Organizational determinants of subjective contour: 
The subjective Necker cube

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With specially arranged inducing elements on a white surface of uniform luminosity, a phenomenally complete Necker cube can be seen in an array where only the 'corners' of the cube are physically represented. The subjectively seen bars of the cube disappear when the inducing 'discs' are seen as 'holes' in an interposing surface, through which the corners of a partially occluded cube are viewed. Illusory brightness effects are also observed in connection with the different organizations of this ambiguous figure.

In this report, we demonstrate a perceptual phenomenon with important implications for theories of subjective contour. A full description of the phenomenon is provided, followed by some preliminary data collected to substantiate its existence in a naive sample. We then conclude with a brief discussion of the theoretical significance of the visual effects observed.

If the reader will invest a few minutes in carefully observing Figure 1, a number of interesting and rather striking visual effects may be seen. First, and most prominent, is the impression of a three-dimensional cube-like object suspended in space such that each 'corner' of the cube is in front of a black 'disc.' The bars connecting the corners of the cube can be seen extending beyond, and therefore between, the discs. They have the appearance of a slightly brightened or more intense area bounded by faint contours or edges the same distance apart as the edges of the bars actually over a disc. Since this display was produced by placing black inducing elements in special arrangements on a white surface of uniform luminosity, the contours seen extending between the discs do not actually exist in the physical array. Consequently, the perception of the cube in its entirety, and in particular those portions seen between the discs, is illusory. Nevertheless, this subjectively seen cube manifests many of the defining properties of a standard Necker cube, such as the strong impression of three-dimensionality, spontaneous reversals in apparent orienta-
tion and depth, and a slight difference in apparent size of the front and back faces of the cube.

The subjective Necker cube (Bradley, Dumais, and Petry, 1976) is a three-dimensional variation of a phenomenon, long known, called subjective contour (Schumann, 1904). A standard configuration for the perception of subjective contour is presented in Figure 2 (Kanizsa, 1955). The 'sides' of a triangle are perceived as faint contours or edges extending from one black disc to the next. As with the subjective Necker cube, the perception of these contours is illusory. Further, the triangle bounded by these subjective contours appears slightly brighter than the background on which the triangle rests, even though the reflectances are equal. Figures 1 and 2 are similar in that they both produce phenomenally complete objects (cube, triangle) that appear brighter than their backgrounds and are bounded by illusory contours between the inducing elements.

However, in one important respect the visual arrays in Figures 1 and 2 are different. In Figure 1, an alternative perceptual organization is possible, whereby the previously noted subjective contours disappear, to be replaced by a new set of illusory contours elsewhere in the display. The

Figure 1. The subjective Necker cube. A phenomenally complete Necker cube can be seen overlying a white surface and eight black discs; so viewed, illusory contours corresponding to the bars of the cube can be seen extending between the discs. The illusory bars of the cube disappear when the discs are seen as 'holes' in an interposing surface, through which the corners of a partially occluded cube are viewed; curved subjective contours are then seen demarcating the interior edges of the 'holes'
alternative organization is simply this: imagine you are looking into a dark room through eight 'holes' in an interposing white surface. A cube is suspended in space in back of the surface such that each corner of the cube is visible through one of the holes but the rest of the cube is occluded by the interposing surface. With this cube-in-back organization, the subjective contours previously seen between the discs are not present: instead, the bars of the cube are now amodally completed behind the occluding white surface. However, careful observation reveals that new subjective contours are present during this cube-in-back organization. In each case where the interior edge of a 'hole' traverses a bar of the cube in back, a curved subjective contour can be seen.

As might be expected, these curved subjective contours disappear when the first, cube-in-front organization prevails. Note that in both cube-in-front and cube-in-back organizations, subjective contours are seen where the interpolation of an edge or boundary by the visual system serves to create a phenomenally complete object consistent with the prevailing organization (i.e., either the 'cube' of the cube in front, or the 'holes' of the occluding surface of the cube in back). These observations suggest that central organizing factors are important in determining the perception of such illusory contours (Bradley and Dumais, 1976).

