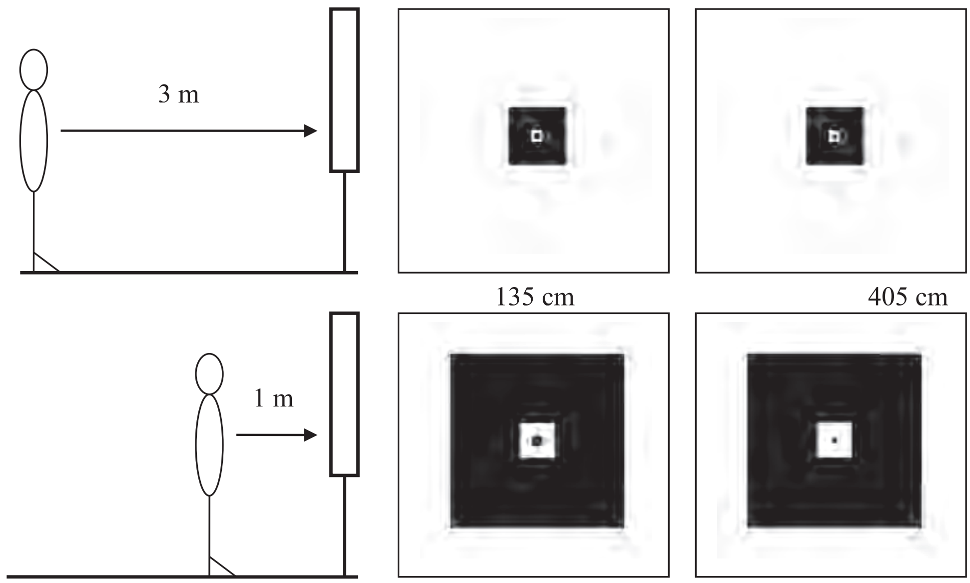

Figure 4. Illustration of the vista frame setup. Panels on the right illustrate the large stimulus (14 × 14 × 14 cm) from the observer's point of view at the starting position (upper panels) and at the stopping position (lower panels, 1 m in front of the frame) for two target distances (left 135 cm, right 405 cm behind the frame).

size on a slide gauge or the distance by moving a miniaturized cube on a map. They also had to estimate the confidence in their estimation and the difficulty of the task on 10-point rating scales. In the next step, they had to move 2 m toward the frame while fixating the object or the frame (fixation condition, except Experiment 1).

After moving toward the frame, subjects were turned around 180° and had to indicate the perceived changes on the slide gauge (size) or the map (distance). They also had to report the perceived change on a six-level rating scale with three subcategories: weak change (1–4), medium change (5–8), or strong change (9–12) for enlargement (positive values) and reduction (negative values). The answers were recorded by one experimenter, while a second experimenter was preparing the next trial. The subjects were allowed to take as long as they needed for their judgment and redo any given trial if necessary but only before releasing their estimations to the experimenter.

The slide gauge for haptic size estimation was closed at the beginning of each trial and to be opened to indicate the perceived size change. It could be opened between 0 and 35 cm. The centimeter value was visible only to the experimenter. For the haptic distance estimation in Experiments 1, 3, and 4, we used a map of the corridor with a schematic drawing of the vista frame and the starting point. The dimensions of the map, except for corridor length (to avoid a fixed-distance cue), were true to scale to compare the results of the map with those of the real floor. For distance estimation, subjects had to place a little black wooden cube (not true to scale for better handling) on the map at the point where they took the real cube to be placed behind the frame. To indicate perceived change of distance, they had to move the cube. The cube was removed from the map after each trial to avoid anchor effects. For the estimation of a perceived change, subjects were forced to make a decision in one direction: enlargement or reduction of object size and distance. If subjects were unable to see a change, they were told to use the minimum of the scale in the preferred direction.

Questionnaire. At the end of the experiment, observers completed a questionnaire to provide information about age, gender, and profession, as well as statements about what they found particularly difficult, whether they were technically skilled, the amount of time spent outdoors, and how accurately they estimated their sense of direction. The last three questions had to be answered by choosing one of five categories. Finally, they were asked whether they had used a strategy for estimating size and distance and whether they had professional expertise in size and distance estimation, such as acquired in some sports or professional training.

Experiment 1: Replication of the Vista Paradox

In the first experiment, we tried to replicate the vista paradox in a real-world setting. We used an indoor setting, and distances were therefore constrained. If the vista paradox is a universal phenomenon, it should arise under conditions that deviate from the original experiment by Walker et al. (1989). To test the robustness of the effect over identical trials, subjects performed two blocks with different random orders of the trials. First, we tested the hypothesis that the perceived target cube appears to shrink, whereas the perceived distance appears to grow. Second, we tested whether this effect would be stronger for larger objects and greater distances.

Method

Observers. Twenty-four observers participated in this experiment. Their ages ranged from 19 to 42 years, with a mean age of 26 years (*SD* = 5.937). Fifteen subjects were female, and nine were male. All had normal or corrected-to-normal vision and were naive with respect to the purpose of the study.

Stimuli and design. The experiment was conducted in a long corridor in the Psychology Institute of the Johannes Gutenberg-Universität Mainz. Three distances (135, 270, and 405 cm) and two target sizes (small: 10 × 10 × 10 cm; large: 14 × 14 × 14 cm) were fully crossed and repeated, resulting in 2 × 6 experimental trials.

Procedure. The subject was placed with his or her back to the vista frame to prevent any advanced view of the experimental arrangement. The subject was first introduced to the procedure and then instructed to the use of the gauge, the map, and the questionnaire. All answers were recorded by the experimenter so that the subject was fully focused on the task. After all questions were answered, the subject was placed 3 m in front of the frame with clear sight to the first object. First, the subject had to estimate the physical size and distance of the target by using the slide gauge for the size and the floor map for the distance estimation. Then the subject moved toward the frame until the experimenter stopped him or her approximately 1 m from the frame. If the subject was ready, he or she turned around and rated perceived size and distance changes. The targets were changed while the subject was turned around. During estimation, the experimenter's assistant was not visible to the subject (hidden behind one of the two curtains).

Results and Discussion

Surprisingly, the vista paradox appeared inconsistently for size and failed completely for distance estimation. Only the large target produced an effect of perceived shrinkage but in nearly all cases only in the second block. In the first block, an enlargement of the target was reported, as would be expected if subjects had used a bigger-nearer heuristic when approaching the frame. The small target was not associated with perceived shrinkage except that targets farther away were estimated smaller than nearer targets. The latter was not the case for the big target in Block 1. The differences between the two blocks were greater in the verbal than in the haptic answering mode (see Figure 5). This means for the size estimation that the vista paradox occurred only for the big target in the second block but was not consistent.

