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Relative Strength of Central and Peripheral Fusion as a Function of Stimulus Parameters

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ABSTRACT

We investigated the role of various stimulus parameters that influence motor fusion responses for peripheral as compared to central fusional stimuli. Results from the initial experiment indicated that a central stimulus equal in size to a peripheral fusion stimulus dominated the response independent of the amount of retinal eccentricity of the peripheral target. A second experiment indicated that the central stimulus dominated even when the peripheral stimulus was larger. However, when the peripheral stimulus was changed in shape so that it became an annulus surrounding the central stimulus, the peripheral stimulus was always stronger. In another phase of the experiment, we found that the extent to which a peripheral stimulus surrounded the central one determined which controlled the response. We concluded that the surrounding perceptual gestalt produced by the peripheral stimulus was the most significant variable determining the relative strengths of central and peripheral fusion stimuli. Clinical implications are discussed.

Key Words: binocular fusion, peripheral fusion, vergence, orthoptics, binocular vision

Burian[1] showed that peripheral targets as small as 1°, positioned 12° from the fovea, could initiate a fusional movement even though these peripheral targets were seen indistinctly by the observer. In a second experiment, Burian displaced a large annulus of print vertically while the subject fixated a central, solid, black circle which contained a fixation target. He reported that the eyes made a vergence fusional movement in response to the peripheral target as shown by the subject's report that the central target doubled. He concluded that peripheral fusion could disrupt central fusion and from this inferred that peripheral fusion was stronger than central fusion. This generalization was based upon experiments in which peripheral and central stimuli differed from each other by more than just a single attribute, e.g., size, configuration, detail, and the required direction of vergence demand.

Sullivan and Kertesz[2] measured both sensory and motor fusion responses to a peripheral/central stimulus. They reported that peripheral fusion stimuli were able to initiate a fusional response, with 75% of the response being motor and the remaining 25% being sensory. When both central circular and peripheral binocular stimuli were rotated in opposite cyclovergence directions, motor fusion responses, as evidenced by eye movements, occurred only for the peripheral target. Sullivan and Kertesz suggested that this finding indicated that peripheral fusion is stronger than central fusion.

Nauheim[3] compared divergence fusional amplitudes obtained with three distinct types of stimuli: (1) a ring subtending an angular measurement of approximately 5.5° with a central fixation point; (2) small peripheral vertical lines about 1.2° long located 5.5° from the central fixation point; and (3) a central fixation target which was identical in size and shape to the central fixation target described above. Findings indicated that fusional amplitudes were largest with the ring stimuli followed by the peripheral line stimuli. The smallest fusional amplitudes were found with the central target. Nauheim concluded that the most important characteristic of a stimulus needed to produce a fusional movement was the locus of points on the retina stimulated. Again, the interpretation of the results of this experiment are confounded because of a lack of control for size, shape, or stimulus parameters.

Ludvigh and associates[4] attempted to answer the question of which stimulus dominates when the two stimuli are of identical size, shape, and physical characteristics, but one is presented foveally and the other in the peripheral retina. They recorded vergence responses to foveal and parafoveal targets which were moved in a sinusoidal pattern. It was found that when the targets were moved as little as ¼° off the fovea, the vergence response decreased precipitiously. They concluded that central fusion stimuli were stronger than peripheral stimuli.

Lyle and Foley[5] also attempted to determine the relative influence of peripheral fusion on central fusion. They presented either polarized or anaglyphic dichoptic images to each eye from two tar-