Figure 3 presents unambiguous versions of the cube-in-front (B) and cube-in-back (C) organizations of the subjective Necker cube, along with a 'straddled' organization (D) that is occasionally reported. Real contours are filled in over those regions of the display where subjective contours would be seen if the ambiguous version were viewed under the same conditions.
organization. It should be noted that the unambiguous organizations depicted in Figure 3 misrepresent the appearance of subjective contours insofar as they imply that black lines are seen. Rather, the experience of a subjective contour is generally described as that of an edge or border separating a discrete change in apparent brightness — as a one-step change in luminance, rather than the two-step change evident with a black line on a white background.

One additional and very striking effect may be observed in Figure 1. After you have gained some facility in seeing both of the organizations described above, carefully direct your attention to the apparent brightness of the cube while in each of the two positions. When the cube is organized in back of the surface, it appears extremely bright; in fact, it may even appear luminous. When the cube is organized in front of the

![Figure 3. Unambiguous versions of three possible organizations of the subjective Necker cube: (A) the original ambiguous configuration; (B) cube in front; (C) cube in back; (D) a 'straddled' organization with the cube partly in front and partly in back](image-url)
surface, however, its apparent brightness is considerably less. The same
effect is present in comparing the brightness of the cubes in B and C of
Figure 3, so it would seem that this difference in apparent brightness is
not dependent on the presence of subjective as opposed to real contours.

Although the reader should be able to verify our observations simply
by spending some time viewing Figure 1 (our experience indicates that
these effects tend to emerge 'all or none'), it is, of course, necessary to
demonstrate their existence in a naive sample.

METHOD

In Experiment I, 50 college students were individually shown a modified
version of the subjective Necker cube in Figure 1. In order to facilitate percep-
tion of the two main organizations, each observer was shown a 'preview'
figure of an unambiguous cube-in-front or cube-in-back configuration. After
being shown one of these preview figures for approximately 2 min, the ob-
server viewed Figure 1 and was asked to describe what he saw. If the observer
was able to see the cube in only one position, the other preview figure was used
to prompt him as to where to look for the "other cube." Order of presenta-
tion of the preview figures was counterbalanced across observers. Finally, after the
observer had achieved facility in perceiving both organizations of Figure 1,
several forced-choice questions were asked, questions which required that the
two cubes be compared to their backgrounds and to each other on various
dimensions. The probing questions were always of the form "Which is brighter?"
with the observer responding either "front" or "back" (for comparisons in-
volving the cubes) or "background" or "cube" (for comparisons involving figure
and ground).

In Experiment II, 35 college students viewed a slide of Figure 1. This experi-
ment was conducted in a group situation.

RESULTS

Of the 50 observers tested in Experiment I, 1 was unable to perceive
either of the possible arrangements of Figure 1, and 8 were unable to
perceive the cube-in-front arrangement (each of these 8 had been shown
the cube-in-back organization first). The remaining 41 observers were
able to perceive the various aspects of the subjective Necker cube phe-
nomenon: the cube-in-front organization with subjective contours ex-
tending between the discs, as well as the cube-in-back arrangement in
which these same subjective contours are not present. Thus, 82% of the
observers in the overall sample reported seeing the illusory bars of the
cube in front [p < .0001, by the binomial test]. When asked to compare
the relative brightness of the cube in front and the cube in back, 80%
of the 41 observers perceiving both organizations reported the cube in
back as brighter \([p < .0001]\). Furthermore, for the cube-in-front organization the 'bars' of the subjective Necker cube were reported as brighter than the background for 68% of the 41 observers \([p < .027]\). It is important to note that this judgment was based on a comparison of the brightness of the bars between the discs (the subjectively seen portions of the cube) and the brightness of the background.

In all essential respects, the results of Experiment II replicated those of Experiment I. Again, the perception of subjective contours connecting the corners of the cube was present for the cube-in-front organization and absent for the cube-in-back organization for 91% of the observers \([p < .0001]\); the cube in back was perceived as brighter than the cube in front by 71% of the observers \([p < .012]\); and the cube in front was perceived as brighter than its background by 94% of the observers \([p < .0001]\). An additional finding was that 79% of the observers perceived the cube in back as being luminous \([p < .0004]\), independently emitting its own light.