For the distance estimations, we found a strong tendency to report a shortening effect: subjects had the impression of a shortening of distance while approaching the frame. This, again, is compatible with use of a bigger-nearer heuristic. This robust effect was consistent in all conditions (see Figure 6).

Repeated-measures analyses of variance (ANOVAs) with Greenhouse-Geisser correction for the degrees of freedom were conducted with the within-subjects factors distance, target size, and presentation block, separately for the verbal and haptic judgments. The *df*-correction factor ε is reported, as well as partial η^2 as a measure of effect size. The ANOVAs on relative size change estimation (3 levels of distance × 2 levels of target size × 2 levels of repetition) showed a significant effect of block for the verbal, $F(1, 23) = 4.864$, $p = .038$, $\eta_p^2 = 0.175$, $\varepsilon = 1.000$, but not for the haptic answering mode in size estimation, $F(1, 23) = 1.853$, $p = .187$, $\eta_p^2 = 0.075$, $\varepsilon = 1.000$. All other factors failed to reach significance.

For the relative distance change estimation, the ANOVAs (3 levels of distance × 2 levels of target size × 2 levels of repetition) showed a significant effect of target size for the verbal, $F(2, 46) = 4.875$, $p = .037$, $\eta_p^2 = 0.175$, $\varepsilon = 1.000$, as well as for the haptic answering mode, $F(1, 23) = 6.989$, $p = .015$, $\eta_p^2 = 0.233$, $\varepsilon = 1.000$.

To analyze the practice effect, we calculated correlations for the 2 × 6 trials (Pearson's *r*). The correlations for the haptic answering mode on perceived change of size and distance show similar inconsistent results for our retest assumption. There was no consistent pattern of estimations in Blocks 1 and 2. We did not find common answering patterns for the retest stability but also high correspondence for diverse stimuli.

Thus, we could not always find the vista paradox in our laboratory setting. The reason might be the differences between the laboratory arrangement and the original study by Walker et al. (1989). For verbal estimation, there was a trend for perceived shrinking of the targets in the first block but not in the second. We also found a shortening of perceived distance, which is likewise not expected for the vista paradox. The effect was not stable because there was a significant difference between the first and second trials for the verbal answering mode. Namely, for the haptic answering mode, we found a strong tendency of perceived enlargement of distance, independent of the stimuli. The failure to

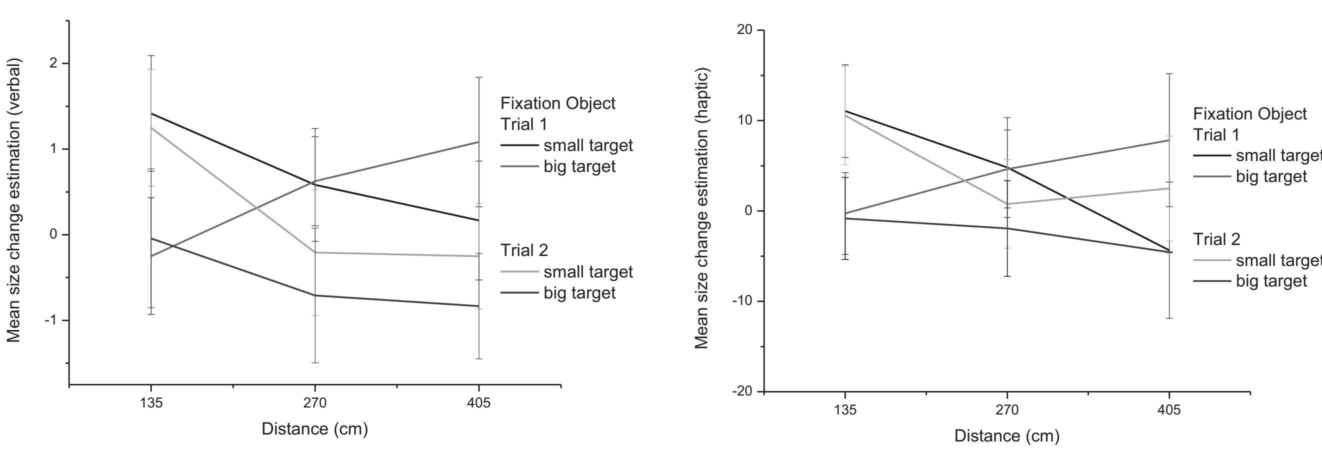

Figure 5. Verbal (left figure) and haptic (right figure) size change estimations. Error bars show the standard error of the mean.

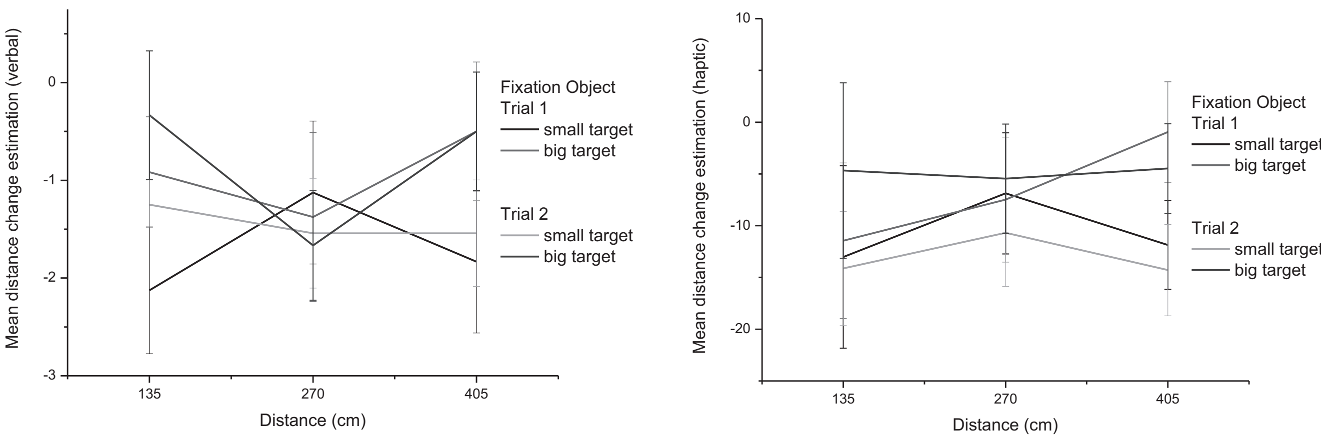

Figure 6. Verbal (left figure) and haptic (right figure) size change estimations. Error bars show the standard errors of the mean.

confirm the vista paradox may be due to our choice of parameters and procedure. In particular, the uniform black color of the objects might not have provided visible texture. Or, the instruction to fixate the object might have induced a somewhat unnatural viewing behavior. We thus manipulated these factors in Experiment 2.

