

INTERACTIONS OF THE HORIZONTAL AND VERTICAL HUMAN OCULOMOTOR SYSTEMS: THE SACCADIC SYSTEMS

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INTRODUCTION

ONE OF the oldest ideas in experimental psychology is that the time between stimulus and response is occupied by a train of processes or stages—some being mental operations—which are arranged so that one process does not begin until the preceding one has ended. This stage theory implies that the reaction time (RT) is a sum composed of the durations of the stages in the series. According to this theory, if one could determine the component times that add together to make up the RT, one might be able to answer certain questions about the mental operations to which these stages correspond. The study of RT should, therefore, prove helpful to an understanding of the structure of mental activity.

For the past 40 yr, researchers in human performance theory have been concerned with the phenomenon which occurs in reactions to stimuli separated by short time intervals (SMITH, 1967). The greatest effort has been directed toward studying the psychological refractory period (PRP). The PRP is the increase in the reaction time to a signal which closely follows another signal. When two stimuli are presented in rapid succession, the reaction time to the second stimulus (S2) is typically prolonged compared with the reaction time to S2 when it is presented alone or after a very long interval (WELFORD, 1952). This increase is maximal at the shortest values of interstimulus interval (ISI) and decreases as the ISI is increased, until at some value of ISI, no further delay is encountered.

The system studied in this investigation is the human oculomotor system. This system has been studied by numerous people for well over half a century. Since the visual system is our primary sensory input channel, it is important for us to know how information is processed by the system. However, the visual system in its entirety is a vastly complex system which involves a large portion of the central nervous system. A subsystem which serves the visual system is the eye movement control system. This subsystem has received a great deal of attention in recent years, since its output, eye position and movement, is relatively easy to measure, and its input can be well specified. The function of the control system is to maintain the portion of greatest interest in the visual field on the area of greatest visual acuity, the fovea.

Most of the work which has been done on modeling the eye movement control system has involved only the horizontal eye movement control system. There are several obvious reasons for a preference of the horizontal system. Under normal conditions, the eye appears

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as an ellipse with its major axis oriented in the horizontal plane. Based only on this information, it is obvious that larger amplitudes of horizontal than of vertical movements are observable. Another consideration which has led to an emphasis of the horizontal system is that in the primary position of gaze, one pair of the extraocular muscles lies in the horizontal plane of the eye (WOLF, 1968). Therefore, based on the greater observable horizontal range and the assumption of an independent extraocular muscle system for horizontal movements, horizontal eye movements seem easier to analyze. It is convenient to note that the assumption of extraocular horizontal independence has been verified (TAMLER, MARG, JAMPOLSKY and NAWRARZKI, 1959).

Much has been done in applying systems theory to describing the oculomotor control system (e.g. ROBINSON, 1964; WESTHEIMER, 1954; YOUNG, 1962; YOUNG, FORSTER and VAN HOUTTE, 1968; ZUBER, 1965). These investigations have drawn heavily upon—and contributed significantly to—the existing body of physiological knowledge of the oculomotor and visual systems. Although most of the research which has been done on the oculomotor control system has been concerned with only the horizontal eye movement system, this research investigates the relationship between the horizontal and vertical saccadic systems.

To reveal the relationship which exists between the horizontal and vertical saccadic systems, experiments consisted of presentation of sequential visual inputs. The use of this type of input necessitates considering sequential task reaction time phenomena and central information processing constraints. No previous work on eye movements has considered the role of various central information processing constraints which are inherent in the performance of certain sequential tasks.

APPARATUS

The method used to measure horizontal and vertical eye movements depended upon detection of the difference in diffuse reflected light from the limbus on both sides of one eye. Figure 1 shows the arrangement of light sources and photodetectors, mounted on a pair of glasses worn by the subject. It is clear from Fig. 1 that the amount of reflected light received by each photodetector is a function of the angle of gaze. By taking the differential output between the two detectors, the effects of any nonlinearities or change in ambient light or temperature were minimized. Since the entire apparatus was light and small enough to mount in glass

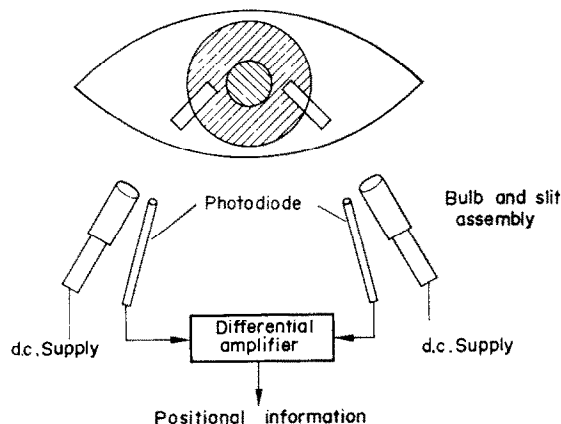


FIG. 1. Schematic representation of eye movement recording apparatus. The light bulb and slit assemblies were capped with Wratten No. 89B i.r. filters. The resultant slits of projected i.r. light were then reflected from the limbi and detected by the respective photodiodes (Texas Instruments No. LS 400). The resultant signals were processed as described in the text.

frames, the monitor could record movements of the eye with respect to the head, independent of any head movements.

