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Contour Interaction in Visual Space

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Technical Report

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This report summarizes work completed under the support of Contract N00014-76-C-1101, work unit number NR197-036, between Vanderbilt University and the Engineering Psychology Program, Office of Naval Research. The contract started on September 20, 1976 and was completed on April 30, 1981. The goal of the project was to determine if interactions among visual stimuli known to occur in 2-dimensional space are substantially

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altered when interacting elements are placed in 3 dimensions. Interaction, or interference, refers to changes in the perceptibility or appearance of stimuli that occur when placed in close spatial proximity to other stimuli. These interactions, which are known to influence the processing of information in visual displays, have been studied extensively in the 2-dimensional case. The extension to 3 dimensions, however, has been limited by technical problems associated with manipulation of stimuli simultaneously in X, Y, and Z axes.

The project overcame these limitations by using, as interacting stimuli, stereoscopic forms generated from random element stereograms. This permitted facile manipulation of stimuli in stereoscopic space without introducing potentially confounding changes in proximal stimulation. The interactive phenomena investigated were: (1) destructive interactions (threshold elevation) under transient threshold level conditions; (2) destructive interactions under suprathreshold conditions, (3) distortive interactions (changes in apparent length) under suprathreshold conditions, and (4) interactions imposed by the geometry of 3-dimensional space.

The major findings were as follows: (a) Separating the interacting stimuli in depth substantially modified their interaction. When a test stimulus was in a depth plane in front of inducing stimuli and closer to the observer, interaction declined as a monotonic function of the difference in depth separation between test and inducing stimuli. When depth positions were reversed and the test stimulus appeared in a depth plane behind the inducing stimuli and farther from the observer, the magnitude of the interaction tended to increase. This asymmetrical effect of depth position, which has been termed the "front effect", applied to both threshold and suprathreshold destructive interactions and to suprathreshold distortive interactions.

(b) The vertical dimension of stereoscopic visual space is tilted away from the observer. This tilt produces a difference in the threshold level perceptibility of stimuli above and below the horizontal line of fixation. Stimuli located above horizontal fixation and in crossed disparity had lower thresholds than those below fixation. This bias could be reversed by physical tilt of the stereoscopic display, and it did not alter suprathreshold characteristics of the stimuli.

Implications of these data for models of visual space and for the processing of information from 3-dimensional displays are discussed in the reports and papers summarized in this report.

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This Final Report describes work completed under the support of Contract N00014-76-C-1101, work unit number NR197-036, between Vanderbilt University and the Engineering Psychology Program, Office of Naval Research. The contract was initiated on September 20, 1976 and was completed on April 30, 1981.

Contour Interaction in Visual Space

Introduction

As the title indicates, this project investigated the interaction of visual stimuli as a function of their location in 3-dimensional space. Interaction is a general term referring to perceived changes in the attributes of a stimulus induced by adjacent stimuli which provide a context for it. These interactions can be destructive as manifested by a reduction in perceptibility of the stimulus at both the threshold and suprathreshold levels, or interactions can be distortive as manifested by changes in the apparent size or shape of a stimulus. One example of destructive interference is the phenomenon of visual masking, characterized by an elevation in the threshold of a transient stimulus when it is closely coupled in space or time with a second stimulus. Many examples of distortive interaction are provided by the geometric visual illusions. These kinds of interactive phenomena, which significantly influence the processing of information from visual displays, have been investigated extensively over the years. Yet almost all investigations have been confined to two dimensions in which the interacting stimuli are varied in X and Y axes while the Z-axis or depth dimension remains the same for all stimuli.

But there are some data and theory that suggest such interactions can be substantially changed or modified when the stimuli are in three dimensions, i.e., their Z-axis value varied. Furthermore, there is reason to believe that 3-dimensional space itself can exert a distorting influence on all stimuli within it. These effects would clearly influence the processing of visual information from stereoscopic displays. But their systematic investigation has been retarded by the difficulty involved in placing interacting contours in three dimensions without introducing confounding cues.

That difficulty was overcome in this project through application of a new technique for generating stereoscopic displays. Using that technique, the project investigated interaction of multiple contours in space and time at threshold and suprathreshold levels as a function of their loci in 3 dimensions.