Experiment 2: The Vista Paradox and the Effect of Fixation

The second experiment was designed to test the influence of fixation and texture. We had the impression that fixating the frame produced greater impressions of perceived shrinking of the object compared to fixation on the object while approaching the frame. Furthermore, if texture plays a role by increasing the relative optic flow, textured frame and object should increase the effect (or produce it in the first place). On the basis of these considerations, we tested four hypotheses in Experiment 2. First, fixation on the frame produces more shrinking of the object than fixation on the object. Second, texture on the frame increases the effect of perceived shrinking. Third, the larger the distances, the stronger the vista paradox. Fourth, the vista paradox is stronger for larger target objects.

Method

Observers. Twenty observers participated in this experiment. Ages ranged from 16 to 54 years, with a mean age of 25 years (SD = 8.610). Fifteen subjects were female, and five were male. All had normal or corrected-to-normal vision and were naive with respect to the purpose of the study.

Stimuli and design. Everything in the methods and procedures was the same as in Experiment 1 unless specified. We used the three distances (135, 270, and 405 cm), the same two target sizes as before (small: 10 × 10 × 10 cm; large: 14 × 14 × 14 cm), and two kinds of texture for the cubes as well as for the frame (black-white checkered texture or black cardboard), which were fully crossed, resulting in 48 experimental trials.

Procedure. The procedure was the same as in Experiment 1, except that we did not ask for distance estimation. After the 24th trial, the frame texture was changed in a randomized order. Subjects were instructed to wait in a side corridor during the experimental modification. After the new frame was in position, the 25th trial started. After both parts were completed, subjects had to complete the questionnaire and were debriefed about the purpose of the experiment.

Results and Discussion

The manipulations worked and show that fixation of the frame is critical for the vista paradox to work under our experimental conditions. Target size appeared to shrink as observers approached (see Figure 7). This effect was substantial when the observers fixated the frame, both in the verbal and especially in the haptic answering mode. This result confirms that fixation is a key variable for perceived shrinking in the vista experiment. Contrary to the first experiment, there was a tendency for perceived shrinking when fixating the small object at the 405-cm distance and even more so for the large target at all distances. However, fixation on the frame produced much larger effects for all target sizes and all distances. Texture on the frame also increased the apparent shrinking of the target, mostly so for large objects and greater distances, whereas texture of the cubes did not influence the effect.

Repeated-measures ANOVAs using Greenhouse-Geisser correction for the degrees of freedom were conducted with the within-subjects variables distance, target size, fixation, frame texture, and object texture. The df-correction factor ε is reported as well as partial η^2 as a measure of effect size. The ANOVAs on relative size change estimation (3 levels of distance × 2 levels of target size × 2 levels of fixation × 2 levels of target texture × 2 levels of frame texture) showed significant effects for distance, $F(2, 38) = 12.331$, $p = .001$, $\eta_p^2 = 0.394$, ε = 0.693; target size, $F(1, 19) = 8.375$, $p = .009$, $\eta_p^2 = .306$, ε = 1.000; fixation, $F(1, 19) = 24.126$, $p < .001$, $\eta_p^2 = 0.559$, ε = 1.000; and frame texture, $F(1, 19) = 6.243$, $p = .022$, $\eta_p^2 = 0.247$, ε = 1.000. This occurred for the verbal as well as for the haptic answering mode: distance, $F(2, 38) = 11.083$, $p < .001$, $\eta_p^2 = 0.368$, ε = 0.849; target size, $F(1, 19) = 5.128$, $p = .035$, $\eta_p^2 = 0.213$, ε = 1.000; fixation, $F(1, 19) = 17.211$, $p = .001$, $\eta_p^2 = 0.475$, ε = 1.000; and frame texture, $F(1, 19) = 8.961$, $p = .007$, $\eta_p^2 = 0.320$, ε = 1.000. The texture of the

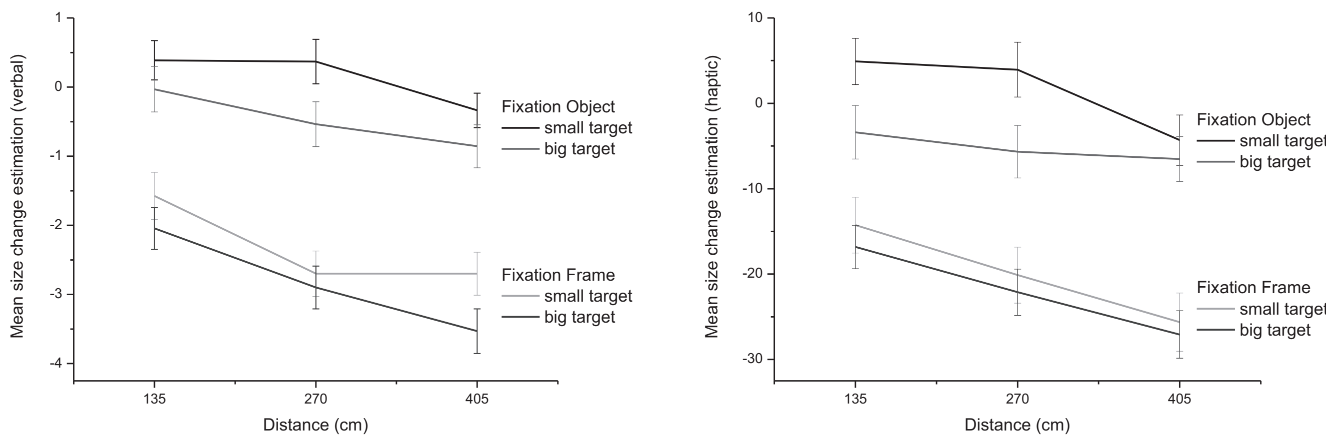

Figure 7. Mean verbal (left figure) and haptic (right figure) size change estimations. Error bars show the standard error of the mean.

object did not reach significance in either answering mode, which indicates that it was not relevant for the perceived size change.

