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THE EFFECTS OF CENTRAL AND PERIPHERAL BINOCULAR VISUAL FIELD MASKING ON FUSIONAL-DISPARITY VERGENCE

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Abstract

Clinicians have long recognised the effectiveness of the peripheral fusion mechanism in eliciting fusional movements and have employed this in the investigation and treatment of squint. In 1939, Burian was the first to demonstrate that fusible stimuli placed in the peripheral binocular field only, were capable of producing fusional movements. The aim of the present study was to investigate the effects of masking of the central and peripheral binocular fields to determine the influence of each on the horizontal fusional amplitudes, and on the duration of jump fusional-disparity convergence movements in normal binocular vision. Twenty one (n=21) young adult subjects took part in the study. The fusional amplitudes were measured with a Risley rotating prism. The jump vergence movements were assessed using an infra-red eye movement recording system. Measurements were performed at 3 meters using full, central and peripheral field stimulus conditions. It was found that under central stimulation, the fusional amplitudes for both base-in (p=0.0008) and base-out (p<0.0001) directions were significantly lower than those under peripheral stimulation. Also, peripheral field masking significantly prolonged the duration of a disparity vergence response induced by a 10Δ base-out prism (p=0.0009), but not by one of 5Δ (p=0.0507). It was concluded that peripheral fusion plays an important role in the production of fusional-disparity vergence eye movements.

Key Words: *Peripheral fusion, peripheral field masking, fusional amplitudes, disparity vergence, jump convergence.*

INTRODUCTION

Clinicians have long recognised the effectiveness of the peripheral fusion mechanism in eliciting fusional movements and have employed this in the investigation and treatment of binocular dysfunction and squint. Even when orthoptics was still in its infancy, Swan and Laughlin[1], in 1944, emphasised the importance of utilising peripheral fusion to train fusional reserves in amblyopic patients with anomalous binocularity. Similarly, Burian[2] stressed the place of peripheral fusion in orthoptic training. Indeed, orthoptists have moved away from training patients with anomalous binocular vision[3], but the use of peripheral stimulation in strabismic patients with 'normal binocular functions' is still advocated[4]. This is certainly the case in the assessment and treatment of the vergence system's dysfunctions[5-8]. However, despite the acceptance of peripheral fusion as a

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powerful factor in the production of fusional movements and the current knowledge of the intricacies of the vergence system, little research has been done into the relative contributions of the peripheral and central fusion mechanisms to fusional vergence. This paper will attempt to address the effects of peripheral and central fusion, firstly on the horizontal fusional vergence amplitudes, and secondly on the duration of a jump convergence movement.

In 1939, Burian[9] was the first to demonstrate that fusible stimuli place in the peripheral binocular field only, were capable of producing fusional movements. In that experiment, targets subtending angles of 0.5° and 1° were haploscopically projected 12° from the fovea and separated vertically to produce fusional sursumvergent movements. Hampton and Kertesz[10] and Winkelman[11] carried out similar investigations and confirmed Burian's findings. In another experiment in which a solid black circular target was surrounded by an annulus of print, Burian[9] found that peripheral fusion could dominate central or foveal fusion and disrupt it if the peripheral stimuli covered a sufficient area. In spite of the subjects' attempts, the central diplopia could not be fused as long as the disparate peripheral stimuli were present. Burian concluded that the peripheral retina plays an important part in the fusion process.

Since Burian[9] introduced the now widely used term *peripheral fusion,* similar findings have been reported[11-15]. Sullivan and Kertesz[14] demonstrated the influence of the peripheral and central binocular fields on the cyclofusional response. They concluded that peripheral fusion exercises a stronger influence than central fusion on cyclovergence or motor cyclofusion. Using objective recording, it was found that the largest target (50° in diameter) produced the greatest cyclovergence component of the response, this being about 60% of the total cyclodisparity (5.75°). In fact, targets of less than 30° apparently did not induce any motor component. Also, when conflicting torsional disparities in the centre and periphery were simultaneously presented, cyclovergence only occurred in the direction of the peripheral disparity. Furthermore, when the torsional disparity in the central 30° region was removed, an even greater cyclovergence component was found, this being about 76% of the total cyclodisparity. It would appear then that the presence of central field stimulation actually hindered the motor response. However, it must be pointed out that only one subject underwent all the experiments and that this subject demonstrated a training effect on immediate retesting that diminished on a subsequent test session about one month later.