General Approach

The key feature of the experimental method was the presentation of interacting stimuli as stereoscopic figures formed from dynamic random element stereograms. These stereograms consist of matrices of randomly ordered elements that contain no discernible contours when viewed under

nonstereoscopic conditions. When viewed under stereoscopic conditions, however, clear-cut stereoscopic forms at different positions in depth can readily be seen. The stereoscopic forms arise at a central stage within the visual system and do not engage peripheral stages (i.e., the retina). This feature permits changes in stimulus position and configuration to be made without introducing confounding changes in peripheral stimulation. In dynamic versions of the stereograms, all elements are randomly replaced many times a second; this rapid replacement provides a kind of camouflage which permits stereoscopic stimuli to be moved about in space and quickly presented without introducing nonstereoscopic cues.

The initial applications of dynamic random element stereograms were severely restricted by the expensive and cumbersome cinemagraphic and computer techniques necessary for their production. But recent advances in electronics have made it possible to generate stereograms using self-contained portable hardwired electronic devices. Such a system for stereogram generation has been developed at Vanderbilt and is part of an ongoing development program. A number of systems, varying in sophistication, have been devised. A description of one system is given in Shetty, Brodersen, and Fox (1979a, b).

All versions of the systems use as display devices modified video color receivers. These provide for the generation of red and green dot matrices, which when viewed through appropriate red and green filters, fulfill the requirements for stereoscopic viewing (i.e., the anaglyph method of stereoscopic presentation). Almost any conceivable physical form can be presented as a stereoscopic form by means of an optical programming device that acts to convert physical forms scanned by the device into their stereoscopic counterpart. Parameters of the stereoscopic form such as disparity magnitude and direction, position in X-Y coordinates, and exposure duration, can be quickly changed by the stereogram generation system. This flexibility allows the same rigorous psychophysical methodology used for conventional stimuli to be applied to stereoscopic stimuli.

Although stereoscopic stimuli arise from a central stage within the visual system, they are functionally equivalent in many ways to conventional physical stimuli defined by changes in luminance. For instance, stereoscopic contours can induce eye movements, aftereffects, and visual illusions. Some question, however, has been raised as to whether stereoscopic stimuli might be more susceptible to cognitive influences such as set and expectancy. But convincing evidence that such factors exert no special influence on stereoscopic stimuli was provided by Staller, Lappin, and Fox (1979, 1980) , who found that both physical and stereoscopic stimuli are processed in the same way.

In summary, stereoscopic stimuli formed from dynamic random element stereograms are an excellent vehicle for investigating the effect of depth position on stimulus interaction. Large changes in apparent depth can readily be made without introducing confounding (i.e., retinal) stimulation. Further, data obtained from stereoscopic stimuli can be generalized to the interaction of conventional stimuli. These features make stereoscopic stimuli the method of choice for the inquiry into the effect

of depth position described in subsequent sections.

Multiple Contour Interaction: Destructive interference at the threshold level

One of the most extensively investigated instances of destructive interference at threshold is visual metacontrast masking, wherein a slightly above threshold transient test stimulus is presented in close temporal and spatial proximity to a masking stimulus. Presentation of the mask after presentation of the test (backward masking) or before the test (forward masking) substantially raises the threshold of the test relative to the threshold obtained when the test is presented alone. The specific stimulus conditions that influence forward and backward masking are well-known and several well-articulated theoretical models have been developed. This research effort, however, has dealt exclusively with two dimensions, X and Y; the Z-axis value of both masking and test stimuli has remained the same. Since masking has been extensively studied in two dimensions, it is an ideal phenomenon for investigating the effect of differences in apparent depth position of test and mask. Such an investigation was carried out in experiments using test and mask configured from random element stereograms by Fox and Lehmkuhle (1978) and Lehmkuhle and Fox (1980). The main results of that investigation were as follows:

1. When test and mask had the same depth or Z-axis values, substantial masking was obtained. Further, many of its spatial and temporal characteristics were similar to those associated with the masking of physical contours. This similarity supports the view that stereoscopic stimuli are functionally equivalent to physical stimuli.
2. Forward masking occurred over a temporal range approximately three times that found during the masking of physical stimuli. This is consistent with other data that indicate the temporal response in stereopsis is relatively slow compared to nonstereoscopic stimulation.
3. Placing test and mask at different depths had a substantial effect on the magnitude of masking. When the test occupied a depth position that placed it in front of the mask and closer to the observer, masking decreased as a monotonic function of increases in depth between the test and the mask. When the relative depth positions were reversed and the test form was located behind the mask and further from the observer, masking was enhanced. The asymmetrical effect of depth position on masking was a new and unexpected observation that was termed the "front effect".
4. It was hypothesized that the front effect might reflect a bias of the visual system to give preferential treatment to the stimulus that is in front of another and closer to the observer.

