Effects of 3-D complexity on the perception of 2-D depictions of objects

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Abstract. In a recent study, Pelli (1999 Science 285 844–846) performed a set of perceptual experiments using portrait paintings by Chuck Close. Close’s work is similar to the ‘Lincoln’ portraits of Harmon and Julesz (1973 Science 180 1194–1197) in that they are composite images consisting of coarsely sampled, individually painted, mostly homogeneous cells. Pelli showed that perceived shape was dependent on size, refuting findings that perception of this type is scale-invariant. In an attempt to broaden this finding we designed a series of experiments to investigate the interaction of 2-D scale and 3-D structure on our perception of 3-D shape. We present a series of experiments where field of view, 3-D object complexity, 2-D image resolution, viewing orientation, and subject matter of the stimulus are manipulated. On each trial, observers indicated if the depicted objects appeared to be 2-D or 3-D. Results for face stimuli are similar to Pelli’s, while more geometrically complex stimuli show a further interaction of the 3-D information with distance and image information. Complex objects need more image information to be seen as 3-D when close; however, as they are moved further away from the observer, there is a bias for seeing them as 3-D objects rather than 2-D images. Finally, image orientation, relative to the observer, shows little effect, suggesting the participation of higher-level processes in the determination of the ‘solidness’ of the depicted object. Thus, we show that the critical image resolution depends systematically on the geometric complexity of the object depicted.

1 Introduction
In 1973 Harmon and Julesz published a benchmark vision science article on the nature of masking in recognition (Harmon and Julesz 1973).(1) Their block portrait of Lincoln has become a staple demonstration with which every student of visual perception is familiar. Subsequent researchers have posited explanations of this type of masking phenomena (cf Legge and Foley 1980; Marr 1982; Marr and Hildreth 1980), and the Lincoln image so inspired painter Salvador Dali that he reinterpreted it in his Gala Contemplating the Mediterranean Sea: Lincoln in Dalivision during the classic period of his later career (Dali 1977).(2)

In a recent Science article, Pelli (1999) performed an ecological-spirited experiment at an exhibit of the work of painter Chuck Close (see figures 1 and 2). Close’s paintings are portraits executed with traditional photorealistic techniques but deliberately re-sampled at a variety of coarse resolutions in a style similar to the Harmon and Julesz Lincoln. Pelli’s experiment was designed to investigate the relationship between one size of an image, the relative size of its constituent image elements, and their interactive effect on the perception of the shape of the depicted object. The results showed that, as the portrait subtends a larger angle on the retina, more detail (in terms of spatial resolution of the picture elements) is needed to perceive the intended subject as being ‘3-D’ rather than a collection of colored markings on a flat plane. The results of Harmon and Julesz (1973), who used a more limited range of element and image sizes, showed that the eventual perception of shape is mitigated by fixed, retina-centric spatial-frequency channels.

(1) Upon re-reading of this work it is humbling to consider the acrobatics that Harmon and Julesz had to perform to create their stimuli. Even more so in light of the ease with which one can perform the same task these days, with a simple menu selection in Photoshop.

(2) Though one might find it difficult to interpret ‘classic’ in this particular case.
This size invariance would imply that there is some amount of detail needed per portrait image, regardless of viewing distance. Pelli’s results counter those of Harmon and Julesz showing that the size has an effect, both that of the image and that of the grid element. This further suggests that the spatial-frequency channels responsible in these cases are not fixed at the resolution of the retinal image, but rather are scale-dependent (Pelli 1999).

Since the images used in these experiments consisted exclusively of portraits, one might well wonder if the subject matter might have had some effect on the findings. Could the scale effect be due to some differential processing mechanism used with faces (cf Farah et al 1998) or does this effect generalize across other types of stimuli? If faces possess some sort of privileged representation or if they activate special perceptual mechanisms, then we might expect them to enjoy some form of differential processing with respect to other classes of objects. For example, it is well known that newborns will orient their attention toward simple face-like schematic arrangements of dots on a head-shaped cutout but not toward configurations that are less face-like
(Johnson and Morton 1991). This would indicate that the mechanism for face recognition is extremely tolerant of limited information and that the results for face stimuli used by Pelli et al might be biased by this tolerance.

