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INDEPENDENCE OF CONJUGATE AND DISJUNCTIVE EYE MOVEMENTS

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Conjugate eye movements, in which the two eyes move in a parallel fashion, can be distinguished from disjunctive eye movements, in which the fixation axes of the two eyes move with respect to each other. Recent experiments (Westheimer & Mitchell, 1956; Yarbus, 1957) have demonstrated clearly that the two types of movements can occur simultaneously and seem to be additive. The purpose of this paper is to illustrate by some further experimental results that conjugate and disjunctive eye movements are organized independently.

METHODS

The subject sat in a dark room and had presented to each eye a small (3 mm) white spot on a cathode-ray tube at 2 m. The spots could be moved independently in a horizontal direction by an externally applied voltage. By a suitable electronic arrangement it was also possible to present independent conjugate and disjunctive target movements of various kinds, including square and sine waves. Target movements were confined to a range of 6–8° centred around the middle of the subject's fusional range.

Eye movements were recorded by a method tending to eliminate, to some considerable extent, artifacts which might arise from lateral translational movements of the eyes. The measure of the positions of the right and left eyes, α_R and α_L, which was available in electric form, could be averaged to give the mean position of the two eyes $[\frac{1}{2}(\alpha_R + \alpha_L)]$, and differenced to give the vergence level $(\alpha_L - \alpha_R)$. Details of the method of target presentation and eye movement recording have been described (Rashbass & Westheimer, 1961). Records were obtained on three normal observers. The recordings are estimated to be good to 5′ of arc and have a frequency response flat up to about 30 c/s.

RESULTS

We have recorded the mean position of the two eyes and the vergence between the eyes while the subjects were presented with targets, one for each eye, under a variety of target movement patterns. If α_R is the angle the fixation line of the right eye makes with the straight-forward line, and

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α_L that of the left eye (using a right-handed co-ordinate system for both eyes), we can define the mean eye position

$$\phi = \tfrac{1}{2}(\alpha_R + \alpha_L)$$

and the vergence

$$\gamma = \alpha_L - \alpha_R.$$

Let α'_R, α'_L, ϕ' and γ' be equivalent angles as applied to the targets.

In the first experiment ϕ' and γ' were each given step changes but at different repetition rates. Figure 1 shows a record taken under these

Fig. 1. Recording of eye vergence (above) and mean lateral eye position (below) when independent step changes are given to target vergence and mean lateral target position. Spikes on records are stimulus artifacts; they indicate the instant a step change was given to the target function.

conditions of γ on the upper channel and ϕ on the lower one. It is seen that the lateral tracking mechanism for ϕ' and the vergence response mechanism for γ' each behaves in the manner typical of itself, quite independently of any changes occurring in the other. The response of either system is a normal one (Westheimer, 1954; Rashbass & Westheimer, 1961), whether its step stimulus occurs simultaneously with the stimulus to the other system, during the reaction time of the other system, or during the response of the other system. Since saccadic movements are so short, the question of a convergence stimulus during a saccadic movement is largely academic.

Secondly, ϕ' and γ' were each given sinusoidal movements at slightly different frequencies. This simulated the movement of a target performing a Lissajous figure in the horizontal plane. The target path, starting as an oblique line from far left to near right, passed through a series of quasi-ellipses of changing eccentricity and obliquity into an oblique line from far right to near left. The path returned in a similar fashion to the original state and the cycle of movements was then repeated. Again there was complete independence of the response mechanism of lateral eye tracking and vergence tracking.

One interesting special case occurs where the convergence component of the targets' motion has a frequency of about 1 c/s. We have shown elsewhere (Rashbass & Westheimer, 1961) that under these conditions the eye vergence follows the target vergence for only a few cycles before deteriorating into small irregular movements around the mean target vergence. In Fig. 2 is illustrated the response of ϕ and γ when ϕ' and γ' are oscillated at frequencies of 1 and 0·66 c/s respectively. Side-to-side tracking proceeds with its normal characteristics, but vergence tracking soon disappears. It follows that the vergence reponses and the smooth pursuit movements are subject to quite different limitations.

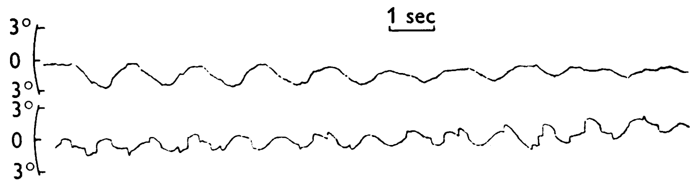

Fig. 2. Recording of eye vergence (above) and mean lateral eye position (below) when independent simple harmonic changes are given to target vergence and mean lateral target position. Note that lateral tracking movement continues unabated while eye vergence, driven at a lower frequency, deteriorates.

It might be argued that vergence and side-to-side eye movements are independent only when these two components are themselves independent simple functions. Finally, we imposed simple harmonic motions of slightly different frequencies on α'_R and α'_L. This resulted in a Lissajous figure in the horizontal plane passing through a series of quasi-ellipses from the mid-sagittal horizontal line to a line in a frontal plane. Once again vergence and tracking proceeded independently each in its characteristic manner.

It is concluded that, along whatever path a target moves, the movement is resolved into two components corresponding to mean target position and target vergence, respectively, and that appropriate responses to these components are made by two independent systems.

SUMMARY

1. A spot target was presented to each eye and the two targets were moved to give simultaneous independent stimuli for lateral and for convergence movements. The stimuli were sinusoidal and square-wave forms.

2. The mean eye position follows the mean target position according to the characteristics of visual tracking and simultaneously the eye-vergence response follows the target vergence according to the characteristics of vergence movements.

3. No interaction between the mechanisms was observed; each can accept and respond to stimuli irrespective of whether the other is being stimulated, is within a reaction time, is responding, or is suffering overload.

4. All target movements are resolved into a vergence and a side-to-side component, even when a resolution into right and left eye components would be simpler.

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