A small interaction effect of frame texture, distance, object texture, and target size could be found for the verbal, $F(2, 38) = 3.748$, $p = .033$, $\eta_p^2 = 0.165$, $\varepsilon = 0.833$, and the haptic answering mode, $F(2, 38) = 4.962$, $p = .014$, $\eta_p^2 = 0.207$, $\varepsilon = 0.937$. All other factors failed to reach significance.

Our hypothesis of fixation was confirmed: fixating the frame led to an apparent shrinking of the target, whereas fixation on the target did not. This shows the modulating effect of the point of fixation for the vista paradox in our experimental arrangement. This effect tends to be even stronger for larger targets and greater distances. For our frame, the texture was dominant in comparison to the cube texture, which indicates that texture on the cubes was irrelevant, perhaps even only perceived as uniform gray rather than as a textured surface.

Experiment 3: Manipulating the Frame

Now that we have established the importance of fixation in the vista paradox, the question arises if the paradox is due to a contrast between the optical flow produced by the near object (frame) compared to the far object (cube) or if it takes a frame surrounding the object to produce the effect. If the contrast is critical, we should obtain a vista effect with half a frame and even when replacing the frame with a small contrast object placed at the frame's location. For this reason, we separated the subjects of our next experiment into three groups who viewed the targets under three different conditions: (a) the vista frame was used as in the previous experiments, (b) a half-frame version of the vista frame was used, and (c) a small fixation ball on a pole replaced the frame. We generated two hypotheses. First, fixation on the ball—independently from the surrounding frame condition—leads to a greater effect of perceived shrinking of the cube than fixation on the cube. Second, if the effects of framing and contrast are additive, the greatest shrinking effect should be produced by the combination of the vista frame and the fixation in front.

Method

Observers. Ninety-six observers participated in this experiment (68 females). Ages ranged from 18 to 53 years, with a mean age of 25 years ($SD = 6.245$). All had normal or corrected-to-normal vision and were naive with respect to the purpose of the study. For the single blocks, we had 32 subjects for each condition.

Stimuli and design. The experiment was conducted in the same laboratory as in Experiment 1. As before, three distances (135, 270, and 405 cm) and two target sizes (small: $10 \times 10 \times 10$ cm; large: $14 \times 14 \times 14$ cm) were fully crossed and repeated with two different points of fixation (fixation on the object vs. fixation on the ball), resulting in 2×6 experimental trials. The essential addition consisted of two new trial blocks (between subjects). The first block was identical to the previous vista experiments: we used the vista frame. In the second block, we used half a frame, which was a cutoff version of the vista frame. That is, the top of the frame was cut off so that no window was present. The resulting space of 85 cm on each side between the frame and the walls of the corridor was covered by a black, opaque curtain, extending from the frame's top to the floor in front to entirely occlude the background. In the third block, we used only a fixation ball on a pole without a frame. For each block, we ran six trials with fixation on the target and the following six trials with fixation on the fixation ball. Half of the fixation trials started with fixation on the object and half with fixation on the fixation ball to avoid effects of presentation order.

Procedure. The procedure consisted of the same random assignment to three groups, with the exception that the first three subjects in each block started with fixation on the object, the next three subjects with fixation on the fixation ball, and so forth until each block was filled with 32 subjects. In the fixation conditions, the fixation ball was present at all times: in front of the vista frame or the half-frame and also by itself in the no-frame condition. Similar to Experiment 1, the subject had to estimate the physical size and distance of the target verbally and haptically using the gauge for size and the map for distance estimation. All targets were presented individually in randomized orders. As before, the subjects turned around when the stimuli were changed, and they had to complete the questionnaire at the end.

Results and Discussion

We found the fixation effect both in the vista frame condition and in the fixation ball condition for almost all object sizes and all distances for the verbal estimations and the haptic adjustment mode. The half-frame produced inconsistent results for the 135-cm distance but also an overall effect of perceived shrinkage of object size for fixation on the fixation ball, whereas fixation on the object did not produce an effect in any frame condition (see Figure 8 for the verbal and Figure 9 for the haptic answering mode). Fixation on the object led to a perceived enlargement of object size and diminishment of distance. Thus, the frame per se had no additional effect on the illusion, contrary to what Walker et al. (1989) would have predicted. The vista paradox does not depend on the frame but rather on the presence of a contrast object upon which the observer fixates.

We could confirm our hypothesis that fixation is the key for a perceived shrinking of an object while approaching. Verbal distance estimation produced results that were compatible with the size estimation for the verbal and the haptic answering mode. The effect of perceived shrinking of the object, as well as related growth of subjective distance, was obtained for fixation on the fixation ball for all frame conditions but not for the direct fixation of the object. For fixating the object, we found an opposite effect: reduction of perceived distance combined with a growth in size of the object. Also, the order of the conditions (fixation on the object or on the ball first) had no influence on the shrinkage of the object.

Repeated-measures ANOVAs using a Greenhouse-Geisser correction for the degrees of freedom were conducted with the within-