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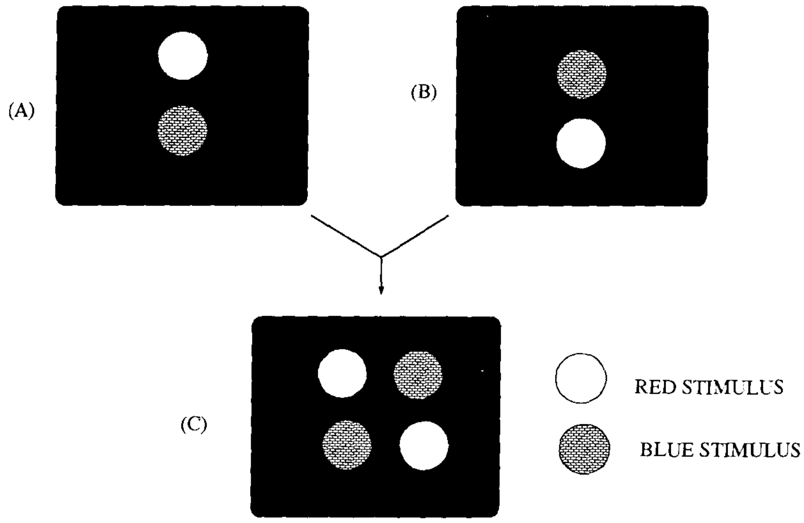
Figure 1. A depicts two stimuli, a red one on top seen by the right eye and a blue one on the bottom seen by the left eye. B shows what happens 0.0167 s later. The top stimulus is now blue and is seen by the left eye, whereas the bottom stimulus is now red and seen by the right eye. A and B are alternated at 60 Hz, and can be separated either horizontally or vertically. If A is moved horizontally to the right and B is moved to the left, then the top and bottom stimuli create opposing vergence demands. In C (the result of A and B), the top stimulus is convergent and the bottom one is divergent. Moving the panels in the opposite direction would reverse the vergence demand. Moving the panels vertically would create supra and infra vergence stimuli.



gets, a 0.5° centrally presented square and a peripheral square. The peripheral fusion target was either 2.5°, 5°, or 10° in size. Contrary to Burian, and Sullivan and Kertesz, they found that most of their subjects reported that the peripheral target doubled first, indicating that central fusion was stronger.

From the experiments described above, it is evident that there is some confusion as to the relative strengths of peripheral and central fusion. Because the peripheral retina occupies the greatest portion of the eye, it might be predicted that peripheral fusion would dominate over central fusion. However, the various studies cited offer contradictory results which are uninterpretable because of stimulus confounding. Initially, our study sought to determine the relative strengths of central and peripheral fusion stimuli, as a function of retinal eccentricity, when stimulus size and complexity were controlled. Subsequently, we investigated other stimulus parameters, e.g., peripheral stimulus size, shape, and retinal position, which we thought might influence fusional movements.

EXPERIMENT 1

Methods

Subjects. Four male and 4 female subjects, between the ages of 20 and 32 years (mean = 24 years), participated in this experiment. All wore their refractive correction, and were paid volunteers solicited from among graduate students and staff at the State College of Optometry. Subjects were required to have corrected Snellen visual acuity of 6/7.5, refractive error <±3.00 D, astigmatism <2.00 D, distance and near phoria <3 Δ, and no evidence of ocular pathology. Each subject also had to pass a Random Dot Stereogram test (Computer Orthopter) by correctly identifying the location of a 660° crossed-disparity target. Before experimental testing, all procedures were described and informed consent obtained.

Procedure. The anaglyph stimuli were produced on an Amiga 2000 HD computer and presented so that 2 images were alternately displayed at 60 Hz. One image contained two stimuli, one red and the other blue, on a black background. The other image had the stimuli in reverse order, one blue and the other red (see Fig. 1). Subjects wore red/blue analyph glasses. The red lens had a band cut off below 610 A°. It was placed over the right eye and totally eliminated the blue image from view. The blue lens had a band cut off above 490 A°. It was placed over the left eye and totally eliminated the red image from view. The images were designed such that horizontal or vertical movements produced an opposing vergence demand for the two stimuli.

Each subject viewed the stimuli, which were located 40 cm from the vertical center of a 65.5-cm, diagonal, RGB color video monitor, with his/her head positioned in a chin rest. Right and left eye stimuli were moved in equal increments to create a change in vergence demand at the rate of 1 D/s.

Initially, each trial consisted of the presentation of two equal-sized, 5.72° filled circles aligned vertically, i.e., one above the other. On one-third of the trials, the circles were spatially separated by either 5.72°, 8.58°, or 11.46° cm, yielding visual angles of the whole stimulus of 17.06°, 19.8°, or 22.68°.

