The disappearance of real and subjective contours

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The disappearance characteristics of luminous designs were studied in three experiments. The stimuli were geometric forms set off by either real or subjective contours. Subjective-contour forms fragmented more often and in a manner qualitatively different from that of forms created with real contours. Previewing a real-contour form increased the subsequent fragmentation of that form, but no adaptation effects were noted among forms created with subjective contours, and there was no cross-contour adaptation. These results are interpreted as inconsistent with the position that subjective contours result from the partial activation of feature-analyzer mechanisms in the visual system.

Subjective contours, as they are now commonly known, were a new class of visual stimuli when they were introduced to psychology by Schumann (cited in Woodworth & Schlosberg, 1954) in 1904. The term "subjective contour" refers to the appearance of a contour where none exists physically. Three examples of such stimuli are presented in the top half of Figure 1. Observers report the presence of a triangle, a circle, and a square in these figures, yet contours are objectively present only along the edge of the physically present inducing areas.

In recent years, a considerable amount of effort has been devoted to a search for mechanisms that fabricate contours in homogeneous areas of a visual field. This search has been triggered by concern with whether subjective contours are created by the same processes responsible for the perception of real contours or by processes that are fundamentally different. An abundance of evidence has accumulated to support the notion that real contours are fabricated, at least in part, by feature-analyzer mechanisms that respond selectively to specific features in the visual field (e.g., Uttal, 1973; Weisstein, 1969). Some investigators have suggested that subjective contours may also be the product of these mechanisms and that they arise from the partial activation of neural feature analyzers (Jung & Spillman, 1970; Smith & Over, 1975; Stadler & Dieker, 1972).

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Figure 1. Three subjective figures and their real-contour analogues.

One way of determining if subjective contours share the same mechanisms as real contours is to compare them under identical experimental conditions. According to this line of reasoning, results obtained with real and subjective stimuli should be qualitatively similar if they are attributable to the same underlying processes. In an extensive series of experiments, Smith and Over (1975, 1976, 1977, 1979) have demonstrated that orientation-specific, motion-specific, and color-contingent aftereffects can be induced by viewing both real and subjective contours. Since these types of aftereffects have been used to infer the presence of neural feature analyzers in the human visual system (Dember & Warm, 1979; Weisstein, 1969), Smith and Over's results led them to conclude that the perception of real and subjective contours might be conceptualized within a fundamentally similar framework. Both can be attributed to the common action of neural feature analyzers.

To date, Smith and Over's work with aftereffects represents the single compelling source of experimental support for a feature-analyzer account of the perception of subjective contours. It should be noted, however, that some question exists as to whether the results of psychophysical experiments using aftereffects can be interpreted as reflecting the operation of relatively simple physiological mechanisms. For example, color-contingent aftereffects can persist for periods of time that are too long to permit the inference that they result from the activity of feature analyzers (Jones & Holding, 1975; Skowbo, Timney, Gentry, & Morant, 1975), and motion aftereffects are not necessarily bound by local stimulation, since they can appear in areas of the visual field where actual visual movement has not occurred (Weisstein, Maguire, & Berbaum, 1977).

Accordingly, the present investigation used an alternative approach to study the sensory basis of subjective contours, one that involved the luminous design technique described by McKinney (1963, 1966, 1967). He found that luminous drawings observed under conditions of reduced illumination appear to fragment after a few seconds of inspection, with parts disappearing and reappearing in meaningful perceptual units. Thus, whole lines or angles, rather than random portions of the stimulus array, drop away. Similar results have been reported by other investigators (Hart, 1964; Schuck, 1973; Schuck, Brock, & Becker, 1964). The disappearance of patterns in organized units under these conditions has been used as an additional means to infer the operation of feature detector systems in human visual perception (Dember & Warm, 1979; Weisstein, 1969). Therefore, the disappearance characteristics of luminous designs might be used to probe further the relation between real and subjective contours. If both are the product of the common action of neural feature analyzers, they should fragment in similar ways when viewed as luminous designs under reduced illumination.