The light sources projected slits of light on the eye at an angle with respect to the horizontal. One slit was at an angle of approximately 45° with the horizontal, while the other slit was at an angle of approximately 135° with the horizontal. Since this research is concerned with temporal events and not with true positional information, little effort was made to achieve complete horizontal and vertical separation.

During calibration and experimental runs, the subject was seated with his head held immobile by the use of a bite bar rigidly supported by the chair in which the subject was seated. The chair was located at the center of curvature of a semicircular screen with a radius of 5 ft; the subject and screen were both contained in a light-proof booth. Also located at the center of curvature was the target projection system, which consisted of a 500 W slide projector and two Harvard Apparatus No. 350 recorder galvanometers. A 1 in. round front surface mirror was mounted on each galvanometer. The target was a well focused $1/4^\circ$ spot of light projected on the semicircular screen. The target projection system has a linear dynamic range of $\pm 40^\circ$ horizontal and $\pm 15^\circ$ vertical. The system frequency response was down 3 dB at 60 Hz.

The input signals to the galvanometers were generated by a special purpose digital computer which was designed and built for this research. The computer produced a series of horizontal and vertical step functions, each series comprised of one horizontal and one vertical step. The computer determined the following:

- (a) Whether a horizontal or vertical step was to occur first.
- (b) A random interstimulus interval (ISI).
- (c) A second step function dependent on the nature of the first, and
- (d) If a horizontal step, then left or right, or if a vertical step, then up or down.

The decisions made by the computer could be preset to be random or deterministic in nature, i.e. random horizontal or vertical steps first with random ISI, or horizontal steps first with fixed ISI; all combinations of the above were possible.

METHODS FOR EXPERIMENT 1

There are several reasons that each of the various experimental paradigms was selected. The reader should keep in mind the fact that a moving spot of light is an irresistible stimulus when there is no other fixation point in the visual field.

It is well known that the eye movement system is an adaptive one capable of predictive tracking. The system characteristics in the predictive mode are not well understood and mainly involve use of the smooth pursuit system for predictive periodic target tracking (ROBINSON, 1965, 1968). Thus, to investigate the saccadic system, non-predictive aperiodic stimuli must be used. For this reason, a four-choice/two-choice experimental paradigm was chosen for Experiment 1. This paradigm results in a high degree of spatial and temporal uncertainty. The stimuli are step functions which evoke responses from the saccadic system only. Through observation of reaction times, the relationship between the horizontal and vertical saccadic systems should become evident.

The four-choice/two-choice paradigm consisted of a series of two target steps, each step having an amplitude of 6° of visual field. The target was presented to the subject in such a manner that a vertical/horizontal displacement from the primary position of gaze was delayed by a random amount of time from a horizontal/vertical displacement. The second (or delayed) displacement occurred while the initial displacement was still present, and both displacements were of sufficient duration to permit easy tracking by the subject. The duration of the first displacement was 1150 msec, and the second displacement was 200 msec in duration. The order and direction of both displacements was also randomized, i.e. the target could move horizontally to the right or left and vertically up or down. Figure 2 is a diagram of a typical input sequence. A typical input might consist of a horizontal step to the right (point 1 of Fig. 2), followed after an ISI by a vertical step up. At this point in time, the target would be located at point 2 of Fig. 2. The target would return to the horizontal right position (point 3 of Fig. 2), then would return to the starting position. Note that the following paths represented in Fig. 2 are equivalent:

$$\begin{array}{ccccc} \text{Starting point} & -1 & = & 3 & - \text{Starting point} \\ & 1 & & -2 & = & 2 & & -3 \end{array}$$

The time for the sequence just described would be approximately 1 sec. After a delay of approximately 3 sec another target sequence would be presented. This input would be a non-predictive one, referred to as the four-choice/two-choice paradigm. A target sequence constitutes one experimental trial and thirty such trials comprise an experimental block of trials.