During one-half of the trials a vertical vergence response, either supra or infra, was required in order to maintain fusion. The remaining one-half of the trials required a horizontal vergence response, either convergence or divergence, in order to maintain fusion. On some trials fixation disparity nonius lines were used in order to improve the accuracy of responding. Vergence direction was random with respect to the upper or lower circle. The order of trials was random except that horizontal and vertical vergence trials alternated so as to reduce vergence adaptation.

On each trial, the subject was required to fixate the center of either the lower or upper circle 50% of the time, randomly determined. The fixated circle was considered the central target. The subject was advised to "try to be aware of the other circle."

The nonfixated circle was called the peripheral target. After fixation, there was a progressive 1 Δ/s increase in vergence demand. In order to maintain fusion during a trial, the central and peripheral targets required opposing vergence responses. As soon as the limits of Panum's area were exceeded, each subject was told to report that either the "top" or "bottom" circle "doubled." This concluded a trial. The interval between trials was 10 s. Each subject was presented each of the 8 stimulus conditions 12 times for a total of 96 trials.

RESULTS

Initial statistical analyses of variance indicated that none of the following: open or solid circles; horizontal or vertical alignment of targets; superior or inferior position of the central target; fixation disparity lines; or, number of trials were significant factors. Thus, the present data analyses were collapsed across these conditions. Fig. 2 depicts the percentage of trials in which the peripheral stimulus doubled before the central stimulus as a function of vergence direction and retinal eccentricity of the peripheral stimulus. Statistical analysis revealed that neither retinal eccentricity ($F = 1.53$, $df = 2$, $p < 0.25$) nor vergence direction ($F = 1.93$, $df = 3$, $p < 0.15$) significantly influenced absolute performance. Although the interaction was significant ($F = 3.29$, $df = 6$, $p < 0.01$), *post hoc* Tukey analyses showed no significant differences due to these variables.[6] A One Sample t-test indicated that subjects reported the peripheral stimulus doubling before the central stimulus on significantly more trials, 18.67 or 78% ($t = 5.01$, $df = 7$, $p < 0.01$).[7]

EXPERIMENT 2

Experiment 1 showed that for equal-sized vertically aligned vergence stimuli placed at various eccentric positions from the fovea, the central stimulus dominated the fusion response. This was true under both horizontal and vertical fusional vergence conditions. Experiment 2 addressed the question of how large the peripheral fusion target had to be made before it became stronger than the central target. We also investigated the situation where the peripheral stimulus surrounded or enveloped the central stimulus in order to reconcile Burian's findings that peripheral fusion is stronger than central fusion.

Methods

Subjects. Ten new, experimentally naive, subjects, 5 males and 5 females, between the ages of 20 and 35 years (mean = 24 years), were tested. The inclusion/exclusion criteria were identical to those used in Experiment 1.

Procedure. Stimulus presentation was similar to Experiment 1. Each subject viewed various stimuli during six different experimental conditions: (1) increase in peripheral target size at moderate (see Fig. 3) and (2) small retinal eccentricity (see Fig. 4); (3) increase in size of peripheral annulus target surrounding a filled circle without (see Fig. 5) and (4) with target boundary separation (see Fig. 6); (5) variation in detail of background surround of the peripheral target (see Fig. 7); and (6) increase in amount of peripheral stimulus envelopment or surround (see Fig. 8). The different stimulus conditions were presented randomly, with each subject receiving three trials of each condition.