EXPERIMENT 1

Method

Subjects. Eighteen female and 18 male students from introductory psychology classes at the University of Cincinnati served as subjects. They ranged in age from 18 to 29 years. All of the students received class credit for their participation, and all had normal or corrected-to-normal vision.

Design. A mixed design was used in which contour (real and subjective) was a between-subjects factor and stimulus configuration (triangle, circle, and square) was a within-subjects factor.

Stimuli. Three geometric configurations—triangle, circle, and square—were constructed with both real and subjective contours. The real and subjective configurations were identical in all respects except for the nature of their contours. Since subjective figures are formed in homogeneous areas of a visual field, any effort to compare them with real figures necessarily entails differences in the space-averaged luminance of the stimuli. One frequently used solution to this problem of maintaining isoluminance is to use outline stimuli as real figures (cf. Meyer &

Garges, 1979; Porac, 1978; Streibel, Barnes, Julness, & Ebenholtz, 1980). This technique, however, provides observers with double-edge information for real figures while subjective figures are defined by a single edge. Another solution is to produce single-edge-defined figures for both real and subjective configurations by raising or lowering the overall luminance of the real figures above or below that of their background. This solution, however, maximizes overall luminance disparities between the real and subjective configurations. Since one cannot equate both luminance and number of edges, we elected to use double-edge real figures as comparisons for the subjectives to reduce luminance differences, because overall luminance is a critical factor in the perception of subjective contours (Dumais & Bradley, 1976) and because it is also an important element in the fragmentation paradigm that we employed. The stimuli are presented in Figure 1.

Procedure. Eighteen students were assigned at random to each contour condition, with the restriction that each condition have an equal number of females and males. The sequence with which each subject experienced the three geometric configurations as she or he progressed through the experiment was counterbalanced.

The subjects were seated in front of a table in a totally darkened room. A 12-in. square electroluminescent panel with uniform luminosity was fitted with a black frame and mounted on the table, at eye level, directly in front of the subject. Stimuli were cut out of heavy black construction paper and mounted in grooves in the frame surrounding the panel. They appeared as black figures on a pale green background. Except when the stimuli were exposed for viewing, the panel and the stimuli were covered with a black mask. The subjects viewed the stimuli in a head restraint in order to insure a direct line of sight and to reduce head movements. The luminance of the electroluminescent panel was approximately .3426 cd/m². The stimuli subtended a visual angle of approximately 14 deg. This visual angle insured that disappearances would not be confounded with receptor insensitivity to dim illumination associated with foveal vision (Hart, 1964).

The subjects were dark-adapted for 5 min at the start of the experimental session. They were told that when a stimulus was exposed, they would see a luminous figure glowing in the dark and that stimulus fragmentation occurs under viewing conditions such as these. Fragmentation was described as a disappearance or breaking up of the stimulus, either as a whole or in parts. The subjects were instructed to depress a telegraph key located near their preferred hand as soon as any portion of the stimulus disappeared and to keep the key depressed until it reappeared. If there was a change in the nature of the fragmentation, the subjects were told to lift their finger momentarily and then to depress the key again, and continue to keep it depressed for the duration of the new fragment. Keypresses were transcribed onto a cumulative recorder located out of the subjects' view in another portion of the laboratory. Three measures of fragmentation were obtained—time elapsed to first fragmentation, number of fragments per unit time, and total time fragmented per unit time.