The data for Experiment 1 were obtained from three male subjects, J.H., W.O. and B.C., ranging in age from 19 to 21 yr. Each subject was run through 6 blocks of trials, each block given on a different day. Prior to each block, the eye movement apparatus was aligned and calibrated. The first block of trials served to

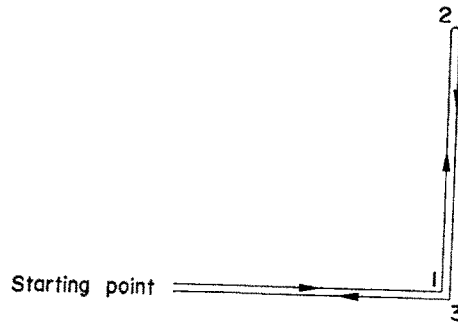


FIG. 2. A spatial representation of a typical target sequence. A typical target presentation might consist of the following events which are depicted here:

- (1) At time zero the target, which consists of a well focused spot of light $1/4^\circ$ dia., is located at the primary position of gaze.
- (2) The target jumps to position 1, which in this case represents a 6° right horizontal displacement from the primary position of gaze. After a random time delay, the target would then jump 6° vertically to position 2. At this point in time, the target would be 6° up and 6° to the right of the primary position of gaze.
- (3) After approximately 200 msec at position 2, the target would jump to position 3 and remain there until approximately 1150 msec after its initial movement at which time it would return to the starting position. Details regarding the utilization of these sequential stimuli are discussed in the text.

familiarize the subject with the apparatus and the experimental paradigm; no data were recorded for this block. In each of the remaining 5 blocks of trials, the first 10 trials were used to acquaint the subject with the paradigm, and the remaining twenty trials were recorded and used as data. No other experiments were run concurrently with this experiment. The subjects were instructed to follow the target as accurately and quickly as possible. In this experiment, the values of ISI were random from trial to trial. Three quantities were recorded for each trial: ISI, RT_1 , and RT_2 . A fourth quantity, the System Delay ($RT_2 - RT_1$) was computed for each trial. The raw data for each subject's 5 blocks of trials were processed by sorting them into bins 20 msec in width as a function of ISI. Using a computer, the following calculations were made for each such bin: the number of points lying within the bin, the average value over that bin, and the standard deviation for that bin. These calculations were made for each of the dependent variables, ISI being the independent variable.

RESULTS FOR EXPERIMENT 1

A typical recording obtained using the four-choice/two-choice paradigm and the variables measured are shown in Fig. 3. In the experimental trial illustrated in Fig. 3, the vertical displacement occurred first, followed by a horizontal displacement in 740 msec. Figures 4, 5 and 6 represent plots of the averaged data for the three subjects for RT_1 vs. ISI, RT_2 vs. ISI and System Delay vs. ISI, respectively. Each point on these plots represents the average of at least 10 experimental trials.

It can be seen from Fig. 4 that there is little variation of RT_1 as a function of ISI for all three of the subjects. The only differences among the three subjects are their individual mean reaction times. Figure 5 shows the relationship of RT_2 vs. ISI for the three subjects. Again the results for all three subjects are similar, with the differences among the subjects again being in mean reaction times. Figure 6 is a plot of System Delay vs. ISI for the three subjects. This again points out the similarity among the three subjects.

Note that the range of the data shown in these figures is not uniform for all three subjects. In particular, W.O.'s data were obtained over a different period of time than those of the other two subjects. As a result, insufficient data were obtained at low values of ISI. It should also be noted that even though the results are plotted by points, they represent average values over 20-msec intervals.