In the first two experimental conditions (1) and

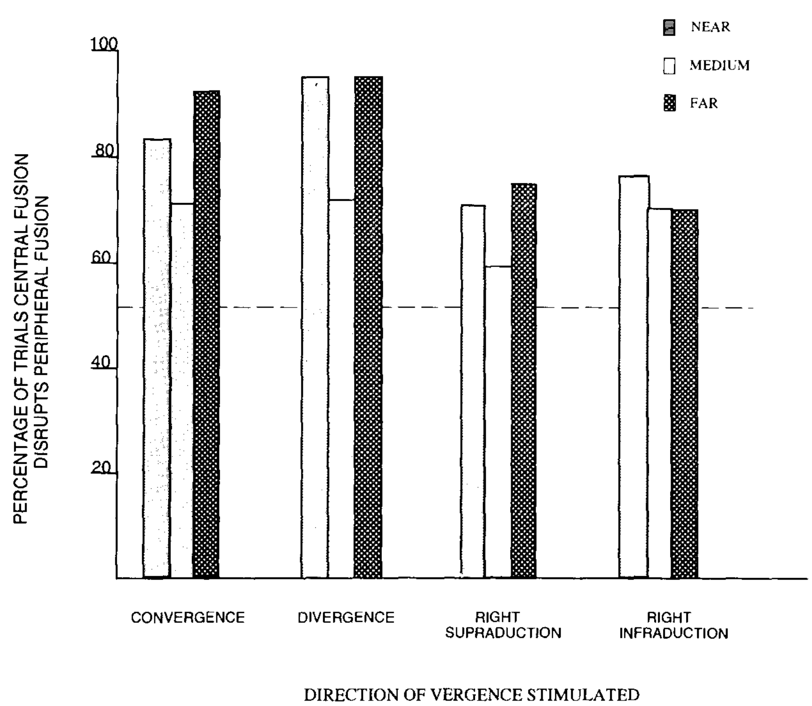


Figure 2. The percentage of trials that the central fusion stimulus disrupted peripheral fusion as a function of vergence direction and retinal eccentricity when the stimuli are identical in shape and size. The legend indicates the retinal eccentricity, near, medium, and far, of vertically aligned central and peripheral stimuli. Note that the central fusion stimulus dominates the response.

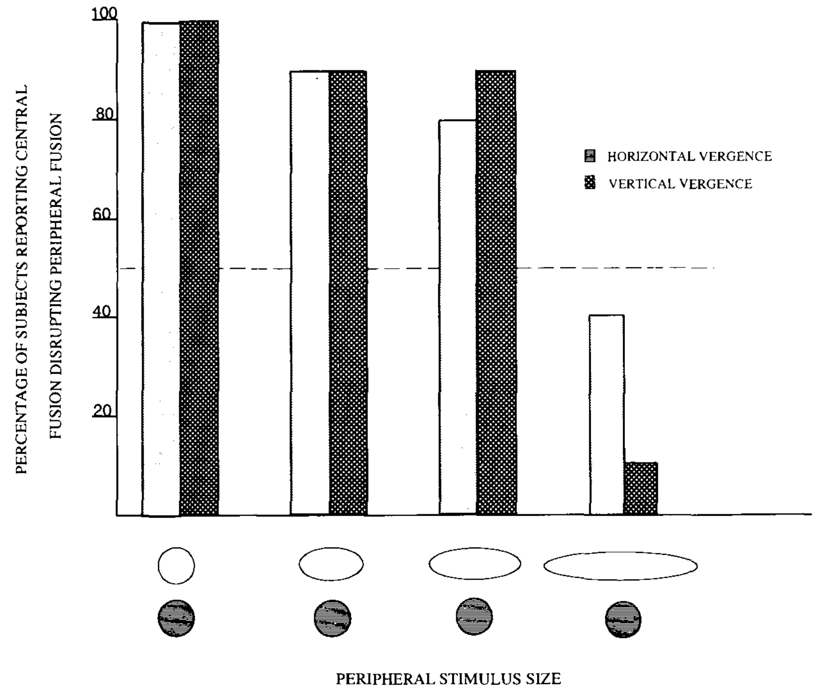


Figure 3. The percentage of subjects reporting that central fusion disrupts peripheral fusion as a function of increased peripheral stimulus size, under moderate retinal eccentricity conditions. Horizontal and vertical fusion responses are shown.