Kertesz[7] also investigated the effect of increasing peripheral stimulation on horizontal and vertical fusional responses. It was found that increasing the stimulus size from 5° to about 58° resulted in a three-fold increase of the horizontal fusional range in both of the subjects tested. Indeed, the average increase in the two subjects tested was from 9.04° and 10.98° to 27.75° and 26.62°, respectively. Kertesz and co-workers[16,17] also demonstrated that step disparities of 1.5 and 5° could induce jump vergence movements (in both convergent and divergent directions) when the large-field stimulus of one eye contained a 10° central scotoma. It is evident therefore that increasing levels of vergence stress and jump vergence to step disparities can be sustained by the peripheral fusion mechanism alone.

That peripheral fusion plays an important role in producing fusional vergence movements has therefore been supported clinically and experimentally by many researchers. However, the belief that peripheral fusion is a more powerful force than central fusion has been disputed by other researchers[18-20]. Lyle and Foley[20] employed a central fusion stimulus of 0.5° and varying peripheral stimuli of 2.5°, 5° and 10° presented either anaglyphically or by polarisation. They found that most of their subjects (64% with the red-green method and 80% with the polaroid test) reported peripheral target doubling before central, indicating that central fusion was the stronger mechanism.

Ludvigh and co-workers[18,19] objectively recorded fusional convergence movements made in response to small (6 x 25') targets positioned at 0°, 0.25°, 0.5°, 1°, 2° and 4° from the fovea. It was demonstrated that even when the stimuli were positioned as little as 0.25° off centre, the vergence response decreased in all three of their subjects tested (even though 0.25° or 15' is certainly within the normal limits of fixation disparity[21] and is smaller than the precision of fixation itself[22]). These findings therefore suggest that fusional responses made to identical stimuli are maximal when they are foveally positioned. However, it may be of significance that the target was moved at a rate of 1.1° per second, and that it has previously been reported that peripheral fusion is more robust with prolonged exposure time of the peripheral stimulus[11]. In another experiment that was similar to Burian's[9], Ludvigh et al[18,19] used competing peripheral stimuli (consisting of six concentric split rings) in an attempt to interrupt central fusion. They found that these "powerful peripheral stimuli" were incapable of disrupting central fusion "except, perhaps, momentarily" (Ludvigh et al[19], 1965, p. 120).

It is clear from the above studies that there is some confusion as to the relative contributions of the peripheral and central components of the binocular visual field to the fusional response. Indeed, while there is general agreement that the peripheral fusion mechanism is effective in producing fusional movements and can, in fact, sustain a position of orthotropia or microtropia in the absence of central binocularity[23,24], some quite contradictory findings are apparent in the literature. This problem was recently addressed by Cooper, Feldman and Eichler[25]. In their initial experiments, it was demonstrated that central fusion was dominant, firstly when equal-sized stimuli were placed at various retinal eccentricities, and secondly when larger peripheral stimuli were used. Hence, their findings confirmed those of Lyle and Foley[20] and Ludvigh et al[18,19]. However, a subsequent investigation using a central circular stimulus surrounded by a peripheral annulus produced converse findings: that peripheral fusion dominated. This explains and is consistent with the results of Burian[9] and Sullivan and Kertesz[14], but not of Ludvigh et al[18,19], whose experiments were all very similar. Finally, Cooper et al[25] increased the extent to which the peripheral stimulus surrounded the central one and found that this was the most important variable controlling fusional movements. Although this was a most important finding and explained the discrepancy in the literature over the previous five decades, it must be acknowledged that Burian[9] (1939, p. 489) had previously stated:

> "One of the most important results ... is that peripheral retinal stimuli are strong enough to break the fusion of images situated on corresponding areas of the macular region, provided they cover a sufficient area...".