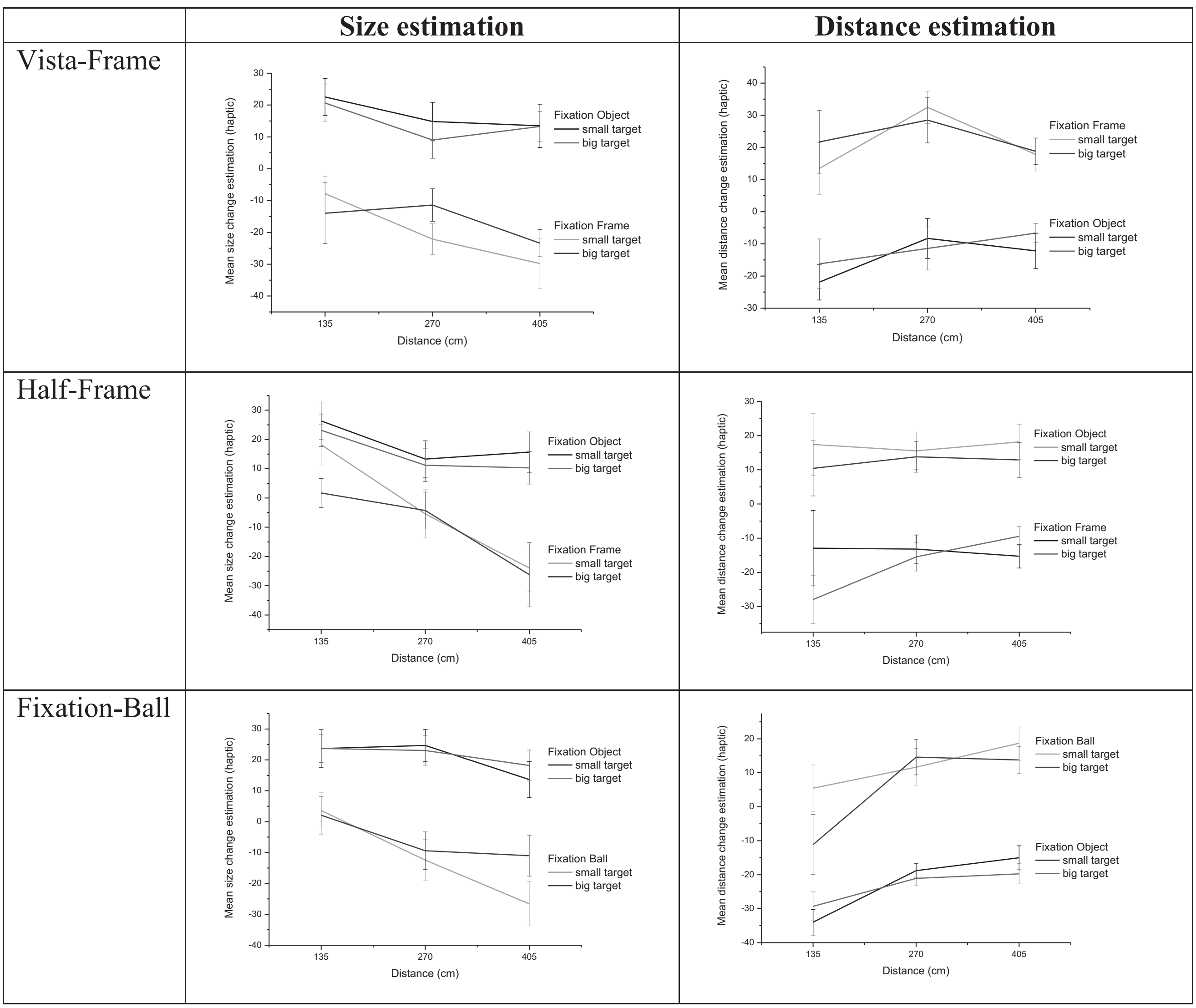

Figure 8. Verbal size and distance change estimations for vista frame, half-frame, and fixation ball. Error bars show the standard error of the mean.

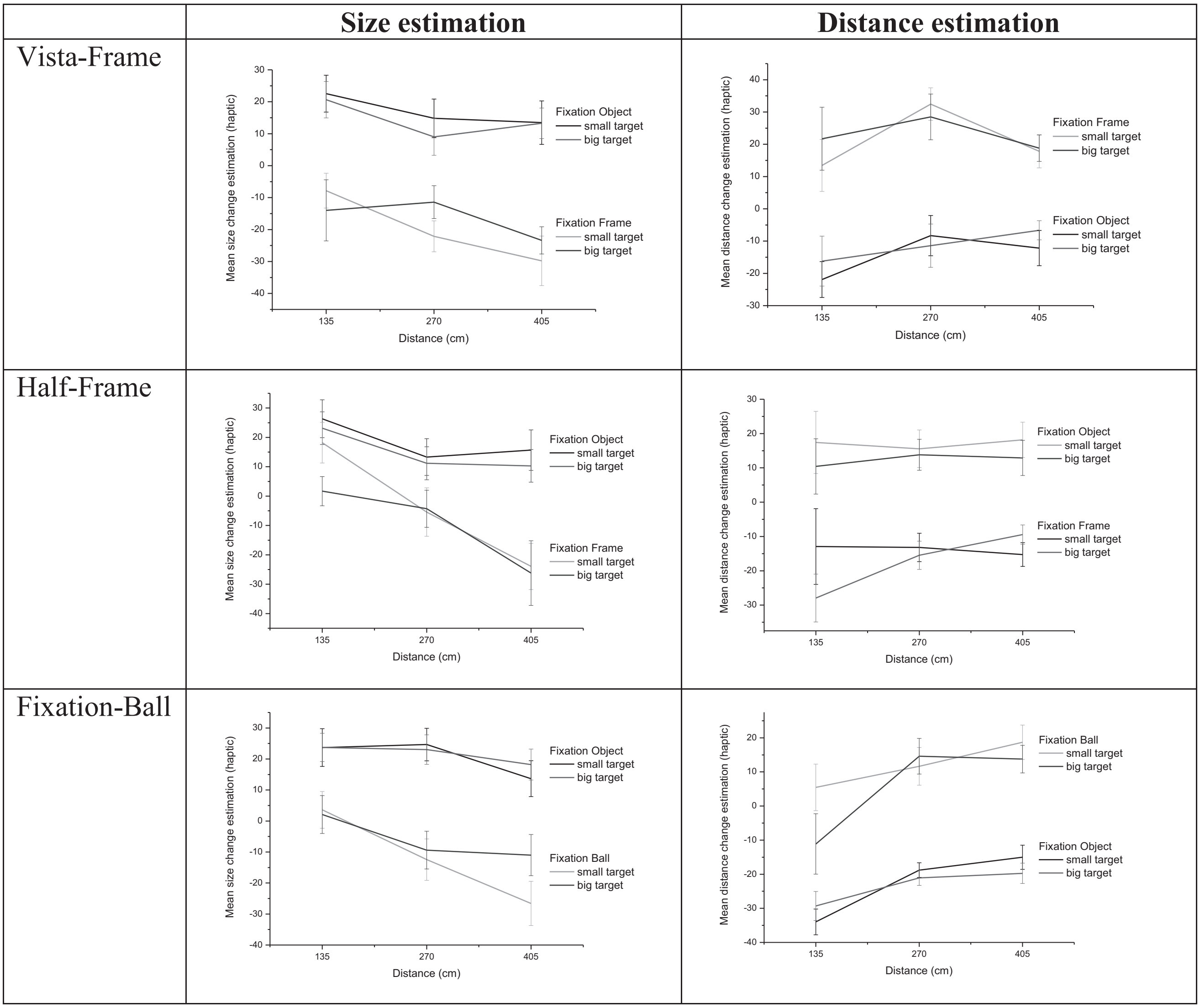

Figure 9. Haptic size and distance change estimations for vista frame, half-frame, and fixation ball. Error bars show standard errors of the mean.