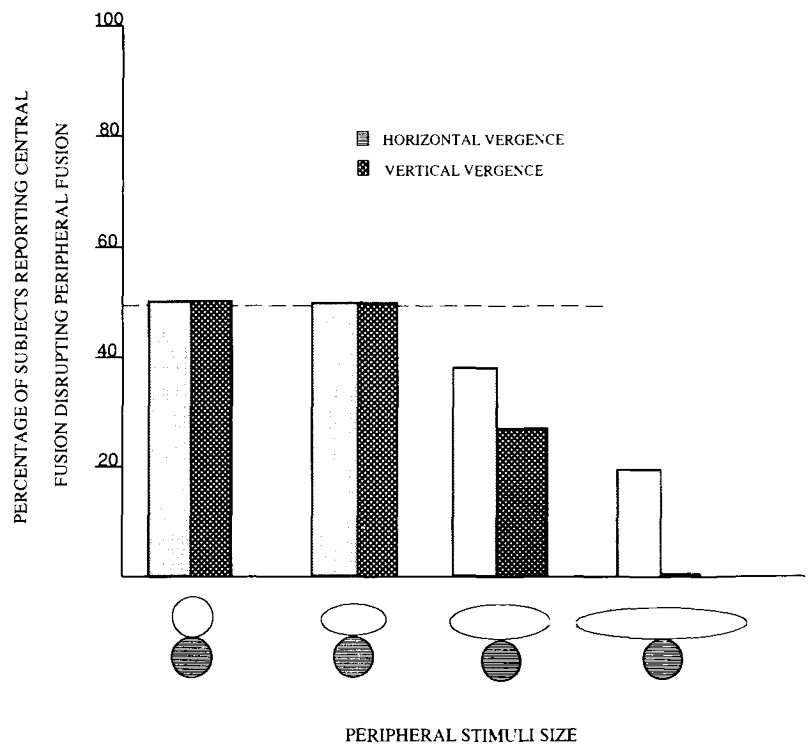


Figure 4. The percentage of subjects reporting that central fusion disrupts peripheral fusion as a function of increased peripheral stimulus size, under minimal retinal eccentricity conditions. Horizontal and vertical fusion responses are shown.

(2) increasing peripheral target size, each trial consisted of the presentation of two filled circles aligned vertically. There was either a moderate, 5.72°, or minimal, 0.0°, separation between the circles, i.e., retinal eccentricity. The central target was always a 5.72° circle. The peripheral target was an ellipse of 5.72° along the vertical axis, and was either 5.72°, 14.26°, 25.36°, or 28.06° along the horizontal axis (see Figs. 3 and 4). In the second set of experimental conditions (3) and (4), the independent variable was an increase in the size of the peripheral stimulus annulus. The central stimulus was a 5.72° circle, completely surrounded by a peripheral annulus making the total visual angle either 6.44°, 11.4°, or 17.06°. On one-half of the trials, a 0.72° black segment or boundary separated the central stimulus from the annulus, making the total visual angle 7.86°, 12.84°, or 18.46° (see Figs. 5 and 6). In experimental condition (5), the peripheral target was varied by the type of stimulus sur-

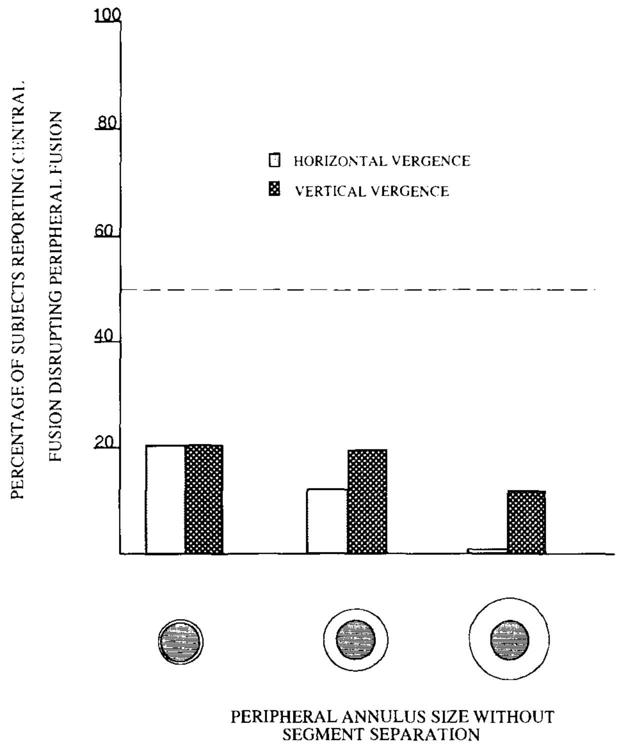


Figure 5. The percentage of subjects reporting that central fusion disrupts peripheral fusion as a function of increased peripheral annulus size, without central stimulus-peripheral annulus stimulus segment separation. Horizontal and vertical fusion responses are shown.