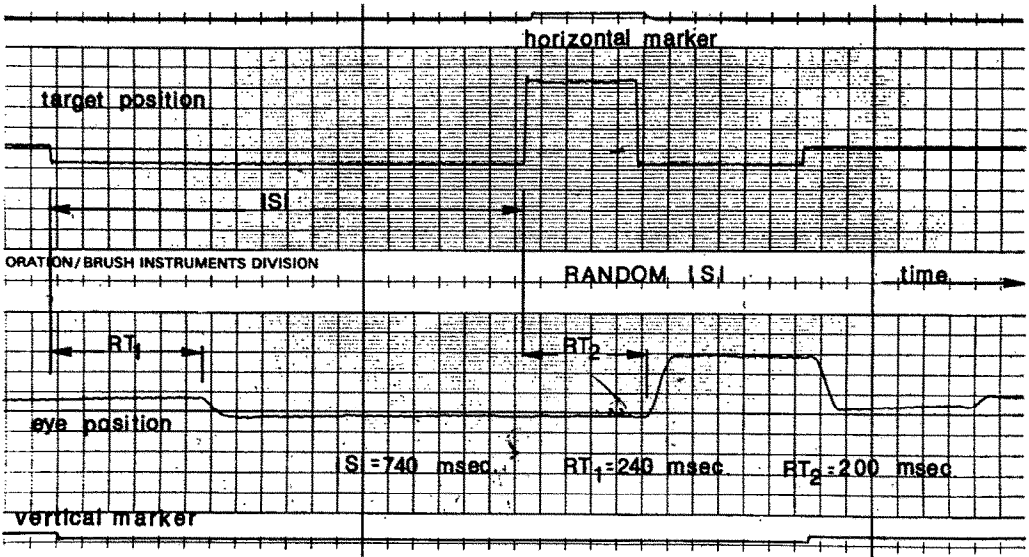


FIG. 3. A typical recording obtained using the four-choice/two-choice paradigm. The top most trace indicates the presence of a horizontal target step. The next trace represents the superimposed horizontal and vertical target displacements with the independent variable, ISI, being shown. The eye position record illustrates the definition of the two dependent variables, RT_1 and RT_2 . The bottom most tracing indicates the presence of a vertical target step. Note the two distinct eye movements, which had previously been verified as being orthogonal movements for all values of ISI used.

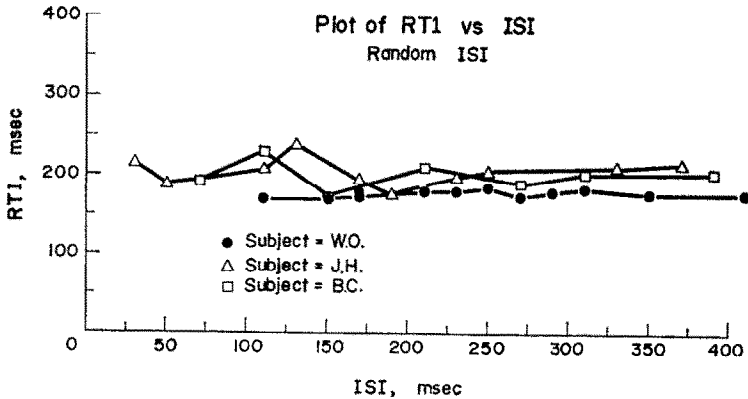


FIG. 4. Plot of RT_1 vs. ISI for Experiment 1. The results for the three subjects are shown here and in the remaining figures. Each point indicated by a symbol represents the mean value of the dependent variable, in this case RT_1 , for the corresponding value of ISI. It can be seen that there is little if any variation of RT_1 as a function of ISI. Note that the symbol used for a given subject is used consistently in all figures and is shown in the symbol table included as part of each figure.

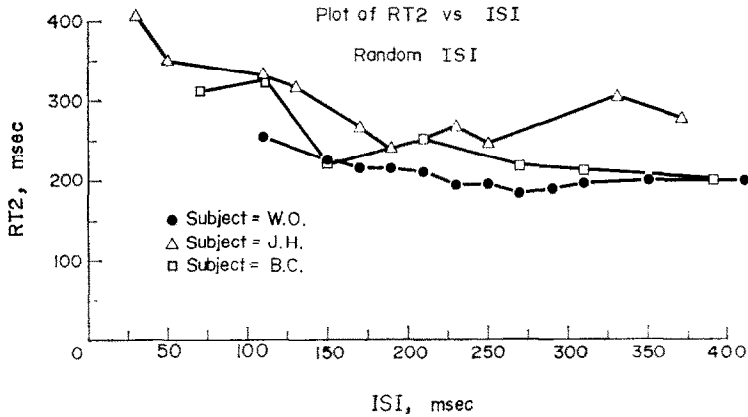


FIG. 5. Plot of RT₂ vs. ISI for Experiment 1. Unlike Fig. 4, the results shown here indicate that there is a substantial effect of ISI on RT₂ for all subjects. The phenomenon observed here is known as the Psychological Refractory Period (PRP). Subject W.O.'s data do not extend to very low values of ISI, since his data were obtained at a later date.