subjects variables distance, target size, and fixation, as well as the between-subjects variable frame condition. The *df*-correction factor ε is reported as well as partial η^2 as a measure of effect size. For the verbal answering mode on size change estimation, the ANOVA (3 levels of distance × 2 levels of target size × 2 levels of fixation × 3 levels of frame condition) showed significant effects for distance, $F(2, 180) = 71.110$, $p < .001$, $\eta_p^2 = 0.441$, $\varepsilon = 0.936$, and fixation, $F(1, 90) = 95.641$, $p < .001$, $\eta_p^2 = 0.515$, $\varepsilon = 1.000$. For the relative distance change estimation, the ANOVA showed significant effects for distance, $F(2, 180) = 39.961$, $p < .001$, $\eta_p^2 = 0.307$, $\varepsilon = 0.852$, and fixation, $F(1, 90) = 56.997$, $p < .001$, $\eta_p^2 = 0.388$, $\varepsilon = 1.000$. We also found a sizable interaction of fixation × distance for both the relative size change estimation, $F(2, 180) = 13.583$, $p < .001$, $\eta_p^2 = 0.131$, $\varepsilon = 0.991$, and the relative distance change estimation, $F(2, 180) = 7.873$, $p = .001$, $\eta_p^2 = 0.080$, $\varepsilon = 0.990$. The order of fixation as a between-subjects factor was not significant for relative size or relative distance change estimation. The frame condition was significant for relative size, $F(2, 90) = 3.432$, $p = .037$, $\eta_p^2 = 0.071$, and relative distance change estimation, $F(2, 90) = 6.733$, $p = .002$, $\eta_p^2 = 0.130$. A Scheffé post hoc analysis for verbal distance change estimation (see Table 2) showed that the vista frame condition differed significantly from the condition without frame ($p = .002$)—there were no significant differences between the half-frame and the other conditions. For the haptic answering mode, we found no significant differences of distance change estimation between the frame conditions (vista frame vs. half-frame vs. fixation ball; table). However, for the relative distance change estimation in the haptic answering mode, we found that the vista frame condition differed significantly from the condition without frame (vista frame vs. no frame, $p = .003$). There were no significant differences between the half-frame and the other conditions.

For the haptic answering mode, the ANOVA on relative size change estimates (3 levels of distance × 2 levels of target size ×

Table 2
Scheffé Post Hoc Analysis: Mean for Groups in Homogeneous Subtests

Frame condition	N	Verbal distance change estimation, subtest 1	Verbal distance change estimation, subtest 2	Haptic distance change estimation, subtest 1	Relative haptic distance change estimation, subtest 1	Relative haptic distance change estimation, subtest 2
No frame	32	−.5391		7.8716	−.0708	
Half-frame	32	.0182	.0182	8.0656	−.0050	−.0050
Vista frame	32		.6406	9.4086		.0467
p value		.228	.160	.133	.141	.265

2 levels of fixation × 3 levels of frame condition) confirmed significant effects for distance, $F(2, 180) = 30.817$, $p < .001$, $\eta_p^2 = 0.255$, $\varepsilon = 0.966$, and fixation, $F(1, 90) = 46.085$, $p < .001$, $\eta_p^2 = 0.339$, $\varepsilon = 1.000$. For the relative distance change estimation, the ANOVA also showed significant effects for distance, $F(2, 180) = 12.068$, $p < .001$, $\eta_p^2 = 0.118$, $\varepsilon = 0.812$, and fixation, $F(1, 90) = 93.374$, $p < .001$, $\eta_p^2 = 0.509$, $\varepsilon = 1.000$. For the haptic answering mode, we also found a large effect of fixation × distance for relative size change estimation, $F(2, 180) = 7.242$, $p = .001$, $\eta_p^2 = 0.074$, $\varepsilon = 0.978$, but not for relative distance change estimation. For the relative size change estimation, we also found an interaction effect of fixation × distance, whereas the interaction effects for the relative distance change estimation are fixation × block and distance × block. Also, the sequence of fixation as a between-subjects factor failed to reach significance for relative size, $F(1, 90) = 3.019$, $p = .086$, $\eta_p^2 = 0.032$, and relative distance change estimation, $F(1, 90) = 3.821$, $p = .054$, $\eta_p^2 = 0.041$. Unlike with the verbal answering mode, the frame condition also failed to reach significance for the relative size, $F(2, 90) = 1.978$, $p = .144$, $\eta_p^2 = 0.042$, but not for the relative distance change estimation, $F(2, 90) = 6.423$, $p = .002$, $\eta_p^2 = 0.125$. All other factors were nonsignificant.

Fixating a location closer than the object (frame or a fixation ball) led to a perceived shrinking of the object. In contrast to Experiment 2, where fixation on the large target was indicative of a vista paradox, fixation on the target in Experiment 3 always resulted in a perceived growth of the object and a diminishment of its distance. Fixation of the ball, in contrast, produced a subjective recession of the object. Although the effect of the frame was disappointingly small, it seems that the frame did amplify the impression of growing distance during ball fixation. In the same vein, it minified the impression of approach during target fixation. This might explain the absence of the vista paradox in Experiment 1, because fixation on the frame might have cancelled the effect produced when fixating the object. When subjects were adapted to the strong effect of perceived shrinking when fixating the frame, they may have overlooked the smaller shrinking effect of the object in the vista frame condition when directly fixating the object. If this effect is noticeable, it should have appeared in the trials with the vista frame, which means using the vista frame and starting with fixation on the object first, before subjects got an impression of the fixation effect. However, on average, we did not find any perception of shrinking in any condition with fixation on the object in the present experiment, so we can say even the strong conditions for the vista paradox did not show the effect. Note that for the condition without a frame, the resulting view of the corridor walls, ceiling, and floor might have given the impression of a huge frame window (240 × 270 cm). The effect for the half-frame could be less effective (140 × 270 cm).

Experiment 4: The Robustness of the Fixation Effect

In Experiment 4, we tested whether the fixation effect is robust or whether it is ephemeral and wears off with repeated viewing. To do so, we ran the procedure twice. With instructions to fixate the reference object in front, the vista paradox should be strong in both blocks, if the effect is replicable. Also, the perceived object should seem to shrink independently of its size or distance behind the window, whereas perceived distance should grow correspondingly. We expected this effect to be stronger for larger objects and greater distances.

Method

Observers. Twenty-four observers participated in this experiment (16 female). Ages ranged from 18 to 33 years, with a mean age of 24 years ($SD = 3.223$). All had normal or corrected-to-normal vision and were naive with respect to the purpose of the study.

Stimuli and design. The experiment was conducted in the same laboratory of the Johannes Gutenberg-Universität Mainz. Three distances (135, 270, and 405 cm) and two target sizes of small (10 × 10 × 10 cm) and large (14 × 14 × 14 cm) were fully crossed and repeated, resulting in 2 × 6 experimental trials.