Previously, most studies that have addressed the issue of peripheral versus central fusion used stimuli that were projected haploscopically and usually in the dark. To the author's knowledge, no study has attempted to determine the relative contributions of the two mechanisms to normal fusional vergence by masking of parts of the binocular visual field. It is the aim of this study to address the effects of central and peripheral field masking, firstly on the positive and negative fusional vergence amplitudes, and secondly on the duration of a jump convergence movement induced by prismatic step disparity.

METHOD

Subjects

Twenty one (n=21, mean and median age=19 years) orthoptic students, semi-naive to vergence testing, participated in this study. All subjects had normal bifoveal binocular single vision, meeting the following inclusion criteria:

i. random-dot stereoacuity to 550" on the Lang stereotest;

ii. no heterotropia on cover test;

*iii.*no significant esophoria (>2Δ), hyperphoria (<Δ2) or exophoria (>6Δ) on alternative cover testing at 3 meters;

iv. bifoveal motor fusion response on the 4Δ prism test. Two of the subjects had a small amount (<-2.00 DS) of myopia that was corrected for testing.

Apparatus

Objective recording of the fusional vergence movements was done using the Ober-2 Eye Movement Registration System (*Permobil Meditech AB*, Timrå). The principle of this infrared unit is the differential reflective properties of the iris and the sclera. It involves the subject wearing goggles that house an emitting light source and two pairs of infrared sensitive photoelectric cells that intercept the reflected light. As the eye moves, the cell in the direction of movement receives less illumination since the infrared light is absorbed by the iris, while the other cell receives more illumination from light reflected off the sclera. The amplitude of the potential change from the cells is proportional to that of the eye movement. Recordings were made with the sampling rate set at 100 Hz. The unit's goggles have been fitted with a pair of Halberg clips on which trial frame type glass prisms were mounted during the experiments. The fusional vergence amplitudes were measured using a Risley rotary prism and glass trial frame prisms. The fixation target consisted of a full sized Bailey-Lovie LogMAR visual acuity chart, modified with a 6/12 sized letter on a white background in the centre. Peripheral field masking was achieved using a thin tube (18mm in diameter, 95mm in length) mounted onto a circular trial frame lens holder. This allowed an 8° central binocular visual field. Central field masking was achieved by an after-image produced by a visuscope. This precluded binocular vision in the central 8° of the visual field[26].

Procedure

All measurements were performed at a fixation distance of 3m. The subjects were instructed to fixate the 6/12 letter on the LogMAR chart fixation unit which was positioned at eye level. The testing was carried out in an artificially lit room of 360 lux.

Testing under full (central-plus-peripheral) binocular field stimulation was done first. This was followed by peripheral binocular field masking with the tube before the left eye. It was ensured prior to each measurement that the subject saw the fixation target inside the central field of the left eye. Testing with central binocular field masking, was accomplished using a visuscopic afterimage applied to the left eye for 30 seconds. Holding the visuscope close to the left eye while closing the right, the subject was instructed to fixate only the star in the centre of the grid, so that no more than the central 8° of the retina was 'bleached'. Foveal fixation was confirmed objectively during the 30 seconds. This process was repeated before each measurement or recording in order to maximise the central masking effect. Testing under peripheral stimulation was performed last, that is, after the fusional amplitudes were measured and jump convergence responses recorded under both full and central stimulation, since complete visual re-adaptation did not occur for at least several minutes afterwards.