Multiple Contour Interaction: Destructive interference under suprathreshold conditions

In this series of experiments, described in Fox and Patterson (1980), the effect of depth separation on lateral interference was examined. Lateral interference refers to the inhibitory interaction among spatially adjacent suprathreshold stimuli, as for example, that which occurs in strings of alphanumeric symbols. Interference

was produced by a continuously present suprathreshold circular stimulus whose contours surrounded a test stimulus. The effect of the interfering stimulus on the test stimulus was defined by two indices: (a) forced-choice recognition threshold of the test stimulus in the presence and absence of the interfering stimulus, and (b) ratings of the clarity of the test stimulus while it was continuously visible. The main results were as follows:

1. When both interfering and test stimuli were in the same depth plane, considerable interference was obtained.

2. Increases in the distance between the inner contour of the interfering stimulus and the outer contour of the test stimulus produced a monotonic decline in interference. This is consistent with the hypothesis advanced by Fox and Lehmkuhle that the inhibitory interaction seen in the front effect occurs only when stimuli are spatially close and have potentially competing visual directions.

3. Separation in depth of the interfering and test stimuli had a substantial effect on the magnitude of interference. The effect was asymmetrical and followed the pattern of the front effect described earlier. This outcome indicates that the front effect is not restricted to the transient threshold level stimulation associated with visual masking.

Multiple Contour Interaction: Distortive interference

The previous experiments demonstrated that depth position exerted a strong influence on destructive interactions. Whether this influence would apply to distortive interactions was the experimental question that was pursued later. The stimulus configuration chosen as a clear example of distortive interaction was one in which a change in the apparent length of line segments is induced when they are placed within the arms of an acute angle. Such a distortion occurs in many natural situations involving linear perspective gradients and, within the context of research in geometric visual illusions, it is known as the Ponzo illusion. As described by Fox and Patterson (1981a), the inducing triangle and the test lines enclosed within it were formed from dynamic random element stereograms, and the relative depth positions of the triangle and the lines varied. The main results were as follows:

1. When all contours were in the same depth plane, substantial distortion occurred of the same order of magnitude as that observed for physical contours. This similarity in magnitude supports the hypothesis that stereoscopic contours are functionally equivalent to their physical counterparts.

2. When the depth planes of the triangle and the test lines were varied, and the lines appeared in depth planes in front of the triangle, distortion decreased as a monotonic function of the depth difference between triangle and lines. When the depth positions were reversed, and the triangle appeared in a depth plane in front of the lines, distortion tended to increase. This pattern of results was virtually identical to that observed for the front effect.

Overall, the results support two general conclusions. First, depth

position appears to have a substantial effect on all classes of interactions. Second, the pattern of that influence as defined by the front effect appears to be a very general characteristic of depth position.

Effect of the Tilted Vertical Horopter

The previous experiments dealt with the effect of depth position on the interactions among stimuli and the asymmetrical nature of that effect. The experiments in this section examined an asymmetrical effect of 3-dimensional space itself on all stimuli within it. Recent research has suggested that the vertical dimension, or horopter, of visual space does not coincide with the gravitational vertical but tilts away from the observer, with the degree of tilt varying with observation distance. One consequence of the tilt would be to differentially bias the processing of stimuli above and below the horizontal line of fixation. Stimuli with crossed disparity located above horizontal fixation would be relatively more perceptible than those with crossed disparity below fixation. The characteristics of this tilt were investigated in five experiments that are described in Fox and Patterson (1981b). The main results were as follows:

1. Perceptibility of stimuli, defined in terms of changes in forced-choice recognition thresholds, did vary as a function of their location relative to the horizontal line of fixation: Stimuli above fixation had lower thresholds than those below it. This result is consistent with the hypothesis that the vertical horopter is tilted away from the observer.
2. The bias, or asymmetry, could be reversed by either physically tilting the visual display, or by changing the relative disparity between the fixation stimulus and the test stimuli. Theoretically, these results support the hypothesis that the vertical horopter remains tilted in a fixed position despite changes in physical tilt or in the location of the fixation stimulus. Empirically, the results suggest techniques that could be used to correct or compensate for the asymmetry.
3. The asymmetry does not seem to change the apparent size of objects as a function of their position (i.e., above and below fixation) in the display, nor did the depth relationships seem to require maintaining a fixed position of the head and eyes.

Overall, the results indicate that the tilted horopter, and its attendant effects on the processing of visual stimuli, is an intrinsic property of all stereoscopic and 3-dimensional displays.

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