Procedure. The experimental procedure was the same as that of Experiment 1. The only difference was the fixation. Subjects in this experiment had to fixate the small ball that was attached to the frame.

Results and Discussion

The relative size change estimation shows a perceived shrinking of the target in both haptic and verbal answering mode (see Figure 10). Analogously, the relative distance change estimation shows an increase in perceived distance for all conditions (see Figure 11). The effect of perceived shrinking grows over the three distances for both answering modes and was similar in the replication trials of Block 2. Target size had no effect on the perceived shrinking.

Repeated-measures ANOVAs using a Greenhouse-Geisser correction for the degrees of freedom were conducted with the within-subjects factors distance, target size, and presentation block. The *df*-correction factor ε is reported as well as partial η^2

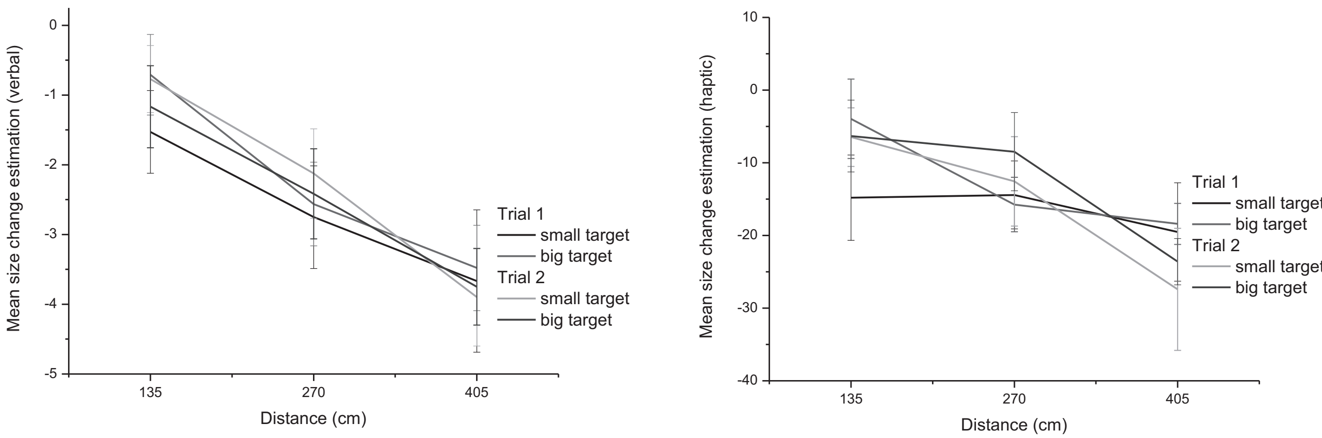

Figure 10. Verbal (left figure) and haptic (right figure) size change estimations. Error bars show the standard error of the mean.

as a measure of effect size. The ANOVA on relative size change estimation (3 levels of distance × 2 levels of target size × 2 levels of repetition) showed a significant effect of distance for the verbal, $F(2, 46) = 26.509$, $p < .001$, $\eta_p^2 = 0.535$, $\varepsilon = 0.857$, and the haptic, $F(2, 46) = 12.735$, $p < .001$, $\eta_p^2 = 0.356$, $\varepsilon = 0.961$, answering mode in size estimation. All other factors failed to reach significance.

For the relative distance change estimation, the ANOVA (3 levels of distance × 2 levels of target size × 2 levels of repetition) confirmed a significant effect of distance only for the verbal answering mode, $F(2, 46) = 7.269$, $p = .004$, $\eta_p^2 = 0.240$, $\varepsilon = 0.826$.

Consistent with our hypotheses, we found a robust effect of perceived shrinking of the object when the point of fixation was held on the vista frame in both blocks for the verbal and the haptic answering mode. For perceived change of distance, we found a consistent enlargement, which is expected when a reduction of perceived object size is the dominating effect. The correlations show that these estimations are not consistent over the two trials, which means that subjects' judgments of perceived change of size and distance vary. Overall, we can say that the vista paradox can be evoked when fixation is on the level of the frame and that this effect is robust. Thus, the vista paradox does not arise as a function of previously viewed objects, but it arises consistently as long as fixation is maintained on the frame (or reference object) in front of the object to be judged in size and distance.

General Discussion

The vista paradox is a fascinating phenomenon in which size and distance appear to change for objects that are not changing in either size or position and that are seen in a rich and unambiguous spatial context. The effect as described by Walker et al. (1989) requires the observer to move toward a window. To explore the conditions for the effect, we used a purpose-built window aperture, a long corridor, and a target object. Experiment 1 failed to reproduce the effect with free viewing, despite a layout similar to that used by Walker et al. Based on this failure to replicate, we have tried to find the conditions for the illusion by entertaining three hypotheses. In Experiments 2–4, we were then able to replicate the illusion for certain conditions in which fixation is controlled.

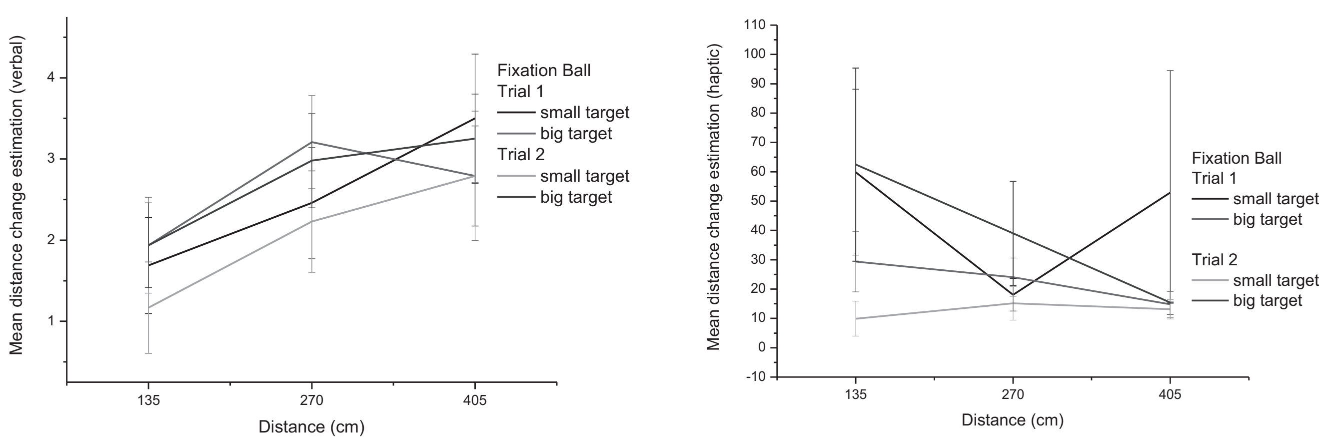

Figure 11. Verbal (left figure) and haptic (right figure) distance change estimations. Error bars show the standard error of the mean.