In addition, we are interested in the effect the 3-D geometric structure of the depicted object has on these phenomena. Insofar as the portraits are concerned, the 3-D geometry of the subject matter has rather low-frequency features with amplitudes that rarely exceed the size of one wavelength (i.e., the width and depth of the human nose are roughly similar). In Close's paintings the cell size (visual image resolution) is almost always well above the Nyquist requirements for accurate reconstruction of the information needed for shape-from-shading theories (Norman et al 1995). Obviously this does not need to be the case all of the time. On a computer or video monitor, the size of a depicted object may subextend only a handful of discrete picture elements. Still, in general, objects depicted in the far background of such displays do not usually appear to be totally flat. One rarely mistakes a distant, geometrically complex object, such as a tree, as being flat when depicted in this manner, despite the highly impoverished stimulus information.

In the following experiments we systematically investigated the possible contributions and interactions of 2-D image information and 3-D geometric information on the perception of 3-D shape. In the first experiment we examined the potential bias of content (i.e., faces), in the second the relative effects of geometric complexity, and in the third the viewpoint-dependence of these phenomena.

2 Experiment 1

If the number and scale of picture elements, interacting with their distance from the viewer, affect the perception of shape, then one might reasonably ask if there are additional factors, inherent in the 3-D geometric structure of the depicted object, that contribute to this phenomenon. Our initial experiment was designed to systematically replicate the findings of Pelli and to investigate the role of subject matter in the images. For this initial experiment we chose to use three classes of stimuli—portraits, ecological scenes, and artificial objects.

Portraits were used primarily to determine if our simulation of Close's painting style (see section 2.1.1 below) was sufficient to recreate the effect found in Pelli's research. Since there is significant evidence to support the ideas that faces are somehow given privileged representation in our perceptual systems, we were curious if the effect would be replicated across stimuli other than faces.

Ecological scenes, including exterior and interior images featuring both natural and man-made objects, were included as a second stimulus class. This was primarily to gain an understanding of the role of the type of object being depicted on its eventual perception. If the 'faces are special' theory is true in this context, we would expect to see an advantage for them in our results. Conversely, if faces do not possess an a priori advantage, we would expect to see similar performance across classes. However, this may or may not be true, depending on the total geometric complexity of the depicted object. Elementary sampling theories show that there is at least some minimal amount of information needed to fully reconstruct a signal of some given frequency. In this case the lowest-frequency information is likely to be sufficient to simply detect the presence or absence of the entire object. It is also very likely that, for many classes of objects this low-frequency information is completely diagnostic for identification purposes. For example an octagonal 'STOP' sign can be identified easily with a minimal amount of information as is obvious from computer-icon representations.

Finally, artificial objects were used to remove any cognitive bias or advantage that ecological scenes and faces might possess. The artificial-object stimuli are far less likely to be recognized by some privileged brain subsystem or via a learning paradigm, since
they are most likely novel to the observers and lack coherent structure that could be used as anchors. Rather than using completely contrived stimuli, we used stimuli that possess self-similar characteristics thought to be important in the composition of objects in nature (Pentland 1983). In this way, we produced stimuli that are grossly statistically probable but whose particular composition is rather unlikely to occur naturally.

2.1 Method

2.1.1 Stimuli. Stimuli for this experiment were derived from images from the aforementioned classes: portraits, ecological scenes, and artificial objects. Examples of the images can be seen in figure 3. Portraits consisted of both male and female images, and ecological scenes included interior and exterior images. The artificial-object stimuli were from a collection of convex objects generated by a ‘noisy’ displacement method (Phillips, in press).

These objects are spheres distorted by superimposing a self-similar, pseudo-random wave function along their surface normals. The amplitude, phase, and frequency of the wave components can be directly controlled, along with the number and scaling of higher-frequency components superimposed on the carrier wave. (For detailed information on the creation of these objects, see Phillips, in press.)

The images were re-sampled and rendered at a variety of viewing distances with PhotoRealistic Renderman software. The re-sampling was implemented as a Renderman shader designed to mimic the appearance of the paintings of Chuck Close that were used by Pelli (see figure 4). Close’s work (see figure 2) is typically executed on a 45° rotated grid.

Figure 3. Examples of the three classes of stimuli used in experiment 1. Each image is shown in high and low resolution (though not at the extremes used in the experiment). On the left, example faces; in the middle, natural scenes; and on the right, artificial objects.