The fusional vergence amplitudes were assessed first, the base in (BI) direction being measured before base out (BO). A larger sized letter was fixated when the BO amplitude was being measured, since the increasing convergence accommodation would have blurred the 6/12 letter. The total values were adjusted appropriately when the prisms were divided between the two eyes or stacked upon each other[27]. The limits of the fusional vergence amplitudes were recorded as being the strongest prism that would allow single vision to be maintained. When measuring under peripheral stimulation only, the subject was instructed to take note of peripheral diplopia, that is, doubling of the edges of the LogMAR chart, as central diplopia would not be appreciated.

The jump convergence responses to prisms were recorded after measurement of the fusional amplitudes. The 5Δ BO prism response was tested before the 10Δ response, firstly under full field† and then central field stimulation. The responses under peripheral stimulation were assessed afterwards. The subject was positioned at a head and chin support unit with a BO prism before the right eye which was

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† The unit's goggles restrict the binocular visual field to at least 60° horizontally and 40° vertically.

neutralised by a BI prism. At the onset of the recording, the BI prism was quickly removed from the goggles' trial frame, effectively creating a step convergent disparity of 5Δ. The subject was instructed to join the resultant double images as quickly as possible and remain fixating on the target.

The beginning of a vergence movement in response to a prism disparity was in most instances (83.9%) preceded by a saccade, with or without a vergence component, in the direction of the prism apex. As this *vergence saccade* has been thought to play an important role in the execution of a vergence movement[28,29], it was included in the duration measurement of the vergence response. Therefore, the time taken to fuse the BO prism included the vergence phases as well as this initial unequal saccadic movement (and any other vergence saccade that may have been apparent during the fusional vergence response). A typical recording is shown in Figure 1.

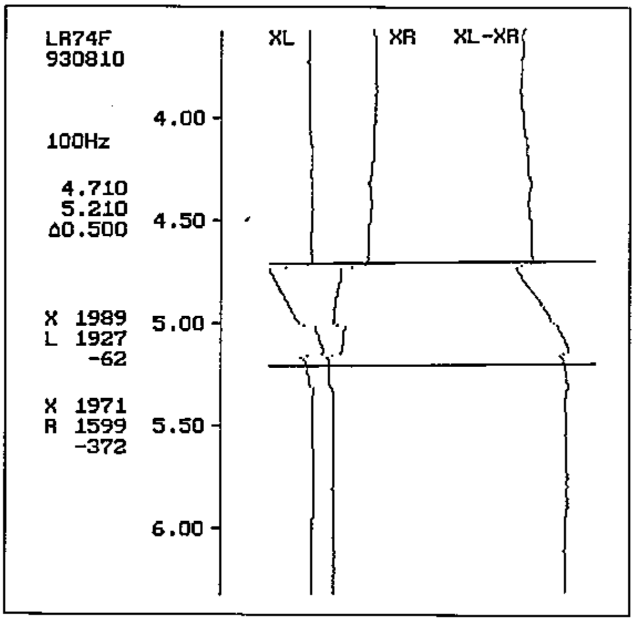

Figure 1. A typical recording of a 10Δ BO response (prism before RE) under full stimulation. XL is the trace of the left eye, and XR the right. Lefward movement of the trace indicates that the eye is moving to the left. XL-XR represents the difference between the two eyes and therefore indicates changes in vergence. For this trace, rightward movement indicates overall convergence and leftward movement indicates overall divergence. The upper calibration line indicates the beginning of the response and the lower line indicates the end, the duration of this response being 0.50 seconds.

Data Analysis

The statistical tests used were: the 1-way (single factor repeated measures design RMD) analysis of variance (ANOVA) test and the 2-way (2 factor RMD with 2 repeated measures) ANOVA. The level of significance (∞) was set at 0.05.

RESULTS

Fusional vergence amplitudes

The mean BI amplitude for full field stimulation was 5.91Δ (with a standard deviation, sd, of 1.45). For central stimulation, the mean was 5.57Δ (sd=1.91), while for peripheral stimulation it was 6.86Δ (sd=1.96) (Table 1.). The BI amplitudes for peripheral stimulation were significantly higher than those for full and central stimulation ($F_{2,40}=8.505$, p=0.0008).