Each stimulus was presented for a 3-min inspection period. Prior to the start of an inspection period, the stimulus was first uncovered until the subject could identify the configuration. This was done to insure that each subject actually saw the figure before reporting disappearances. Subjects were instructed to fixate on the center of the figure and to try to avoid gross head and eye movements. At the end of each inspection period, a 12-W lamp located adjacent to the subject was illuminated and the subject was provided with an answer sheet containing 10 identical dotted configurations that matched the stimulus just seen. For example, if a subject inspected a triangle, either subjective or real, the answer sheet contained 10 dotted triangles. The subject's task was to trace over the portion of the figure that had disappeared, up to a maximum of 10 disappearances, for as many of the disappearances as could be remembered. Duplications were permitted. The tracing method of reporting disappearances has been shown to be preferable to verbal reports, which bias subjects' responses toward easily verbalized descriptions (Schuck, 1973).

Results

Quantitative data. Disappearance frequency, temporal duration to first disappearance, total time disappeared, and average disappearance duration (computed by dividing total time disappeared by disappearance frequency) were tallied for each subject under all experimental conditions. Mean disappearance frequencies for the two types of contours and three stimulus configurations are presented in Table 1. Disappearance frequencies were subjected to a square root transformation (as suggested by Myers, 1979, for frequency data), and the scores were tested by an analysis of variance. There were significantly more disappearances for the subjective-contour figures than for the real-contour figures [$F(1,34) = 6.28$, $p < .025$]. Neither the main effect of figure nor the Contour by Figure interaction was significant ($p > .10$). Analyses of variance on all of the remaining response measures revealed no significant differences; however, the difference in temporal duration from the beginning of a trial to the first disappearance approached significance [$F(1,34) = 3.05$, $p < .10$], with first disappearances appearing sooner for subjective-contour forms than for real-contour forms (mean real = 44 sec; mean subjective = 24 sec).

Qualitative data. To determine which portion or portions of the figures disappeared, each tracing was assigned to one of the following disappearance categories: entire figure, inducing area or portions of an inducing area only, contour or portions of a contour only, or a combination of inducing area and contour. Because of the high variability in disappearance rates among subjects, category scores were then converted to proportions. Each subject's qualitative disappearance measure was expressed as four proportions, one for each disappearance category. Because proportion data necessarily sum to 1 for each subject, and therefore are not independent, an analysis of variance was computed on the first three categories only. For the qualitative analysis, contour (real and subjective) was a between-subjects factor; form (triangle, circle, and square) and disappearance category (entire figure, inducing area only, and contour only) were the within-subjects factors. A significant Category by Group interaction was found [$F(2,68) = 13.78$,

Figure 2. Proportions of reported disappearances for real- and subjective-contour forms according to disappearance category.

$p < .001$]. All other components of the analysis lacked significance. The Category by Group interaction is graphically presented in Figure 2. It is evident that most of the disappearances among the real-contour figures involved fragmentation of the contour lines (noninducing areas) or fading of the entire figure. In contrast, among the subjective figures, most disappearances occurred in the inducing areas only.

Discussion

The finding that figures formed from subjective contours fragmented more often than analogous real-contour figures was anticipated. As noted in passing by other investigators (e.g., Coren, 1972; Frisby & Clatworthy, 1975), subjective contours will disappear if observers fixate on them under normal viewing conditions. Thus, the phenomenal impression that subjective contours are less stable than real contours was experimentally borne out. However, the difference in the qualitative nature of the disappearances of real and subjective contour forms was not anticipated.

Among real-contour figures, most of the disappearances involved a fading of the entire contour or fragmentation of a portion of the contour. Relatively few disappearances were noted in the inducing areas. On the other hand, with subjective-contour figures, most of the fragmentation occurred in the physically present inducing areas. Relatively few disappearances involved fading of the entire subjective figure or portions of the figure's subjective contours. When subjects report these results, they are, in effect, stating, "What is there isn't, and what isn't there is." One possible explanation for this surprising outcome is

Table 1
Mean Number of Disappearances and Standard Deviations for Three Geometric Forms Displayed With Real and Subjective Contours During a 3-Min Viewing Period