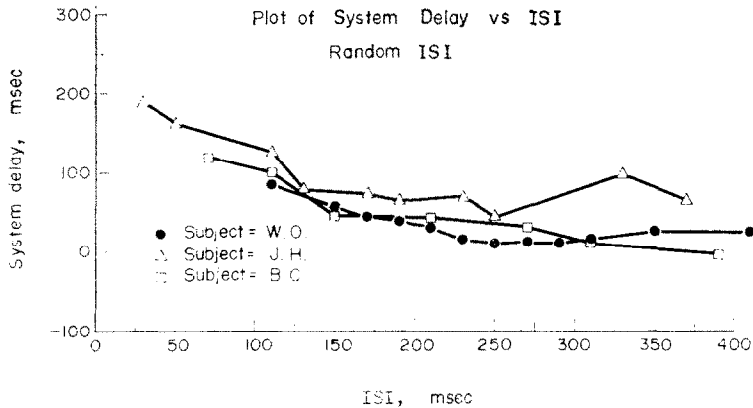


FIG. 6. Plot of System Delay vs. ISI for Experiment 1. The System Delay is defined as $RT_2 - RT_1$. Thus if there were no interaction between the horizontal and vertical saccadic systems, the System Delay would be zero and not a function of ISI as is shown.

DISCUSSION OF EXPERIMENT 1

As a preface to the interpretation of the results of Experiment 1, let us consider some of the previously documented properties of the horizontal and vertical saccadic systems. As stated in the Introduction, most of the previous work on eye movements involved only the horizontal eye movement system. Of these various studies, there are several which are relevant to Experiment 1. The findings of BEELER (1965) and WHEELLESS (1965) both alluded to the influence of central processing on horizontal eye tracking performance. Beeler found that the reaction time to the second of two sequential horizontal steps was a function of whether the two steps were in the same direction or in opposite directions. He found that reaction time to the second step was shorter when the second step was in the opposite

direction from the first. He attributed this result to a physiological refractoriness. An analogous experiment was performed by FEINSTEIN and WILLIAMS (1968). In that experiment the target moved first horizontally to the right and after a random delay, it moved vertically up or down. Another experiment was performed in which the target moved just vertically up and after a random delay, horizontally left or right. No significant difference in reaction times was noted between the data for horizontal first and vertical first. Furthermore, in a recent paper by ST-CYR and FENDER (1969) they reported little interaction between horizontal and vertical eye movements.

WHEELLESS' (1965) experiment involved the use of a "pulse step" target function. He varied the width of a pulse which was superimposed on a target step and determined the reaction time. He found that the subject responded both to the pulse and step and to the step only. This behavior was a function of the pulse width, i.e. for pulse widths of 50 msec the subject responded to both stimuli only 8 per cent of the time. The results of his experiments indicated a role for central information processing other than that of mimicking target movements. This aspect of eye movements has been shown before (COOK, 1965; ZUBER, 1965) and has been taken as an indication that the eye movement system samples the visual information; however, Wheelless gives evidence that sampling as previously proposed by YOUNG (1962) cannot adequately describe performance to pulse-step targets.

Let us now consider the results obtained in Experiment 1. Figure 4 indicates that there is no significant effect of S_2 on RT_1 . This result differs from the findings in some manual reaction time tasks, (TRIGGS, 1968). The effect found in manual reaction time tasks may be due to the fact that in these tasks, a much larger part of the CNS is utilized. In eye movement studies, only one sensory motor system is in use. Figure 4 indicates a degree of parallel processing; otherwise, one would expect a second input to influence the first.

Figure 5 shows the relationship between RT_2 and ISI. The phenomenon illustrated by these results is similar to the psychological refractory period, PRP, which has been reported previously for manual reaction time studies, (TRIGGS, 1968). The only significant difference between the results shown in Fig. 5 and those reported for manual tasks is the task reaction time. Eye movement reaction times are approximately 100 msec faster than manual task reaction times. For values of ISI greater than 250 msec, the values for RT_2 approach those of RT_1 . It should be pointed out that the values obtained for RT_1 correspond to simple reaction times obtained for single step presentations. Thus, for ISI's shorter than 250 msec, the subject's reaction time to S_2 is affected by S_1 . As discussed in the manual reaction time literature (e.g. TRIGGS, 1968; WELFORD, 1952), the presence of the PRP indicates that serial information processing is involved, which implies that the vertical and horizontal saccadic systems share a common information processing unit.

Figure 6 shows the results of System Delay vs. ISI for Experiment 1. This plot is similar to Fig. 5 except that compensation has been provided for variations of RT_1 vs. ISI.

METHODS FOR EXPERIMENT 2

The use of the four-choice/two-choice paradigm introduces one possible objection: the subject knows that once the target has moved horizontally, it will then move vertically, or vice versa. This might result in the subject's anticipating the second input and thereby doing some unwarranted preprocessing. To determine whether or not this phenomenon was present in Experiment 1, a second experiment was performed in which the first stimulus (S_1) was predetermined as being horizontal, and the value of ISI was fixed, thereby creating an extreme of the situation which might have existed in Experiment 1. This procedure, known as the two-choice/two-choice paradigm was used to serve as a cross-check on Experiment 1. The combined results of these two experiments enable one to determine whether predictive tracking was involved in either of them.