Table 1
Summary table of result means

		Stimulus Field		
		Full	Central	Peripheral
Fusional vergence amplitudes	BI (Δ)	5.91	5.57	6.86
	BO (Δ)	36.29	18.38	36.24
% subjects able to converge to	5Δ	100	100	96.2
	10Δ	100	76.2	100
Duration (s) of prism responses to	5Δ	0.45	0.67	0.52
	10Δ	0.72	1.79	0.71

The mean BO amplitude for full field stimulation was 36.29Δ (sd=10.48). For central stimulation, the mean was 18.38Δ (sd=5.87), and for peripheral stimulation it was 36.24Δ (sd=8.49) (Table 1.). As would be expected from these values, the BO amplitudes for both full and peripheral stimulation were significantly higher than those for central stimulation ($F_{2,40}=54.863$, p<0.0001).

Execution of jump convergence movement to a step disparity.

All subjects were able to execute a jump convergence movement to a 5Δ BO prism under all three stimulus conditions (Table 1.) However, two recordings were excluded from the statistical analyses: one subject's 5Δ response to peripheral stimulation was accidentally deleted from the computer's hard disc; in another subject, the 5Δ response to peripheral stimulation was not clear, even on a repeated recording. In fact, the response appeared more like a divergence movement when the recording was analysed.

All of the subjects were able to execute a jump convergence movement to a 10Δ BO prism under full and peripheral field stimulation, however, under central field stimulation, only 16 of the 21 (76.2%) subjects could do so (Table 1.). The 5 subjects who could not fuse the prism, in fact, noticed diplopia for the whole 20 second recording period.

Effect of peripheral and central field masking on duration of the jump convergence movements to a step disparity.

The mean duration of the jump convergence movements made to a 5Δ step disparity for full field stimulation was 0.45 seconds (s) (sd=0.13) (Table 1.). The mean duration for peripheral stimulation was 0.52s (sd=0.35), and slightly longer for central stimulation, 0.67s (sd=0.23), although these differences just failed to reach statistical significance ($F_{2,36}=3.244$, p=0.0507). Therefore, masking of the peripheral and central binocular visual field did not have a statistically significant effect on the duration of a vergence response to a 5Δ prism.

Nevertheless, this was not the case for the 10Δ responses under the three stimulus conditions. The mean duration for central stimulation was 1.79s (sd=1.46), which was significantly longer than for full and peripheral stimulation, 0.72s (sd=0.22) and 0.71s (sd=0.32), respectively (Table 1.) ($F_{2,30}=8.940$, p=0.0009). This difference between the 5Δ and 10Δ responses also showed up a statistically significant interaction effect ($f_{2,28}=4.712$, p=0.0172). That is, the effect of peripheral field masking differs according to whether a 5Δ or a 10Δ prism was used.

DISCUSSION

Unlike most previous experiments, normal viewing conditions were used in this study in that the subject viewed in free-space while light adapted. However, one limitation was that the order of the prism strengths presented and the binocular visual field conditions used was not random. It is the author's contention that this was perhaps the reason for the marginally non-significant difference in the mean duration of the jump convergence movements to a 5Δ prism under the three viewing conditions. It is possible that the responses under central field stimulation, for example, were made easier since the subject had just fused a 5Δ and then a 10Δ BO prism under full stimulation.