Form	Contours				
	Real		Subjective		
	Mean	SD	Mean	SD	Mean
Triangle	11.11	6.64	18.22	11.12	14.67
Circle	9.56	6.13	18.11	9.37	13.84
Square	11.44	7.97	18.06	14.28	14.75
Mean	10.70		18.13		

that subjective contours become visible whenever the inducing areas responsible for their perception are visible. When the inducing areas disappear, the subjective contours remain visible for a brief period via sensory and/or cognitive persistence. Since eye blinks and attentional shifts can restore the entire figure when patterns are presented as luminous designs (McKinney, 1963), it is further suggested that the very act of responding when the inducing area disappears (with a keypress) can cause the reappearance of the entire figure. Thus, the disappearance phase would end before the subjective contour fades.

As noted earlier, experiments with aftereffects have led to the conclusion that real and subjective contours have a common origin: Both are produced by the action of feature detectors in the visual system. Since the luminous design paradigm has also been used to infer the presence of human feature detectors, it might be expected that real and subjective contours would fragment in similar ways if they are both the result of a common feature-detection analyzer. The qualitative differences in the fragmentation of real and subjective contours found in the present data do not fit this expectation.

EXPERIMENT 2

One possible explanation for the quantitative and qualitative differences in the fragmentation of real and subjective contours is that the contours differ in perceived clarity. If the subjective contours appeared weaker than their real-contour analogues, the results of Experiment 1 could have been an artifact created by differences in the strength of the perceived contours. Accordingly, a second experiment was conducted to test the hypothesis that the subjective contours employed appeared weaker than the real contours.

Method

Subjects. Eighteen female and 18 male students from introductory psychology classes at the University of Cincinnati served as subjects. They ranged in age from 18 to 27 years. All received class credit for their participation, and all had normal or corrected-to-normal vision. None of the subjects had participated in Experiment 1.

Design. A mixed design was used in which contour (real and subjective) was a between-subjects factor and stimulus configuration (triangle, circle, and square) was a within-subjects factor. This is identical to the design employed in Experiment 1.

Stimuli and Apparatus. The stimuli and apparatus were identical to those described in Experiment 1.

Procedure. Nine female and nine male subjects were assigned at random to either the real- or the subjective-contour condition. The subjects were instructed to rate for clarity the contours of the three configurations viewed. A 7-point rating scale was employed, ranging from "very, very clear" (1) to "very, very unclear" (7). Dark adaptation and stimulus viewing conditions were the same as those described in Experiment 1.

Results and Discussion

An analysis of variance of the contour clarity ratings revealed no significant overall differences between real and subjective figures or among the three geometric forms, and there was no significant interaction between the factors of contour and configuration ($p > .05$ in all cases). Under the luminous conditions of this investigation, both the real and the subjective contour figures were clearly visible to the observers. The mean contour clarity ratings for real contours (2.8) or subjective contours (2.4) ranged from "clear" to "very clear." It seems unlikely that the differences in fragmentation found with real and subjective contours in the first experiment can be attributed to an artifact created by a disparity in the perceived strength of the contours.

EXPERIMENT 3

In the first experiment, the disappearance characteristics of luminous designs did not lend support to the hypothesis that real and subjective contours are the product of common feature analyzers. In assessing the implications of this study, however, it is important to take note of Porac's (1978) observation that perceptual similarities between real and subjective contours may often be task specific. Consequently, the use of the luminous design technique was modified in Experiment 3 in order to provide a further test of the neural-feature hypothesis.