Figure 4. An example of the ‘Close’ marking simulator. On the left, a face at a high-resolution (small element size); in the middle, at low resolution. On the right, a close-up detail of the low-resolution image. Our simulator was able to recreate the hierarchical marking style of Close, but we chose not to use this feature in this set of experiments to keep the number of variables to a minimum.
Each grid element is painted with a carefully selected combination of colors and patterns which, when integrated, yield a color and edge element. When combined with other grid elements and viewed from a sufficient distance, these provide a compelling percept of the portrait’s subject. For simplicity, we refer to each grid element as a ‘mark’ throughout.

Examples of final re-sampled versions of the images are shown in figure 3. These images were rendered on a virtual plane whose distance and orientation relative to the observer could be controlled. The resulting stimuli varied by subject matter (the three conditions noted above), viewing distance (the stimuli subtended approximately 6 to 60 deg), and mark resolution (4 to 81 marks horizontally across the widest part of the object). Examples of the viewing conditions are shown in figures 5 and 6.

2.1.2 Procedure. Each observer participated in four blocks of stimulus presentation. Each block consisted of 300 viewing conditions—three stimulus classes, 10 field of views, and 10 mark sizes, each level repeated four times. All stimuli were viewed monocularly. The experiments were blocked by stimulus class, and factorial with respect to field of view and mark size. On each trial, observers indicated if the subject matter of the presented image appeared to be 2-D or 3-D. Observers were allowed to establish their own criterion for ‘3-Dness’ of the stimulus.

Figure 5. Examples of the field of views used. The observer was positioned such that they ranged from approximately 6 to 60 deg.

Figure 6. Examples of the mark sizes used. The approximate number of marks, horizontally, across the widest part of the object (ie image resolution) ranged from 4 (upper left) to 81 (lower right). As a result, each object was depicted with a range of approximately 12 to 5000 marks in total, respectively.
2.1.3 **Apparatus.** Stimuli were generated and displayed with Macintosh G3 and G4 microcomputers running the 'eel' experiment language (Phillips et al 2000). The observer was seated about 17.5 cm in front of a luminance- and color-calibrated ViewSonic PT795 flat-screen monitor running at a spatial resolution of 1280×1024 pixels at a color depth of 24 bits (8 bits per component), driven by ATI Rage128 and Radeon video cards. A chin-rest was used to maintain a constant viewing distance. All observations were made monocularly with dim background lighting. Responses were gathered with a hand-held USB button box.

2.1.4 **Observers.** The observers were three adults, all with normal or corrected-to-normal vision. Two were members of the laboratory (FP and CHT) and aware of the purpose and scope of the experiments. A third, naïve, observer (BJM) was also used.

2.2 **Results and discussion**

Figure 7 shows the resulting criterion functions (ie the function that specifies the boundary between stimuli judged 2-D and 3-D) for three observers in the face condition. Dots represent the locations of individual criteria for each field of view (y axis)/mark size (x axis), and the lines are the best fit of these locations. An independence of field of view (ie size) would predict a vertical line. As can be seen in our results, a significant interaction is present between size and marking frequency. The log–log fits have slopes that range on (0.5, 0.7) (p < 0.01). These results closely resemble those of Pelli (1999) with the minor difference that our slopes are slightly shallower—Pelli found a slope around 1.0. This may very well be due to the difference in the parameter spaces explored in the two experiments. Pelli’s space was constrained by the number of available paintings and thus not as many size/frequency combinations were available as in this study. Still, the differences are minor and show the same general pattern of results that leads to the same conclusion—that the size of the image does have an effect on the perception of the shape of the object depicted.

Figure 7. Criterion functions (ie the function that specifies the boundary between stimuli judged 2-D and 3-D) for three observers in the face condition. Dots represent the locations of individual criteria for each field of view/mark size, and the lines are the best fit of these locations. Log–log slopes range on (0.5, 0.7), roughly approximating the findings of Pelli. These results further endorse Pelli’s findings that image size in the visual field and relative size of the marks used to depict the object interact when used in object perception.

Figure 8 shows results for natural scenes and artificial objects. The slopes in these two conditions are similar to those in the face condition, again ranging on the interval (0.5, 0.65) (p < 0.01). Finally, figure 9 shows summary results for the three observers. The dashed line in each graph shows the results for faces, with the solid lines representing the non-face conditions. In two of the three observers there appears to be a very slight bias away from seeing faces as 3-D with similar amounts of information.