There was an extraordinary difference in the BO fusional vergence amplitude under the three stimulus conditions. In fact, the mean amplitude for central stimulation was half that for both full and peripheral stimulation. Peripheral fusion obviously plays an important role in producing and maintaining a gradually increasing position of fusional convergence. This finding is in agreement with the observation of Parks.[26] The sheer extent of the retinal periphery must play a role here. Furthermore, it is probable that central vision is degraded by the associated convergence accommodation to the point where fusion in that region is eventually disrupted. Central fusion is the fine-tuning vergence mechanism[30], partly because of the visual integrity there, so blur must be a hindrance to its function, despite the fact that disparity has been considered to be quite robust to blurring[31,32]. Peripheral vision and indeed fusion, on the other hand, is not as sensitive to this blurring while the BO disparity is being increased[33]. Moreover, that this was not the case for the BI amplitudes lends support to how blurring due to the associated convergence accommodation plays a role in decreasing the BO amplitudes under central stimulation. Clearly, this does not occur when fusional divergence is stimulated. Alternatively, because the BI amplitude is inherently lower than the BO, the central 8° binocular field may have been sufficient to sustain fusion. The latter explanation is probably unlikely, however, since vertical and torsional fusional amplitudes are also relatively small, but they are demonstrated to be larger using peripheral stimulation[6,14].

The difference in the BI amplitudes under the three stimulus conditions, however, was less striking than that for the BO amplitudes. It was found that the mean BI amplitude under peripheral stimulation was significantly higher than for both full and central stimulation. That this was due to a training effect is unlikely, although the fact that the diplopia threshold is greater in the periphery, given the increase in Panum's areas and decrease in visual resolution may explain this.

Peripheral field masking also had adverse effects on the execution of jump convergence movements, at least to a 10Δ step disparity. Whereas all subjects could jump converge to a 5Δ BO prism, about one quarter of them could not overcome a 10Δ BO prism under central stimulation and experienced diplopia for the whole recording period. Similarly, the duration times of the 10Δ responses were significantly prolonged under central stimulation, although the slightly longer duration times under central stimulation for the 5Δ responses were found to be statistically insignificant. Obviously, peripheral fusion is important to the processing and dynamics of step disparity vergence. The fact that the 10Δ responses were more affected than the 5Δ responses is probably in part a function of the amount of disparity that was induced within the central 8° binocular field. Also, the lesser disparity of 5Δ, allowed a greater overlap of the two central fields seen in diplopia than the 10Δ disparity. Consequently, it would be a relatively easier task to fuse the 5Δ prism, whereas greater voluntary effort would be required to fuse the 10Δ prism. Besides, it is not unreasonable to expect that the higher the disparity induced, the greater the voluntary or conscious effort required to achieve fusion.

Owing to the anatomic and physiologic differences between the retinal periphery and centre, and their respective topographic representation in the 'binocular centres' of the cortex, it is not unreasonable to expect that peripheral and central fusion have quite differing features and functions. Therefore, it is difficult to impartially compare the performance of the two systems for a set binocular task, especially when artificial viewing or stimulus conditions are employed. Besides, it is very probable that peripheral and central fusion complement one another, given the many factors involved in the fusional process and the production of fusional-disparity vergence eye movements. For example, as was evident in the present study, during gradually increasing fusional convergence stress, peripheral fusion may assume a greater role as it is more resistant to the blur that results from the convergence accommodation than central fusion. Finally, it is recognised that the control of vergence and the extent to which it is influenced by the central and peripheral fusional mechanisms is susceptible to voluntary control and selective attention[34,35], thus adding to the difficulty of evaluating the integrity of the two systems.

CONCLUSION

It seems that the peripheral fusion mechanism in normal binocular vision is very capable of producing full fusional vergence amplitudes in both BI and BO directions, whereas the central fusion mechanism is not. One of the most significant findings was that the BO amplitudes tested under central stimulation, were about half those for the full and peripheral stimulus conditions. It was found that peripheral fusion was more effective than central fusion in eliciting jump convergence movements made to a 10Δ BO prism, but that there was no significant difference in the responses to a 5Δ BO prism. Furthermore, it was demonstrated that the duration of a jump convergence movement to a 10Δ BO prism was significantly longest under central stimulation, taking on average about 1 second longer than for full and peripheral stimulation. In conclusion, there can be no doubt that peripheral fusion plays an important role in the production of fusional-disparity vergence eye movements and that masking of this component of the binocular visual field can be debilitating to vergence dynamics.

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