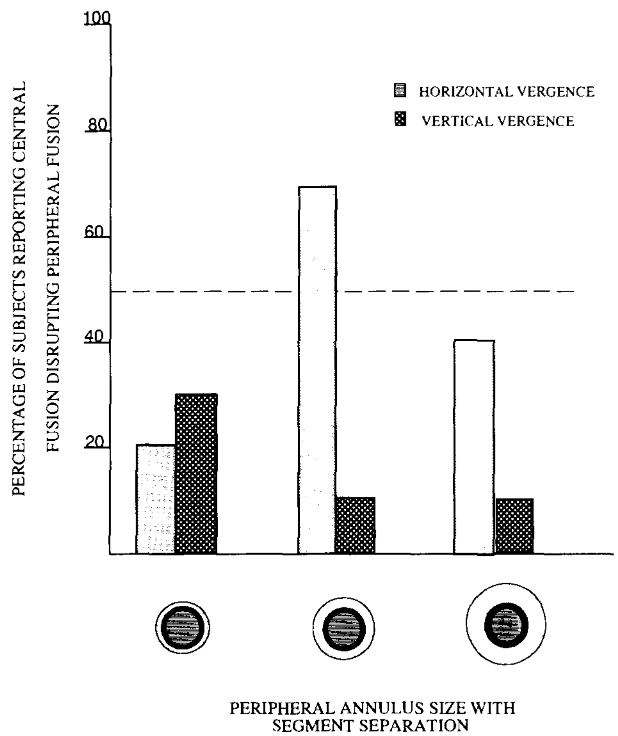


Figure 6. The percentage of subjects reporting that central fusion disrupts peripheral fusion as a function of increased peripheral annulus size, with central stimulus-peripheral annulus stimulus segment separation. Horizontal and vertical fusion responses are shown.

round. Again, a 5.72° central target was used. Five qualitatively different peripheral stimulus backgrounds, which surrounded the central target, were presented (see Fig. 7): four equidistant 0.72° by 4.28° rectangular bars; four equidistant 0.72° by 4.28° semi-circle bars; four equidistant 1.42° circles; eight equidistant 1.42° circles; and, a random pattern background. The total visual angle was 11.42°. In the last experimental condition, (6), the extent to which a 0.72° by 11.4° peripheral stimulus surrounded a 5.86° central circular target was varied. The peripheral stimulus was seen either as a rectangular bar sitting on top of the central circle, a slightly downward curved incomplete annulus partially enveloping the circle, or a semi-circle (see Fig. 8).

As in Experiment 1, both horizontal and vertical fusional vergences were assessed. The order of trials was random except that horizontal and vertical vergence trials alternated so as to reduce vergence adaptation. On each trial, the subject was instructed to fixate the central stimulus and to "try to be aware of the peripheral stimulus." After central stimulus fixation, vergence demand progressively increased until the subject reported diplopia.

RESULTS

Fig. 3 shows what happens when the peripheral stimulus, located 5.72° above the top of the central target, is increased in size along the horizontal axis. It is apparent that the central stimulus dominated the fusion responses for about 90% of the subjects when the peripheral stimulus was increased in size. According to nonparametric statistical analyses,[8] only when the largest peripheral stimulus was presented was there a smaller percentage of subjects, about 30%, reporting that the central stimulus dominated both for horizontal (Cochran $Q = 15.8$, $p = 0.007$) and vertical fusion (Cochran $Q = 21.8$, $p = 0.00007$) conditions. Pairwise *post hoc* McNemar analyses also supported this finding for both vergence conditions ($p < 0.03$). Thus, except for the largest peripheral stimulus, most subjects reported that the central stimulus dominated.