This result led us to investigate the geometric nature of the depicted objects in each category. Our original choices of stimulus classes were motivated merely by the difference between face and non-face content. The fact that performance was actually decreased slightly in the face conditions led us to wonder exactly why this might be the case.
Examining the depicted scenes and objects used in this experiment led us to the interesting observation that the geometric complexity of the depicted objects in most non-face conditions was far greater than that of a human face. For example, images from this set contained trees, stacks of books, architectural decoration, and many other high-geometric-complexity details. Could this difference explain the unusual results we have obtained in this experiment with respect to faces? Furthermore, what is the nature of the relationship between geometric complexity and image information?

3 Experiment 2
The results of experiment 1 replicated Pelli’s findings with respect to size and shape; however, for two observers images of faces were slightly less likely to be perceived as 3-D than images of other scenes and objects. This result led us to further examine the nature of the 3-D geometric information provided by the object. In almost all the scenes and objects used, the phenomenal complexity was far greater in the natural scenes than what was present in a portrait image.

![Figure 8](image1.png)
**Figure 8.** Results for three observers in (a) the natural-scene and (b) the artificial-object conditions. The slopes range on (0.5, 0.65), demonstrating the interaction between the size of the object in the field of view and the number of marks per object on the perceived dimensionality of the depicted object.

![Figure 9](image2.png)
**Figure 9.** Results for each observer across all conditions. The dashed line in each plot shows the results for the face condition and the solid lines show results for the natural-scene and artificial-object conditions. The slopes of the fitted lines demonstrate an interaction between the viewing distance and the 2-D information needed to see the subject as 3-D. The slopes are similar across observers and the difference in intercepts indicate the differences in criterion for each. Note also that, for two observers, the face condition requires more spatial information to be seen as 3-D.

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This result begged the following question: Does the 3-D geometric structure of an object in some way dictate or constrain the amount of 2-D image information needed to perceive the object as in fact being 3-D?

To investigate this we chose to focus on the artificial stimuli used in experiment 1. We have used these stimuli in many other experiments owing to their natural-appearance qualities. The geometric complexity of these objects is explicitly controllable in scale, frequency, and self-similarity, making these ideal dimensions to examine the effect of geometric complexity on the perception of these images.

In this experiment we manipulated not only the 2-D (image) information systematically, as was done in experiment 1, but we also manipulated the 3-D (object geometry) information in the same systematic fashion. Since the frequency component was the most directly relevant factor we chose to manipulate only it, holding the amplitude constant.

3.1 Method
3.1.1 Stimuli. Stimuli consisted of a superset of the artificial objects used in experiment 1. The mean amplitude of the distortions was held constant at 1 cm. The spatial frequency of the distortions ranged from approximately 2 to 60 cycles per object, where ‘per object’ is meant in the sense that there would be 2 to 60 bumps visible across the widest part of the sphere, from any given vantage point. As in experiment 1, the rendered objects were re-sampled into images resulting in 4 to 81 marks horizontally across the widest part of the object. Finally, the resulting images were depicted at viewing distances that subtended between 6 and 60 deg.

3.1.2 Procedure, apparatus, and observers. The procedure and apparatus were the same as those used in experiment 1. A second naive observer was added for a total of four. In short, on each trial the observers indicated if the subject matter of the image appeared to be 2-D or 3-D.

3.2 Results and Discussion
Figure 10 illustrates the criterion surface for the observers. The planes shown are regressed against the 2-D/3-D responses. Locations above the plane represent stimuli judged as 3-D, while locations under the plane represent stimuli judged as flat or 2-D. As with experiment 1, a lack of interaction would manifest itself via a zero-slope plane with respect to the axes of interest.

Slopes in the (x, z) plane (2-D frequency versus field of view) are similar to those found in experiment 1, again demonstrating an interaction between size and 2-D marks. In addition, there is a significant slope of the plane with respect to 3-D frequency. This further implies an effect of geometric complexity on the observers’ judgments. As we suspected on the basis of the results of experiment 1, the geometric complexity of the object that is sub-sampled into image space will contribute to the overall percept of ‘solidness’ (as opposed to planarity) of the shape.