**DISCUSSION**

These data, though preliminary, do seem to substantiate the major perceptual effects of the subjective Necker cube described in the opening sections of this report. We would now like to briefly consider the implications of these findings for several current theories of subjective contour.4

First, since the location of the subjective contours seen in Figure 1 depends on the prevailing organization, it is unlikely (although not impossible) that peripheral physiological mechanisms such as lateral inhibition or simultaneous brightness contrast can account for the perception of subjective contour (Brignier and Gallagher, 1974; Frisby and Clatworthy, 1975). Recent data indicating that the apparent strength of subjective contour varies inversely (rather than directly, as predicted by contrast theory) with the illumination incident on the display is consistent with this conclusion (Dumais and Bradley, 1976).

Nor is it sufficient to say that subjective contour simply results from the presence of implicit depth cues which stratify one perceptual object in a plane over others — to argue, for example, that interposition cues in Figure 2 imply a triangular object partially occluding three black discs (Coren, 1972). Although depth information is certainly important in facilitating or inhibiting the perception of subjective contour (Lawson, Cowan, Gibbs, and Whitmore, 1974; Lawson and Gulick, 1967; Gregory and Harris, 1974; Harris and Gregory, 1973), this does not prove that depth cues per se are the causal factor. In cases where depth information is open to more than one interpretation, as in Figure 1 where the bars
of the cube can be seen as either overlying or underlying the white surface (B or C, Figure 3), the perceived location of the subjective contours will depend on how such ambiguous depth information is processed to organize objects stratified in depth (Bradley and Dumais, 1976).

Finally, recent attempts to account for subjective contour by assuming selective filtering of spatial frequencies (Ginsberg, 1975) would also seem to have difficulty explaining the alternative organizations of Figure 1, since a two-dimensional Fourier transform of the spatial information in that figure would presumably yield only one solution.

A theoretical perspective not yet considered by workers in the field involves subjective contour as the product of perceptual synthesis. In terms of a cognitive or information-processing theory of perception (Neisser, 1967; Hochberg, 1968, 1970), the visual system 'synthesizes' or 'constructs' a perceptual object under the guidance of both sensory and nonsensory information. Subjective contours represent an instance in which the visual system goes well beyond the information given in organizing sensory data, such that objects are created by interpolating edges and surfaces across objectively homogeneous regions of the visual field. Since the visual synthesis of a perceptual object is under both stimulus and central control, it may be influenced by all or some of the following: (a) directly given sensory information corresponding to the object, as in viewing a real cube or triangle; (b) contextual information conveyed by features in the stimulus array that indirectly imply the presence of a particular object, as in viewing Figure 2, where the sectors in the discs imply a masking triangle; (c) nonsensory factors like past experience, expectation, or perceptual set, as in being given an alternative construction of the cube in Figure 1. Where the available sensory information is particularly ambiguous, as in the subjective Necker cube, the relative importance of nonsensory factors in determining the visual synthesis is increased.

As is evident from Figure 3, there are at least three possible visual solutions to organizing the ambiguous array of Figure 1. Which particular solution is achieved would seem to depend primarily on central determinants rather than on stimulus factors, although peripheral factors such as eye movements during inspection would certainly be important. Given a particular visual solution, however, subjective contours are interpolated or 'filled in' throughout the visual field wherever necessary to demarcate the perceptual objects 'postulated' under the prevailing perceptual interpretation. From this view, subjective contours are simply the phenomenal correlates of the edges or boundaries of visually constructed objects. Insofar as a given ambiguous array permits various possible constructions and
organizations of perceptual objects in depth, subjective contours will be seen in varying locations in the display (Bradley and Dumais, 1975).

Thus, when the cube-in-front inference is tentatively applied to the ambiguous array of Figure 1, the interpolation of contours over the intervening regions between discs occurs because only this filling in will complete and maintain the impression of an overlying cube. When the cube-in-back inference is adopted, however, the interpolation of contours over these same intervening regions would be incompatible with the requirement to maintain the impression of an occluding surface. Rather, the visual interpolation required in this instance gives rise to the illusory contours that complete the 'holes' of the occluding surface. Finally, the straddled-cube inference (D, Figure 3) requires a combination of the previous two forms of visual interpolation, with subjective contours extending between discs in some locations and completing holes in others.