Fragmentation occurs not only when patterns are presented as luminous designs, but also when they are presented under stabilized retinal-image conditions (Heckenmueller, 1965). A series of studies by Brown and his co-workers has demonstrated that the fading rates of stabilized-image stimuli are increased following prolonged adaptation to the stimuli (Brown, Schmidt, Cosgrove, & Zuber, 1972; Schmidt, Cosgrove, & Brown, 1972). While stimuli generally tend to fragment in similar ways under stabilized-image and luminous-design conditions (Eagle, Bowling, & Klein, 1966; MacKinnon, Forde, & Piggins, 1969), little data are available on adaptation effects with luminous patterns. Accordingly, Experiment 3 was designed to assess the consequences of previewing luminous designs containing real and subjective contours on the subsequent fragmentation of these stimuli. Such an approach would permit an exploration of the general effects of adaptation on the disappearance characteristics of luminous patterns as well as a further test of the notion that real and subjective contours are created by the partial activation of neural feature analyzers in the visual system. More specifically, if real and subjective contour forms are the product of common feature analyzers, an initial viewing of one figure would be expected to increase the subsequent fading rate of that figure irrespective of contour

type. That is, adaptation with a real-contour figure should increase the number of disappearances during a subsequent viewing phase for the same real-contour figure and its subjective-contour analogue. Likewise, adaptation with a subjective-contour figure should increase the subsequent disappearances of the same subjective figure and its real-contour analogue.

Method

Subjects. Forty-eight students from introductory psychology classes at the University of Cincinnati served as subjects. Equal numbers of females and males were employed. They ranged in age from 18 to 30 years. All of the students received class credit for their participation, and all had normal or corrected-to-normal vision. None had served as subjects in Experiment 1 or Experiment 2.

Design. A mixed experimental design was used in which contour sequence (real-real, real-subjective, subjective-real, subjective-subjective) was the between-subjects factor and configuration type (triangle, circle, square) and viewing phase (first, second) were the within-subjects factors. Twelve subjects were assigned at random to each contour sequence condition, with the restriction that each group have an equal number of females and males. The order of presentation of the three stimulus configurations was counter-balanced within each contour sequence group.

Stimuli and Apparatus. The stimuli and apparatus were the same as in Experiment 1.

Procedure. Subjects were dark-adapted for 5 min prior to beginning the experiment. They were instructed to indicate stimulus fragmentation with a keypress, as in Experiment 1. Subjects viewed the first-phase stimulus for 3 min, closed their eyes for 15 sec, then viewed the second-phase stimulus for 3 min; 3-min rest intervals in the totally darkened room were provided between stimulus configurations. For example, a subject in the real-subjective group might indicate the fragmentations of a real contour, for example, a triangle, for 3 min, spend 15 sec with her or his eyes closed in the dark, then indicate the fragmentations of a subjective-contour triangle identical to the real-contour triangle in all respects except for the nature of the contour, for 3 min. The subject would then spend 3 min in the dark before repeating the contour sequence with the square and circle configurations. As in Experiment 1, all subjects were asked to identify the configuration they were viewing to ascertain that they actually saw the figures whose disappearance they were reporting.

Results

Means and standard deviations of disappearance

Figure 3. Frequency of disappearances for the four contour sequence groups in each viewing phase.

frequencies in all experimental conditions are presented in Table 2. Disappearance frequencies were transformed to square roots (Myers, 1979) and subjected to an analysis of variance. Overall, there were significantly more disappearances during the second viewing phase than during the first viewing phase [$F(1,44)=12.75$, $p < .001$]. The Phase by Group interaction was also significant [$F(3,44)=10.54$, $p < .001$]. All other components of the analysis lacked significance. The Phase by Group interaction is presented in Figure 3.

The locus of this interaction was probed with Scheffé post hoc tests. Mean disappearance frequencies for the first phase only were computed for real- and subjective-contour forms, respectively. These

Table 2
Means and Standard Deviations of Disappearance Frequencies for Four Contour Sequences,
Two Viewing Phases, and Three Configuration Types