These results indicate a significant slope with respect to all three factors, illustrating an interaction between all three—the spatial characteristics of the solid shape, the spatial characteristics of the image of that shape, and the size of the field over which it is viewed. This further demonstrates that not only is there an effect of size on shape, but this effect is further mitigated by the geometric complexity of the shape in question. Informally, the results show that, as an object gets further away from an observer, we are more likely to give it the benefit of the doubt that it is 3-D, even with extremely impoverished image information.

Of course, this result would break down at the extremes of these characteristics. For example, an extremely close-up image of a simple object, like a blade of grass, will result in a single-colored green image and the field of grass from which this blade was selected would similarly be a monochromatic green image if viewed from far enough.
4 Experiment 3

In experiments 1 and 2 we have shown a systematic effect of image size and object complexity on our perception of 3-D objects from 2-D image information. These results suggest that the determination of solidness or 3-Dness in these cases takes place with the use of information beyond that which would be available from simple retinotopic channels, as otherwise size would have no effect. In experiment 3 we further investigated this phenomenon by considering images slanted relative to the viewer.

Slanted images further distort the retinotopic information available to the viewer, yet we are typically able to effortlessly identify objects, people, and scenes in paintings and photographs. Furthermore, impressionist and pointillist works by painters such as

![Image of 3D complexity and 2D object depiction](image-url)

**Figure 10.** Results of experiment 2 for four observers. 2-D frequency of the image marks is represented, on the x axis, in cycles per image at the widest part of the object. 3-D frequency of the bumps and dimples on the object, in cycles per object, is represented on the y axis. The z axis shows the visual angle each object subtended. All scales are logarithmic. The planes are the best fit to the “2-D” and “3-D” responses. Points above the plane (those shown) are for stimuli judged as 3-D, points below are for stimuli judged at 2-D. All three factors show significant non-zero slopes; if any factor was independent of the others its slope (relative to them) would be zero. Therefore, the three image components interact.

away. Impressionist painters who employed the technique of pointillism were almost certainly aware of this fact (if only heuristically). We will revisit this notion of scale later. On the subject of painting—when examining artwork in situ the viewpoint is not always directly frontoparallel with the plane of the image. Does this skewed viewing position have an effect on our ability to see shape as 3-D?
Van Gogh, Miró, Seurat, and Signac suggest that they were quite aware of some sort of ‘level of detail’ necessary to accurately convey the notions of shape and form from a wide range of vantage points.

Just as with the case of 3-D complexity and viewing distance, there are obvious limits at the extremes. An image viewed edge on or from behind obviously will not be visible at all. Still, it is easy to demonstrate that we are able to recognize shape and 3-D form in images presented at a very wide range of orientations relative to the observation point. Some of our previous work (Phillips et al 1997) has shown that observers are quite capable of accurately locating features and landmarks on 3-D objects that are oriented away from the observer by not less than $\pm 35^\circ$.

In this experiment, we used the same paradigm as in experiments 1 and 2 to examine the effect of slant on the perception of 3-D shape from coarsely sampled images.

4.1 Method

4.1.1 Stimuli. The stimuli consisted of the same artificial objects as those used in experiments 1 and 2. In this experiment the re-sampled images of the objects were projected onto a plane that was then slanted $\pm 35^\circ$ about the vertical axis, relative to the observer (see figure 11). Only one set of 3-D object distortions, whose frequency was in the lower-middle of the range used in experiments 1 and 2, was used to keep the number of trials tractable.

![Figure 11. Example stimuli from experiment 3. The x axis illustrates changes in the field of view, from 1 to 60 deg, the y axis shows tilt in the image plane ranging from $-35^\circ$ to $+35^\circ$ relative to the observer, and the diagonal axis illustrates changes in image resolution from 6 to 60 marks horizontally across the widest part of the object.](image)

4.1.2 Procedure and apparatus. The procedure and apparatus were the same as those used in experiments 1 and 2. In short, on each trial the observers indicated if the subject matter of the image appeared to be 2-D or 3-D. Each observer made 10 judgments for each stimulus condition with orientations ranging from $-35^\circ$ to $+35^\circ$, spatial resolution ranging from 6 to 60 marks horizontally across the widest part of the object, and field of view ranging from 1 to 60 deg.
4.1.3 Observers. Observers consisted of six adults with normal or corrected-to-normal vision. Two observers (FP and MGV) had participated in experiments 1 and 2, or its pilots, and were aware of the nature of the experiments. The remaining were naïve as to the purpose of the experiment.