The data for Experiment 2 were obtained from 3 male subjects, J.H., J.M. and W.O., ranging in age from 19 to 21 yr. Each subject was run through 6 groups of 8 blocks for each value of ISI used. These fixed values of ISI were (in msec): 50, 100, 125, 150, 175, 200, 300 and 400. Each of the 8 blocks of trials had a different fixed value of ISI. One group of blocks was given to each subject on a different day; however, on these days, the subjects also participated in other experiments. One initial group of blocks was administered to each subject in order to familiarize him with the apparatus and the experimental paradigm; no data were recorded for this group. For the remaining 5 groups of blocks, the first 10 trials of each of the eight 30-trial blocks were used to acquaint the subject with the paradigm; the remaining 20 trials for each of the 8 blocks were recorded and used as data. All of the subjects were run during the same period of time and all were instructed to respond as accurately and quickly as possible. The quantities measured and the methods of processing the raw data for Experiment 2 were the same as those in Experiment 1. The order of presentation of the fixed values of ISI was randomized over each group of blocks.

In order to relate results from these experiments to the work which has been done on the horizontal saccadic system by others, an experimental paradigm similar to the horizontal-vertical paradigm just described was employed. In this case, however, both the first and second target movements were horizontal. The responses of two subjects (J.H. and W.O.) were obtained for the following values of ISI: 50, 100, 200 and 300 msec. The number of trials and the order of presentation were similar to the methods used in the horizontal-vertical case.

RESULTS FOR EXPERIMENT 2

The results expected from this experiment were basically the same as those of Experiment 1 if the subjects were not able to utilize the added information available to them in the form of fixed ISI and reduced choice. However, if the subjects were able to utilize this information, then the values obtained for RT_2 should be significantly less than those obtained in Experiment 1. If preprogramming occurred in Experiment 1, the values of RT_1 should also be affected. In this case, a decrease in RT_1 in Experiment 2 would be expected because the number of choices has been reduced.

Figures 7, 8 and 9 are plots of RT_1 vs. ISI, RT_2 vs. ISI, and System Delay (as defined in Experiment 1) vs. ISI, respectively, for each of the 3 subjects. Each point on these plots represents the average of at least 40 experimental trials. It can be seen from Fig. 7 that there is little variation of RT_1 as a function of ISI for all 3 of the subjects. The only difference among the 3 subjects are their individual mean reaction times.

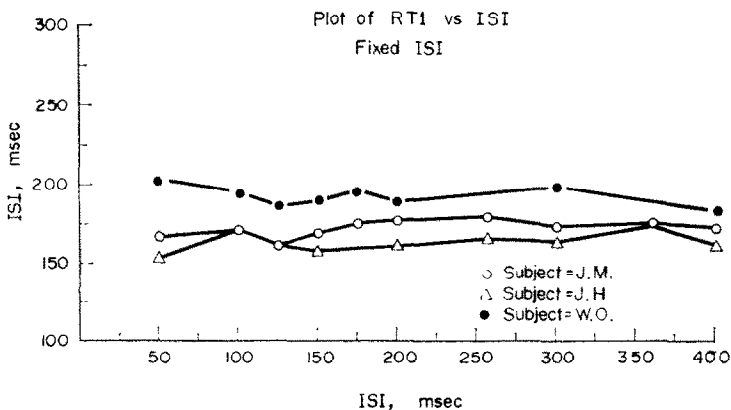


FIG. 7. Plot of RT_1 vs. ISI for Experiment 2. Note that one of the subjects, J.M., was not used in Experiment 1. The other two subjects, W.O. and J.H., were used in both Experiments 1 and 2 and the symbols used for their results in both experiments are the same throughout. Also note that the results presented here and in the remaining figures are plotted on an expanded scale in relation to Figs. 4, 5 and 6. It can be seen that as in Fig. 4 there is little variation of RT_1 as a function of ISI.