Contour Sequence	Phase	Configuration Type						Mean
		Triangle		Circle		Square		
		Mean	SD	Mean	SD	Mean	SD	
Real-Real	1	9.67	9.77	10.00	10.29	12.00	11.50	10.56
	2	21.33	14.06	14.75	8.59	15.33	11.88	17.14
Real-Subjective	1	10.50	12.28	10.67	9.90	12.67	19.53	11.28
	2	18.33	26.41	13.67	13.53	15.67	19.59	15.89
Subjective-Real	1	16.33	16.95	16.17	15.33	17.00	14.30	16.50
	2	13.08	12.82	16.25	17.59	10.33	11.39	13.22
Subjective-Subjective	1	16.58	8.22	14.33	8.12	16.00	10.68	15.64
	2	19.92	7.97	17.92	10.53	20.00	13.86	19.28
Mean		15.72		14.22		14.88		

values, which served as baselines, were: real = 10.92 and subjective = 16.07. The mean number of second-phase disappearances for each group was then compared with the appropriate first-phase baseline. Thus, for the real-real group, the mean number of disappearances in the second phase was tested against the real-contour disappearance baseline and found to be significantly greater than this baseline [t (Scheffé test) = 3.52, $p < .025$]. Analogously, the mean number of disappearances in the second phase for the subjective-real sequence group was tested against the real-contour disappearance baseline and found not to differ significantly from this baseline ($p > .10$). The second-phase disappearance frequency for the subjective-subjective and real-subjective groups was tested against the disappearance baseline for subjective-contour forms. Neither of these groups differed significantly from this baseline ($p > .10$).

Discussion

The fading of real contours conforms to expectations derived from the feature-analyzer hypothesis: Previewing a real-contour form increased the subsequent fading of that form. This adaptation effect, observed under luminous-design conditions, is similar to the adaptation effects found with stabilized images. It provides additional support for the functional equivalence of the stabilized-image and luminous-design techniques and strengthens the notion that they tap similar perceptual processes (MacKinnon, Forde, & Piggins, 1969).

Whereas the results of Experiment 3 suggest that real contours may be fabricated, at least in part, by feature-analyzer mechanisms, they do not support Smith and Over's (1975, 1976, 1977, 1979) view that subjective contours result from fundamentally similar processes. No evidence for adaptation effects was noted among the subjective contours. Also, there was no evidence of adaptation across contours; that is, previewing a real or a subjective figure had no substantial effect on the subsequent fading of its opposite-contour analogue. In this regard, it may be instructive to recall that, while similar in other respects, the real figures were outline stimuli bounded by double edges, while the subjective figures were bounded by a single edge. From the point of view of the feature-detector hypothesis, the absence of adaptation effects among the subjective contours could be accounted for by arguing that fewer neural elements were triggered by these stimuli than by real figures. By the same token, however, one could also argue that the double-edge real figures should have exerted a strong adaptation effect on the single-edge subjectives, since the former would excite twice as many edge detectors during adaptation. In light of such an expectation, the fact that real contours did not adapt subjective ones is particularly notable.

The single-edge/double-edge difference is an im-

portant methodological element of this investigation. For reasons mentioned previously, these stimulus arrangements were selected because they seemed to us to be the most suitable for the luminous conditions that we employed. Nevertheless, one might question whether the single-edge/double-edge difference permits the conclusion that the results reflect a real-subjective contrast.

More specifically, it is conceivable that single-edge and double-edge stimuli generally fragment in different ways or that the single-edge double-edge difference precludes the observation of perceptual similarities between real and subjective figures. With respect to the first possibility, there is evidence that among real figures, fragmentation characteristics do not depend upon whether single or double edges are involved. Both types of stimuli have been utilized in luminous design and stopped-image paradigms and with both sorts of stimuli fragmentation occurs in a similar manner (McKinney, 1963; Pritchard, 1961; Schuck, 1973). As for the second possibility, a recent study by Meyer and Garges (1979) has shown that the single-edge/double-edge difference does not necessarily preclude the observation of similar perceptual effects among real and subjective figures.