In summary, the process of visual synthesis seems to produce that interpolation which would segregate perceptual objects into different planes and demarcate their phenomenal borders in such a way as to serve the prevailing perceptual interpretation. The pervasive effect of such organizational determinants of subjective contour argues against stimulus-bound or peripheralist explanations of the phenomenon.

Notes

The subjective Necker cube was discovered by the second author (while enrolled in a research seminar on subjective contour supervised by the first author), and he presented some of the data discussed in this report at the April, 1975, meeting of the Eastern Psychological Association. Support for this research was provided by a Faculty Research Grant (837-00-Bradley) awarded the first author by Bates College. Both authors thank Robert Moyer for a critical review of an earlier draft of this paper. Requests for offprints should be sent to Drake R. Bradley, Department of Psychology, Bates College, Lewiston, Maine 04240. Received for publication May 18, 1976; revision, June 10, 1976.

1. Although the connecting bars of the cube are not visibly present in the perception, they are phenomenally present as objects obscured by an occluding surface. This 'amodal' completion of the cube in back should be distinguished from the 'modal' completion of the cube in front, where the connecting bars are phenomenally and visibly present (this distinction comes from Kanizsa, 1974, 1976).

2. The display was chromatic with dark-blue inducing elements mounted on a bright-orange surface. It was viewed from a distance of about 12 ft so that the 'cube' subtended approximately 2.5 deg visual angle in lateral extent. Another experiment was conducted using an achromatic stimulus identical to Figure 1. The data indicated that the perceptual effects observed do not differ substantially as contingent on using chromatic or achromatic displays.
3. This test was based on $p = .50$ as chance expectation: that in response to the question "Do you see the bars of the cube extending between the discs?" half of the observers would respond ‘yes’ and half ‘no,’ even though illusory bars were never seen. This is certainly a conservative test, since the question asked the observer is highly unlikely to produce this strong a response bias (the appropriate level of expectation is $p = .00$ assuming no illusion and no effects due to response bias). Nevertheless, we must be alert to the possibility of response bias in these data, since some observers may just have reported seeing the illusory bars because of the expectation (perhaps created by the preview figure of the cube in front) that this is what they were ‘supposed’ to see. If so, no difference in the apparent brightness of the illusory bars and the background should be found, since that difference arises only with perceiving the subjective contour (i.e., the whiter-than-white subjective Necker cube). Since a significant proportion of the observers who reported seeing the illusory bars also reported seeing a difference in the apparent brightness of the illusory bars and the background, it would seem that for these individuals the illusory bars did have a phenomenal reality.

4. The theoretical significance of the difference in apparent brightness of the cube in front and the cube in back will not be discussed in this paper, as we wish to focus on the shifting subjective contours. However, we would note that the fact that the cube in back appeared brighter than the cube in front is consistent with Helmholtz’s unconscious-inference theory of brightness constancy (Helmholtz, 1962). Since the cube in back appears to be situated in a dark enclosure of some sort, the amount of illumination incident on this cube would be ‘registered’ as less than that for the cube in front. However, since both cubes reflect the same absolute amount of light to the eye, the cube in back would therefore be judged as the intrinsically brighter object (see Coren and Komoda, 1973, and Hochberg and Beck, 1954, for related phenomena and theoretical interpretations). Further, the fact that the cube in back appeared luminous to some observers is also consistent with this theory. If the registered level of illumination in the cube-in-back enclosure is sufficiently low, then the actual amount of light reaching the eye from the cube may be greater than could be accounted for even by an object capable of reflecting 100% of the incident light. If so, the cube would then appear to be emitting its own light.

5. The view that perceptions represent ‘hypotheses’ selected by, but going beyond, sensory data has been emphasized by Gregory (1970, 1972). The role of nonsensory factors in determining the perceptual organization of ambiguous visual displays has been elaborated by Hebb (1949) in a neurophysiological theory capable of providing a physiological basis for the process of visual synthesis.

References