Fig. 4 depicts the same experimental condition described above except that the peripheral stimulus was now separated from the central stimulus by 0.0°. Here, about one-half of the subjects reported that the central stimulus was stronger under most conditions. Only when the peripheral stimulus was the largest did most subjects report that fusion broke first on the central stimulus. Significant differences due to size were found for horizontal (Cochran $Q = 11.5$, $p = 0.02$) and vertical vergence (Cochran $Q = 19$, $p = 0.008$) conditions. *Post hoc* McNemar analyses also supported this finding for vertical fusion conditions for the largest peripheral stimulus compared to the smallest ($p < 0.03$).

When the peripheral stimulus was changed to an annulus surrounding the central stimulus, findings changed dramatically. Figs. 5 and 6 show the effects of increasing annulus size, without and with a 0.72°

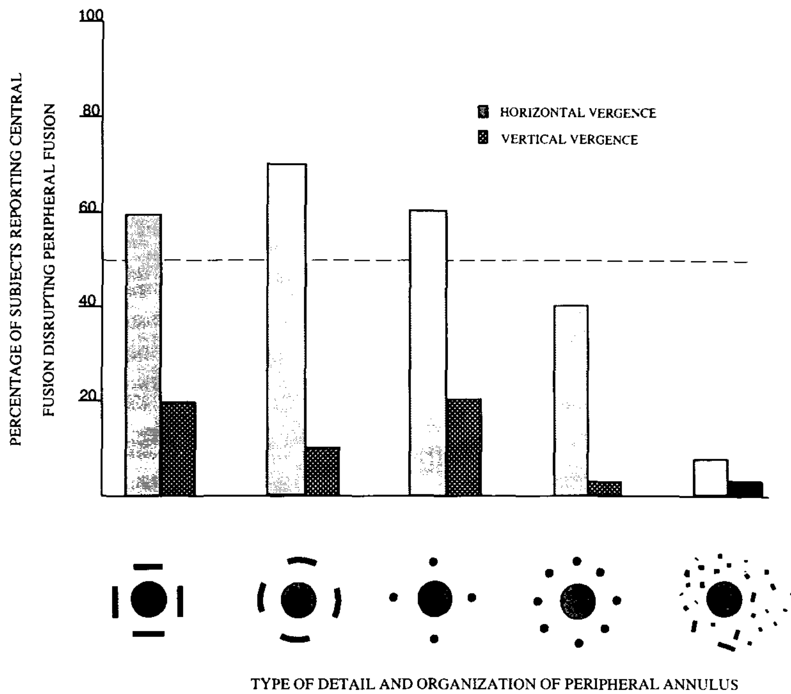


Figure 7. The percentage of subjects reporting that central fusion disrupts peripheral fusion as a function of five qualitatively different types of peripheral annulus. Horizontal and vertical fusion are shown.

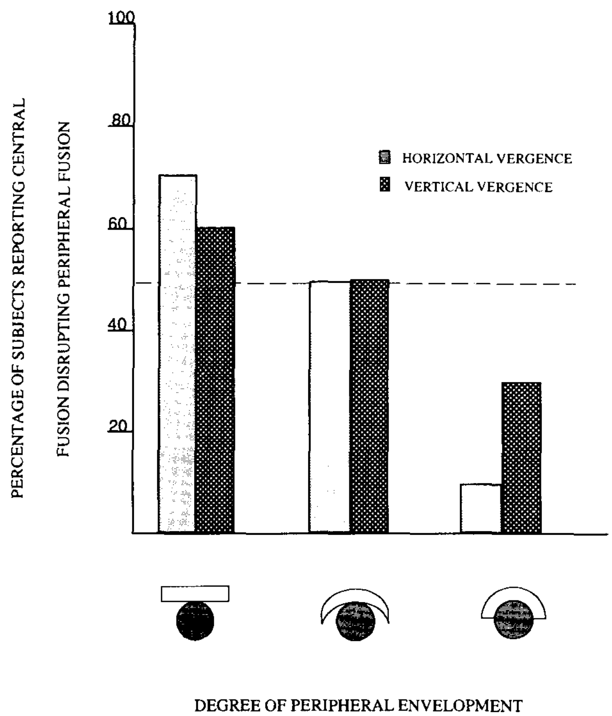


Figure 8. The percentage of subjects reporting that central fusion disrupts peripheral fusion as a function of the degree to which the peripheral stimulus surrounds the central stimulus. Horizontal and vertical fusion responses are shown.

black segment separating the two stimuli. It is apparent that the peripheral stimulus completely dominated the response for most subjects under most conditions. Cochran Q analyses indicated no statistically significant differences due to increases in peripheral stimulus size for stimuli with or without segment separation, or under horizontal or vertical fusion conditions.