Evaluation of the Hypotheses

The fixation hypothesis, the enclosure hypothesis, and the retinal reference hypothesis each focus on a different factor that might be required for the illusion. In Experiment 2, we tested the fixation hypothesis and instructed observers where to fixate. Fixating the frame led to a perceived shrinking of the target, whereas fixation on the target did not, and this effect was stronger for larger targets and greater distances. Thus, fixation outside the object of interest is a necessary condition for the illusion to arise. Experiment 3 tested whether the frame is necessary for this process. This enclosure hypothesis was clearly refuted. The illusion was maintained for a partial frame and also for a mere reference object as long as these were fixated. Therefore, the vista paradox does not require a frame but rather the presence of a reference object upon which the observer fixates. Thus, the more general retinal reference hypothesis has to be preferred over the more specific enclosure hypothesis. Finally, Experiment 4 replicated the necessary role of fixation, confirming a perceived shrinking of the target in both haptic and verbal answering mode, as well as an increase in perceived distance. The illusion was stable from a first to a second block.

Further Necessary Conditions

Is observer movement necessary for the illusion? We would argue that it is. If we just take snapshots, the mere comparison between stationary frame and stationary object will not give rise to the illusion. We do not report a direct test of this contention; however, when piloting the study, we did use stationary judgments and were not able to detect an effect. It appears that motion is involved in the vista paradox, at least to the extent that the illusion becomes salient when the undue "shrinking" of the object is observed when approaching the window frame. Note that the underlying concept of illusion is one where a mere discrepancy between percept and stimulus is not sufficient; instead, the discrepancy has to be noticed by the observer (for a discussion of such manifest illusions vs. mere errors, see Hecht, 2015).

Is movement sufficient for the illusion? Reinhardt-Rutland (1990) seems to suggest that it just may be so. According to him, the relatively large (retinally speaking) frame serves as a background for the relatively small object, which is judged to move in relation to this background. If this motion induction by the retinal motion difference between frame and object were responsible for the illusion, then a mere fixation dot should not suffice to make this motion difference salient. Note, however, that the retinal size relation between object and frame does also change. When approaching, the relative area of the object diminishes. Thus, the induced motion hypothesis is unlikely. An experiment with stationary stimuli—once farther from the object and once closer up—would have to be conducted to entirely rule out this explanation.

Is a large-scale environment required for the illusion? It is likely that the effect of loss of size constancy is not specific to large-scale environments. We were able to reproduce the effect informally by holding up our own thumbs (with extended arms) and fixating them while gauging an object in the background: movement of the fixated thumb toward the eyes (monocular and binocular) produces the effect of shrinking objects in the visual background. It is rather easy to explain how the vista paradox arises in diminished environments. Just as size constancy breaks down when distance cues are removed or lighting becomes inadequate (e.g., Holway & Boring, 1940), the retinal size relations between object and frame may dominate the percept. Note, however, that it is hard if not impossible to attend to these retinal size relations (see, e.g., Bertamini & Parks, 2005). However, why does the vista paradox arise in a rich visual context where size constancy normally holds up nicely?

Comparison With Previous Studies

We had chosen to conduct our experiments in a real-world setting that allows for maximal stimulus control. Thus, moving to an indoor laboratory entailed that we were not able to use the same scale as the large outdoor environment used by Walker et al. (1989). This resulted in smaller visual angles, and we need to evaluate if this difference might challenge any direct comparisons. Whereas the array of the flagpoles used by Walker et al. subtended visual angles of 6.1° horizontally × 9.1° vertically at the maximum, as well as 6.5° × 9.6° at the minimum viewing distance, the visual angles in our laboratory setting were 0.81° × 0.81° for the small and 1.84° × 1.84° for the large cubes at the maximum, as well as 1.13° × 1.13° for the small and 3.41° × 3.41° for the large cubes at the minimum distance of 1 m in front of the frame (see Table 3). In the original study, the window subtended 8.5° × 10.1° horizontally and vertically at the distance of 3.5 m and approached 180° at the minimum distance. In our study, the visual angle of the aperture was 3.82° × 3.82° for the maximum and 11.42° × 11.42° for the minimum distance. Because we were able to find and replicate the vista paradox effect, its underlying mechanism has to be of rather general nature and is not limited to large-scale outdoor viewing environments.

Table 3
Differences of the Actual Replication in the Physical Conditions and Dimensions Compared With the Original Study by Walker et al. (1989)

	Distance start (m)	Distance end (m)	Width (m)	Height (m)	Angle start (°)	Angle end (°)
Original						
Flagpoles	65.5 + 3.5	65.5	2 × 3.7 = 7.4	11	6.1 × 9.1	6.5 × 9.6
Window	3.5	0	.52	.61	8.5 × 10.1	180 × max
Replication						
Cubes S[a]	3 + 4.05	1 + 4.05	.1	.1	.81 × .81	1.13 × 1.13
Cubes L[b]	3 + 1.35	1 + 1.35	.14	.14	1.84 × 1.84	3.41 × 3.41
Aperture	3	1	.2	.2	3.82 × 3.82	11.42 × 11.42

Note. The dimensions of the window are taken, whereas Table 1 reflects the entire frame.
[a] Smallest cube at largest distance. [b] Largest cube at shortest distance.

Conclusion

It appears that the vista paradox—at least as studied in our laboratory environment—is a contrast illusion in which size constancy fails. We have entertained three hypotheses, which describe potential conditions necessary for the illusion. The fixation hypothesis holds that fixating the frame (or a reference object) is necessary. This was indeed the case. Fixation is of critical importance for the vista paradox. The enclosure hypothesis holds that the illusion arises only when the target object is surrounded by a frame. We refuted this hypothesis. A mere small reference object was sufficient to produce the illusion if observers fixated this object. This result favors the retinal reference hypothesis. It remains to be seen if fixation on a virtual point outside the target object might suffice to produce the illusion or if a physical reference object has to present as an anchor. It also remains to be seen if observer movement is required for the illusion or whether movement is only the best way to maximize the paradoxical experience of a loss of size constancy.

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