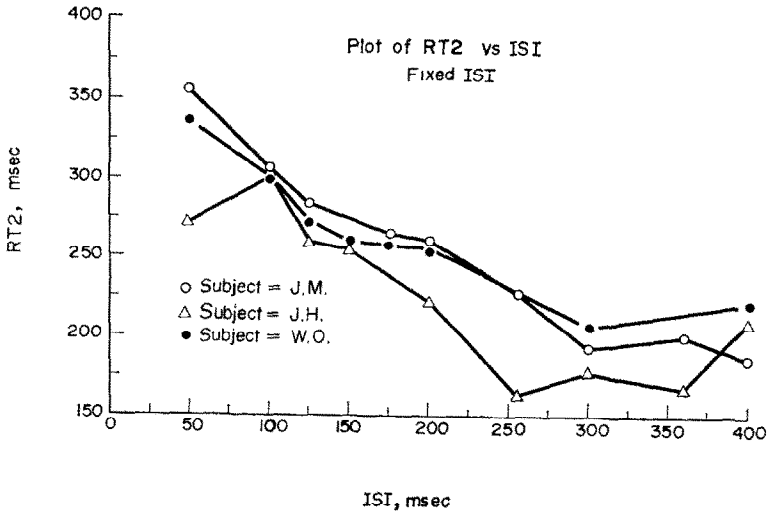


FIG. 8. Plot of RT₂ vs. ISI for Experiment 2. As in Fig. 5, these results indicate the presence of the PRP and an interaction between the orthogonal saccadic systems.

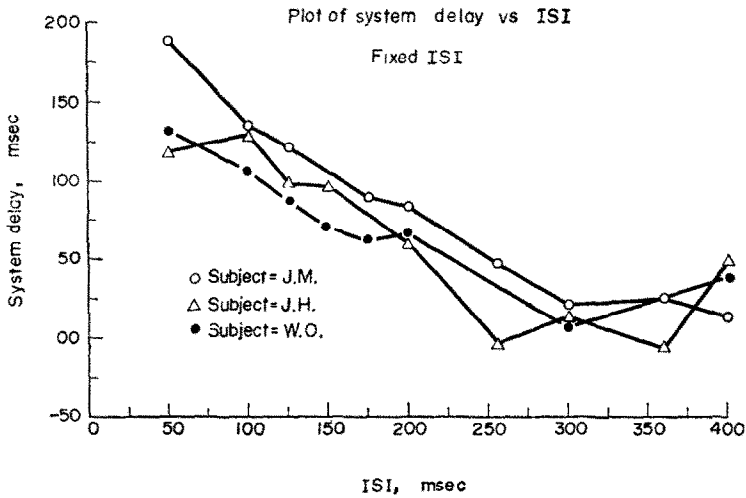


FIG. 9. Plot of System Delay vs. ISI for Experiment 2. As in Fig. 6, System Delay is not independent of ISI, thus indicating interaction of the horizontal and vertical saccadic systems.

The results obtained for Experiments 1 and 2 are almost identical for all of the dependent variables. This indicates that there is sufficient randomness introduced by the spatial uncertainty in the two-choice/two-choice paradigm to make it unpredictable. Thus, the two sets of results confirm each other.

TABLE 1. COMPARISON OF RESULTS FOR HORIZONTAL-VERTICAL AND HORIZONTAL-HORIZONTAL EXPERIMENTS (ALL VALUES IN MSEC)

ISI	RT ₁ (H-V)	RT ₂ (H-H)	RT ₁ (H-V)	RT ₂ (H-H)	System delay		% Incorrect (H-H) responses
					(H-V)	(H-H)	
Subject: J.H.							
50	154	160	272	185	118	25	67.0
100	171	156	301	177	130	21	41.5
200	161	176	223	156	62	-20	5.5
300	164	179	178	165	14	-14	0.0
Subject: W.O.							
50	204	174	336	201	132	27	65.0
100	195	175	301	198	106	23	8.5
200	190	179	256	193	66	14	4.25
300	199	174	207	172	8	-2	0.0

This table shows a comparison of results for the two subjects who were common to Experiment 2 and the horizontal-horizontal experiment. All values given are mean values. Values for RT₁ (H-V), RT₂ (H-V) and System Delay (H-V) were obtained from Experiment 2. Values for RT₁ (H-H), RT₂ (H-H) and System Delay (H-H) were obtained from the horizontal-horizontal experiment. Per cent incorrect responses were only reported for the H-H case since there were no incorrect responses in the orthogonal cases. In particular, note the relationship between corresponding RT₂'s and System Delays. This comparison indicates that the process described by Experiments 1 and 2 is distinct from the properties of either saccadic system alone, but due to their interaction.

Table 1 is a comparison of the responses to the horizontal-vertical and horizontal-horizontal stimulus presentation paradigms. The horizontal-vertical results are from Experiment 1. The results for the two paradigms differ substantially, especially for small values of ISI. These results indicate that the ISI has a significant influence on system delay for the horizontal-vertical paradigm, whereas the effect of ISI on system delay for the horizontal-horizontal paradigm is very small.

The horizontal-horizontal paradigm is similar to that employed by BEELER (1965). In our experiments no attempt was made to categorize the second response with respect to the first as Beeler did.