Fig. 7 shows what happens when the qualitative detail of the surrounding peripheral stimulus is independently varied for a given central stimulus. Once again, the surrounding peripheral stimulus background dominated the response independent of the type of detail for vertical fusion conditions, with less than 20% of the subjects reporting central fusion disrupting before peripheral fusion. However, peripheral stimulus control was less evident under horizontal vergence. Cochran Q statistical analyses indicated no significant differences between the kinds of peripheral stimuli used for either vertical or horizontal vergence.

Fig. 8 shows what happens when the extent to which the peripheral stimulus surrounds the central stimulus is systematically increased. As can be seen, as the amount of surround increased, the peripheral stimulus tended to control the response. Although significant differences between the amount of surround occurred only under horizontal fusion conditions (Cochran $Q = 6.2$, $p < 0.04$), it is also clear that more subjects reported the peripheral stimulus dominant as the surround increased under vertical fusion conditions.

DISCUSSION

It is evident that when equal-sized fusional stimuli are placed at various eccentric positions from the fovea, central stimuli dominate the fusional response. This was true with either horizontal or vertical vergence conditions. In Experiment 2, we posed a number of questions; the first was how large the peripheral target had to be before it became stronger than the central stimulus. Our findings indicated that only when the peripheral stimulus became approximately seven times larger than the central did it begin to dominate. Our results were similar to those reported by Lyle and Foley,[5] but different from those reported by Burian,[1] and Sullivan and Kertesz,[2] in that central fusion stimuli seemed stronger than peripheral stimuli.

To investigate the discrepancy between our findings and those of Burian, Sullivan and Kertesz, we repeated the experiment using a central circular stimulus surrounded by a peripheral annulus. Our findings were now consistent with Burian's. The peripheral stimulus dominated independent of annulus size or segment separation. In order to investigate the effect of various parameters of peripheral stimulus surround, the peripheral stimulus was presented as various background patterns surrounding the central target. Again, the peripheral stimulus typically dominated. Finally, we increased the extent to which the peripheral stimulus surrounded the central one, e.g., from tangential contact to partial surround. These results showed that the most important variable controlling fusional movements was the extent to which the peripheral stimulus surrounded the central stimulus. Discrete nonsurrounding targets, falling only slightly off the fovea, had a much weaker influence over fusion than did surrounding targets. One possible explanation for this might relate to the perceptual phenomenon of "gestalt" or wholeness that is provided by peripheral stimulus surround. However, this hypothesis is only suggestive and requires future research.

These findings also have clinical implications. For example, patients who develop significant maculopathy would be expected to maintain fusion because a peripheral fusion annulus is stronger than a central fusion stimulus, which can on longer be perceived due to disease. On the other hand, patients with a heminopsia would be less likely to maintain fusion and would complain of misaligned or diplopic views. From an orthoptic standpoint, large annulus-shaped targets should be used initially to invoke a stronger response than simple discrete targets in both testing and training fusional amplitudes. Therapy should progress from improving vergence amplitudes first with large surrounding stimuli which evoke a peripheral response, and later to small central stimuli.

In summary, the present study has confirmed Burian's, and Sullivan and Kertesz's findings in that peripheral fusion can disrupt central fusion. We have also confirmed the findings of Ludvigh and associates, and Lyle and Foley that central fusion can dominate peripheral fusion. We have accounted for the discrepancy between the above findings by noting that peripheral stimulus surround is a controlling factor. When present, these stimuli dominate central fusional targets. When peripheral surround is lacking, or when the central and peripheral targets are spatially discrete, central targets usually dominate over identically shaped discrete peripheral fusion targets. This result is independent of size and retinal locus.

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