4.2 Results and discussion
Figure 12 illustrates the results for the six observers. The x and z axes illustrate the 2-D sampling frequency and field of view as in the results of experiment 2. Here, the y axis illustrates absolute image slant relative to the observer. The plane is the best fit to the observers’ “2-D” and “3-D” responses (dots). As with experiments 1 and 2, 2-D frequency and field of view continue to have a considerable interacting effect. An effect of slant would be illustrated with a slope of the y axis of the plane and very little or none is seen across observers. Thus we conclude that, at least for the range of orientations used in this experiment, slant has little or no effect on the perception of the solidness or 3-Dness of these stimuli.

5 General discussion
The three experiments presented here further support the findings of Pelli (1999) and the follow-up work of Majaj et al (2002) with respect to the field of view and 2-D image information. We expand upon them to consider the effects of object complexity and viewpoint dependence. As 3-D complexity increases, the image needs to be further away from the observer, of higher spatial resolution, or some combination thereof to be seen as 3-D. Unlike geometric complexity, image slant does not have much of an impact over the 70° viewing-angle range used in this experiment. A picture of a 3-D
object on a wall, when viewed obliquely, will still be seen as 3-D when subjected to the same constraints as the frontoparallel viewing position.

In motion-picture photography the practice of matte painting has been used for decades, where cinematic footage of a large glass plate with a (usually crudely rendered) surrounding scene is composited with footage of live action to create the visual illusion of a complex, expansive scene. On close inspection, the matte painting itself is usually rendered in a pseudo-impressionistic style with very coarsely painted and exaggerated strokes (Rickitt 2000). Yet, when viewed on the projection screen the moviegoer is largely insensitive to this fact. Our results suggest that this may be due to more than just simply the lack of attention one pays to the background.

However, it should be obvious that the matte painter cannot depict moderately complex objects that occupy a large portion of the scene without considering the ratio of object complexity to depiction area. Still, on the basis of our results it should be possible to calculate a measure of ‘level of detail’ needed for a given imaging situation. This further suggests a scale–space interaction of these qualities that could be derived from these results.

As further testimony, one of the authors (Thompson) employed our findings in the recently released animated film Ice Age with excellent results. In one scene, leaves on the ground are rendered as 3-D geometric objects in situations where their level of geometric complexity and rendered screen resolution would ‘give them away’ as being flat if they were rendered in only 2-D (ie as pictures of leaves). Flat, 2-D painted leaves are then mixed with the 3-D geometric leaves starting at the edge of the detection threshold and the geometric leaves are omitted after the detection threshold asymptotes (see figure 13).

Many studies have shown that the degree of slant present in an image or an object plays some role in how it is perceived. For example, Kumar and Glaser (1991) have shown that simple images surrounded by a trapezoidal picture frame have enhanced depth relative to when they are shown surrounded by a rectangular frame. When subjects are

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**Figure 13.** A frame from the film Ice Age showing the combination of geometric and photographic leaves. Leaves in the foreground are geometric objects while those further away are a mix of photographic and geometric objects. As the 3-D detection criteria roll off, the geometric leaves are omitted completely. (Image Copyright 2001 20th Century Fox.)
required to perform judgments on an image, the phenomenal perception of inferred slant tends to be one of underestimation, which is in turn significantly affected by the surface texture of the image (Newman et al 1973).

Furthermore, it has been suggested that the perception of a 3-D object from a heavily slanted image would be largely ambiguated when attempting to match the aspect ratios of one image to another (Pizlo and Schleesessele 1998). In this case the largely image-based process of forcing one to adjust for slant appeared to hinder performance. On the other hand, Koenderink et al (2001) showed that observers largely correct their representation of the shape of a perceived object when it is viewed via a range of oblique projections. Their findings expand on our previous work on locating features and landmarks on similarly presented objects (Phillips et al 1997). Finally, with respect to portraits, Busey et al (1990) concluded that images of faces were not judged as “distorted” within $\pm 22^\circ$ of slant.

Our results with respect to slant largely support these findings in that the solidness or 3-Dness of the object seems to be stable over viewpoint changes. The results showed that the perceived metric properties may vary, but the categorical nature of the percept of being 3-D would remain stable.

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