The results of the 2 paradigms differ in another important respect. For the horizontal-vertical stimulus pairs there were no incorrect responses. However, the subjects frequently responded to the horizontal-horizontal stimulus pairs with only 1 saccade rather than 2. This result agrees with that of WHEELER (1965).

One must conclude from these results that the response to orthogonal step pairs is significantly different from step pairs in the horizontal plane alone. The interaction of the horizontal and vertical saccadic systems introduces a delay which is dependent upon ISI. This delay is due to the interaction of the orthogonal saccadic systems and not the type of stimulus.

SUMMARY

The results of Experiments 1 and 2 indicate that the horizontal and vertical saccadic systems are complexly interrelated. The phenomenon of the PRP was observed in both experiments. The observed delay is due to the interaction of the horizontal and vertical saccadic systems. This interaction may be due to sensory information being processed in a parallel manner and motor activity being mediated by a serial processing stage.

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Abstract—The human oculomotor system has been studied by numerous people for well over half a century. Since the visual system is our primary sensory input channel, it is important for us to know how information is processed by the system. Most of the previous work on eye movements has been on modeling the horizontal eye movement control system.

In the present series of experiments, human subjects were given the task of tracking a spot of light which moved both horizontally and vertically. The temporal relationship of the horizontal and vertical eye movements was recorded using a light reflection technique. The results of these experiments indicate that the horizontal and vertical saccadic systems are complexly interrelated. The phenomenon of the Psychological Refractory Period was observed. The interaction of the orthogonal saccadic systems may be due to visual information being processed in a parallel manner and motor activity being mediated by a serial processing stage.

Résumé—De nombreuses études ont été consacrées au système oculomoteur humain depuis bien plus d'un demi siècle. Comme le système visuel est notre principale source d'information sensorielle, il nous importe de connaître le traitement de l'information dans ce système. La plupart des travaux antérieurs sur les mouvements des yeux ont recherché un modèle du système de contrôle du mouvement horizontal de l'oeil.

Dans la série présente d'expériences, les sujets humains devaient suivre un point lumineux qui se déplaçait à la fois horizontalement et verticalement. On enregistrait par une technique de réflexion de lumière la relation temporelle des mouvements des yeux horizontaux et verticaux. Les expériences indiquent une interrelation complexe entre les systèmes de saccades horizontal et vertical. On observe le phénomène de Période Réfractaire Psychologique. L'interaction des systèmes orthogonaux de saccades est peut-être due à un parallélisme dans le traitement de l'information visuelle, tandis que l'activité motrice est engendrée par un processus sériel.

Zusammenfassung—Das okulomotorische System des Menschen wurde an zahlreichen Personen über gut ein halbes Jahrhundert untersucht. Da das visuelle System der Anfang unseres sensorischen Kanals ist, ist es für uns wichtig zu wissen, wie Information vom System übertragen wird. Die meisten der früheren Arbeiten über Augenbewegungen überprüften die Horizontalbewegung des Auges.

In den vorliegenden Experimenten hatten die Versuchspersonen die Aufgabe, horizontal und vertikal bewegten Lichtpunkten zu folgen. Über Reflexionsmessungen wurde die zeitliche Abhängigkeit der horizontalen und vertikalen Augenbewegungen aufgezeichnet. Es ergab sich, daß die horizontalen und vertikalen Sakkaden in komplizierter Weise miteinander verknüpft sind. Das würde das Phänomen der psychologischen Refraktärperiode beobachtet. Die Wechselwirkung des zueinander senkrechten Sakkadensystems könnte visuelle Information auf parallele Weise und motorische Aktivität in einer seriellen Prozeßfolge hervorrufen.

Резюме — Окуломоторная система человека изучалась многими исследователями в течение более чем столетия. Поскольку зрительная система является нашим основным сенсорным входным каналом, для нас важно знать как передается информация этой системой. Большинство предшествующих работ моделировали контрольную систему горизонтального движения глаза.

В настоящей серии экспериментов, испытуемым-людям была предложена задача следить за световым пятном, которое движется как в горизонтальном, так и в вертикальном направлениях. Временные соотношения горизонтальных и вертикальных движений глаз регистрировались с помощью техники светового отражения. Результаты этих экспериментов показывают, что горизонтальная и вертикальная саккадическая системы находятся в сложных взаимоотношениях. Наблюдался феномен психологического рефрактерного периода. Взаимодействие ортогональных саккадических систем может давать зрительную информацию функционируя параллельно, а двигательная активность будет опосредоваться серией фаз этого процесса.