Theory and Evaluative Reviews

Subjective contours 1900-1990: Research trends and bibliography

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A bibliography on subjective contours and a brief summary of trends in research on this problem are presented. The bibliography covers the years 1900-1990 and contains 445 entries, each briefly annotated with a code that indicates the general content and theoretical orientation of the item.

Subjective contours, illusory contours, phenomenal contours, anomalous contours, and quasiperceptive margin figures are all terms that refer to the perception of contours, lines, edges, or surfaces that are not physically present in the stimulus array. Over the past 15 years, they have become one of the most widely studied of the illusory phenomena in vision. In 1985, work on subjective contours had become so widespread that an international conference exclusively devoted to the topic was held in New York (see Petry & Meyer, 1987a).

Although a number of researchers, including Helmholtz, Wundt, Ebbinghaus, Sanford, and Titchner all published figures in which subjective contours appear to be quite evident to us today, they made no comments about them. In 1900, Schumann published the first figure that was specifically used to describe the phenomenon. In that paper too, the first use of the term *subjective* to describe the contours and lines so formed occurs. Yet although a few textbooks and monographs reprinted Schumann's subjective contour figure, there was very little systematic work on the phenomenon for some 55 years after its initial description.

In 1955, Kanizsa presented an analysis of subjective contour figures, in which he used a series of new and more powerful variants of the initial Schumann configuration.

Yet although this is now the most frequently cited work on subjective contours, it did not have much of an initial effect. This was probably because it was published in Italian, in a journal of rather limited circulation. Thus the initial interest in the phenomenon was confined to a few Italian phenomenological psychologists who were closely associated with the traditions of the Institute of Psychology chaired by Kanizsa at the University of Trieste.

For subjective contour research, 1972 was an important year: two articles about subjective contours appeared in English, in widely distributed journals. Coren (1972), in addition to calling attention to Kanizsa's work, offered his "implicit depth cue" theory in *Psychological Review*. Gregory (1972), in a short report in *Nature*, presented variants of Kanizsa's figures and offered his "object hypothesis" model. Following these publications, there was an

Number of Subjective Contour Publications

Figure 1. Number of publications dealing with subjective contours from 1900 to 1990.

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immediate spurt of activity, with researchers both studying subjective contours for their own sake and using them as methodological tools to explore other issues in visual perception. The number of publications that dealt directly with subjective contours has steadily increased, as can be seen in Figure 1. In the 5-year period from 1986 to 1990, there were nearly 150 new entries in the literature on this topic.

To provide a research tool for investigators who wish to pursue studies on subjective contours, we decided to compile as complete a bibliography as possible on this topic. In addition, to facilitate the gathering of information about specific aspects of the problem, we decided to include a brief form of content annotation. The literature search period functionally begins in 1900 (when Schumann first mentioned the topic), although a few items in which the phenomenon is mentioned in passing, from before 1900, are also included. The search period continues through 1990. The search for bibliographic entries on this topic is not as simple as one might expect. The various and diverse labels used for the phenomena complicate the matter quite a bit. We therefore used several forms of electronic search, materials from bibliographies previously collected by the present authors, reference lists from articles on the topic, manual searches of a variety of indexes, mailings to active researchers in the field, plus a lot of "power browsing" through periodicals not usually surveyed by the usual psychological indexing and abstracting services. In addition to journal articles, this resulted in the discovery of several book chapters, as well as some papers either unpublished or in press. The final bibliography contains 445 entries and is about as complete as our stamina would allow.

A brief glance at the entries reveals some interesting features of research in this area. First, since the phenomenon is often referred to as a visual illusion, it is not surprising that, as is the case with most research in the area of the classical visual geometric illusions, theoretical approaches to subjective contours naturally fall into two distinct groups. The first is concerned with physiological or structural mechanisms that might explain the phenomena, while the second is more phenomenological in nature,

Distribution of Theoretical Approaches To Subjective Contours

Figure 2. Distribution of theoretical approaches to subjective contours in the research literature.

Distribution of Physiological Approaches To Subjective Contours

Figure 3. Distribution of the major physiological approaches to subjective contour research (excluding color effects).

drawing its explanations from cognitive-judgmental and Gestalt-like processes. As can be seen in Figure 2, the phenomenological approach has tended to be a bit more popular than the physiological approach, and about 25% of the literature has taken a combined or multicausal viewpoint, which permits the interaction of mechanisms from both levels.