All in all, the qualitative differences in the fading of real and subjective contours observed in Experiment 1 and the absence of adaptation effects with subjective contours in Experiment 3 lead us to the conclusion that real and subjective contours rely on different processes for their formation. It is worth noting that these results do not stand alone in suggesting that the perception of subjective contours cannot be explained solely on the basis of the excitation of neural-feature detectors. For example, Gregory (1972) has shown that, under appropriate conditions, two dots can supply enough information to produce a subjective contour, and Kennedy and Ware (1978) have demonstrated that subjective contours can arise from dotted inducing areas having no linear components with which to trigger feature analyzers.

Recently, Rock and Anson (1979) have offered a more cognitive solution to the conundrum posed by the perception of contours when none exist physically. Their approach might provide a reasonable framework within which the present results may be incorporated. They suggest that indentations in the inducing areas lead the perceptual system to formulate hypotheses as to the type of form most likely to produce such "bites" by occluding portions of the inducing areas. The configuration that best fits the stimulus array emerges as the perceived subjective figure. Gregory (1972) and Piggins (1975) have also favored an interpretation along these lines. According to this view, subjective contours reflect the end product of an inferential leap by the perceptual system (Kaufman, 1979). Some support for such a stance

comes from experiments demonstrating that variations in perceptual set can result in subjective contours becoming visible in homogeneous areas where they were previously not visible (Rock & Anson, 1979) and in subjective surfaces appearing curved where previously they were seen as straight (Bradley & Petry, 1977). To the extent that subjective contours are, indeed, less tied to local stimulation than are real contours, they may well be expected to be less stable than, and to fragment in ways that differ qualitatively from, real contours and, at the same time, to be more resistant to local adaptation effects.

REFERENCES

- BRADLEY, D. R., & PETRY, H. M. Organizational determinants of subjective contour: The subjective Necker cube. *American Journal of Psychology*, 1977, **90**, 253-262.
- BROWN, D. R., SCHMIDT, M. J., COSGROVE, M. P., & ZUBER, J. J. Stabilized images: Further evidence for central pattern processing. *Psychonomic Science*, 1972, **29**, 106-108.
- COREN, S. Subjective contours and apparent depth. *Psychological Review*, 1972, **79**, 359-367.
- DEMBER, W. N., & WARM, J. S. *Psychology of perception* (2nd ed.). New York: Holt, Rinehart & Winston, 1979.
- DUMAIS, S. T., & BRADLEY, D. R. The effects of illumination level and retinal size on the apparent strength of subjective contours. *Perception & Psychophysics*, 1976, **19**, 339-345.
- EAGLE, M., BOWLING, L., & KLEIN, G. S. Fragmentation phenomena in luminous designs. *Perceptual and Motor Skills*, 1966, **23**, 143-152.
- FRISBY, J. P., & CLATWORTHY, J. L. Illusory contours: Curious cases of simultaneous brightness contrast? *Perception*, 1975, **4**, 349-357.
- GREGORY, R. L. Cognitive contours. *Nature*, 1972, **238**, 51-52.
- HART, J. T. Luminous figures: Influence of point of fixation on their disappearance. *Science*, 1964, **143**, 1193-1194.
- HECKENMUELLER, E. G. Stabilization of the retinal image: A review of method, effects and theory. *Psychological Bulletin*, 1965, **63**, 157-169.
- JONES, P. D., & HOLDING, D. H. Extremely long-term persistence of the McCollough effect. *Journal of Experimental Psychology: Human Perception and Performance*, 1975, **1**, 323-327.
- JUNG, R., & SPILLMANN, L. Receptive-field estimation and perceptual integration in human vision. In F. A. Young & D. B. Lindsley (Eds.), *Early experience and visual information processing in perceptual and reading disorders*. Washington, D.C.: National Academy of Science, 1970.
- KAUFMAN, L. *Perception: The world transformed*. New York: Oxford University Press, 1979.
- KENNEDY, J. M., & WARE, C. Illusory contours can arise in dot figures. *Perception*, 1978, **7**, 191-194.
- MACKINNON, G. E., FORDE, J., & PIGGINS, D. J. Stabilized images, steadily fixated figures, and prolonged after-images. *Canadian Journal of Psychology*, 1969, **23**, 184-195.
- McKINNEY, J. P. Disappearance of luminous designs. *Science*, 1963, **140**, 403-404.
- McKINNEY, J. P. Verbal meaning and perceptual stability. *Canadian Journal of Psychology*, 1966, **20**, 237-242.
- McKINNEY, J. P. Handedness, eyedness, and perceptual stability of the left and right visual fields. *Neuropsychologia*, 1967, **5**, 339-344.
- MEYER, G. E., & GARGES, C. Subjective contours and the Poggendorff illusion. *Perception & Psychophysics*, 1979, **26**, 302-304.
- MYERS, J. *Fundamentals of experimental design* (3rd ed.). Boston: Allyn and Bacon, 1979.
- PIGGINS, D. J. Cognitive space. *Perception*, 1975, **4**, 337-340.
- PORAC, C. Depth in objective and subjective contour patterns. *Bulletin of the Psychonomic Society*, 1978, **11**, 103-105.
- PRITCHARD, R. M. Stabilized images on the retina. *Scientific American*, 1961, **204**, 72-78.
- ROCK, I., & ANSON, R. Illusory contours as the solution to a problem. *Perception*, 1979, **8**, 655-681.
- SCHMIDT, M. J., COSGROVE, M. P., & BROWN, D. R. Stabilized images: Functional relationships among populations of orientation-specific mechanisms in the human visual system. *Perception & Psychophysics*, 1972, **11**, 389-392.
- SCHUCK, J. R. Factors affecting reports of fragmenting visual images. *Perception & Psychophysics*, 1973, **13**, 382-390.
- SCHUCK, J. R., BROCK, T. C., & BECKER, L. A. Luminous figures: Factors affecting the reporting of disappearances. *Science*, 1964, **146**, 1598-1599.
- SKOWBO, D., TIMNEY, B. N., GENTRY, T. A., & MORANT, R. B. McCollough effects: Experimental findings and theoretical accounts. *Psychological Bulletin*, 1975, **82**, 497-510.
- SMITH, A. T., & OVER, R. Tilt aftereffects with subjective contours. *Nature*, 1975, **257**, 581-582.
- SMITH, A. T., & OVER, R. Color-selective tilt aftereffects with subjective contours. *Perception & Psychophysics*, 1976, **20**, 305-308.
- SMITH, A. T., & OVER, R. Orientation masking and the tilt illusion with subjective contours. *Perception*, 1977, **6**, 441-447.
- SMITH, A. T., & OVER, R. Motion aftereffect with subjective contours. *Perception & Psychophysics*, 1979, **25**, 95-98.
- STADLER, M., & DIEKER, J. Untersuchungen zum Problem virtueller Konturen in der visuellen Wahrnehmung. *Zeitschrift für Experimentelle und Angewandte Psychologie*, 1972, **19**, 325-350.
- STREIBEL, M. J., BARNES, R. D., JULNESS, G. D., & EBENHOLTZ, S. H. Determinants of the rod-and-frame effect: Role of organization and subjective contour. *Perception & Psychophysics*, 1980, **27**, 136-140.
- UTTAL, W. R. *The psychobiology of sensory coding*. New York: Harper & Row, 1973.
- WEISSTEIN, N. What the frog's eye tells the human brain: Single cell analyzers in the human visual system. *Psychological Bulletin*, 1969, **72**, 157-176.
- WEISSTEIN, N., MAGUIRE, W., & BERBAUM, K. A phantom-motion aftereffect. *Science*, 1977, **198**, 955-957.
- WOODWORTH, R. A., & SCHLOSBERG, H. *Experimental psychology* (2nd ed.). New York: Holt, 1954.

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