Within the two approaches to subjective contours, certain themes have been consistent. When we analyze the publications that have presented an exclusively physiological orientation to the problem (see Figure 3), we find that nearly half have reported some form of lateral neural interactions, analogous to the lateral inhibitory processes on the retina that are used to explain brightness contrast, as the mechanism that produces subjective contours. In some instances, these interactions are moved a bit higher into the visual system, or left with their locus not clearly indicated, rather than with a clearly retinal locus. The second major physiological theme has invoked the action of various feature detectors in the cortex. Some of these are the traditional orientation-specific units found in V1 through V3, but other new and special units have been suggested, such as end-stop sensitive receptors or dipole triggered units, to explain the final perception of subjective lines and edges. Another form of treatment has explored the possibility of visual analogues to Fourier analysis. This approach reached its peak in the early 1980s and has diminished in importance in the more recent literature.

The more cognitive and phenomenological approaches display a bit more diversity. If we ignore theories that have involved color or transparency as a component, we find that the most popular approaches were among the first to be promulgated. Coren's "implicit depth cue" theory is still the most frequently addressed in the literature, followed reasonably closely by Gregory's "object hypothesis," as can be seen in Figure 4. Kanizsa's own "amodal completion theory" is next in popularity. This last approach, which often contains strong elements analogous to the Gestalt interpretation of closure, seems to have encouraged a variety of different variants of Gestalt-like

Distribution of Phenomenological Theories of Subjective Contours

Figure 4. Distribution of the phenomenological and cognitive approaches to subjective contour research (excluding color and transparency).

National Output of Studies of Subjective Contour

Figure 5. Output of publications on subjective contours by country of origin of the research (countries contributing less than 5% not listed separately).

hypotheses that incorporate, in addition to closure, processes analogous to perceptual grouping, good continuation, figural goodness, and Prägnanz to explain the phenomena. In a small number of papers, computational theories of subjective contours have been attempted.

Finally, the international distribution of subjective contour publications also shows some historical hysteresis. Figure 5 shows the national origin of subjective contour publications for nations contributing 5% or more of the literature. Although the largest contribution to the literature comes from the United States, the second largest comes from Italy, which is presumably a direct result of Kanizsa's early influence in this area. Canada and Great Britain are also significant contributors. The publications from Germany are interesting in that they tend to focus almost exclusively on one class of subjective contour stimuli—namely, those that produce the diffuse bright-

ness patterns often referred to as the Ehrenstein illusion and the closely related Hermann grid. This particular class of stimuli is not uniformly accepted as falling into the same class as the Kanizsa type of subjective contours, but they are included here for completeness.

The full bibliography that we collected is presented below. For items not in English, we have provided a translation of the title in square brackets. Each entry is followed with a code that indicates something about the content of the paper. We have chosen the codes to reflect the theoretical orientation of the particular items or to give some indication of the hypotheses tested. This added annotation is provided to help researchers gather materials that may fit within specific areas. Each code contains one or more numbers, defining our interpretation of the global issues and orientation found in that paper, with one or more letters after each number, defining specific hypotheses tested or discussed extensively. The following code categories are used:

1. Physiological theories, mechanisms or methodologies.
 - FD Feature detectors or higher level neural mechanisms.
 - C Contrast-like phenomena, including lateral inhibition and lower level lateral neural interactions.
 - F Physiological responses that mimic Fourier analysis.
 - O Other physiological mechanisms.
2. Cognitive and phenomenological theories and methodologies.
 - OH Object hypothesis theories similar to those of Gregory.
 - D Implicit or explicit depth-cue-based theories analogous to those of Coren.
 - A Amodal completion theories like those of Kanizsa.
 - G Gestalt hypotheses involving any Gestalt-like mechanism other than amodal completion.
 - AS Assimilation-based theories, similar to brightness assimilation.
 - C Computational theories of any form other than Fourier analyses.
 - DV Explicit developmental methodology or theory.
 - O Other cognitive and phenomenological approaches.
3. Miscellanea defined more by specific stimulus pattern or perceptual effects than by theoretical approach.
 - HG Studies focusing on the Hermann grid.
 - E Entries that concentrate on the Ehrenstein illusion.
 - NC The class of phenomena known as the neon color illusion, neon spreading effect, or color spreading effect.
 - IL Mostly attempts to use subjective contours in classical visual geometric illusions, or attempts to explore other illusory effects by using subjective contours as a tool.
 - T Transparency effects.
 - O Other subjective contour entries that defy categorization according to the categories above.

Any bibliography is basically static; it becomes more and more dated moment by moment. We think that it is

important to make this listing of the literature available to other researchers in a form that is useful for composing manuscripts, but that can be updated so that it can continue to grow. For this reason, we will provide a text version of the bibliography in PC DOS or Macintosh formats to any researcher who provides us with an appropriately formatted disk and a return mailer (see authors' note for the address).

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