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Is information acquisition during large saccades possible?

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The functional visual field can be divided into stationary field, eye field, and head field. The processing efficiency of these fields differs: As one deals with a wider field, efficiency of performance decreases. Sanders (1963) explained these differences by a perceptual encoding theory, but they could as easily be due to information acquisition during eye shifts. This was investigated in an experiment in which a left signal and a right signal were presented covering a display angle of either 45 deg (eye field) or 100 deg (head field). The right signal was presented at variable time intervals after the left signal. In the eye field, the short inspection time of the right signal, as usually observed when it is presented simultaneously with the left signal, disappeared when the right signal was presented during or after the eye shift. In the head field, inspection time of the right signal was independent of its moment of presentation. These results suggest that also during large eye shifts, processing of peripheral information occurs only during eye fixations and not during eye movements.

Acquisition of visual information takes place through a sequence of alternating fixations and saccadic eye shifts. It is obvious that most information is acquired during the fixation periods. However, a question that has been subject to a considerable amount of research is to what extent information presented during a saccade can be acquired immediately upon presentation or only during the next fixation pause.

Around the turn of the century, Erdmann and Dodge (1898) discovered that there was virtually no perception of written text during eye movements. Relevant information could only be extracted during fixation pauses. This phenomenon is now generally known as saccadic suppression. Research on this issue has mainly aimed to identify its boundary conditions and underlying mechanisms (Matin, 1974). Thus, saccadic suppression concerns a drastic decrease in sensitivity for outside stimulation, extending from approximately 40 msec before the onset to the end of a saccade (Latour, 1962, 1966). Although vision is severely impaired, it is not totally absent. Explanations of the suppression effect have included peripheral "retinal smear" as well as central inhibition of vision.

The majority of studies on saccadic suppression have dealt with the detection of visual stimuli that were briefly presented during a saccade. Obviously, this is not characteristic of visual stimulation in real life. Instead, the entire visual field is usually filled with potentially relevant information, which remains present irrespective of the accidental fixation point. The present study attempts to answer the question whether information presented during a saccadic eye movement can be processed immediately or only during the next fixation pause.

There are two series of experiments pertinent to this question. The first one stems from Sanders (1963, 1970), who divided the functional visual field into three main areas on the basis of the necessity of either eye or head movements to cover the total display area. Thus, the eye field is defined as the display that can be covered with eye movements only, whereas in the head field, eye movements must be accompanied by a head movement to cover the entire display. Stimulus processing proved to be considerably more efficient in the eye field than in the head field, suggesting that in the eye field, through peripheral vision, processing has already started before a signal is actually fixated; this would be impossible in the head field. There is, however, the possibility that information about peripheral signals can be picked up during a saccade when the shift from a left to a right signal needs only an eye movement, but not when the eye movement is complemented by a head movement. Sanders has not considered this alternative in his experiments, although it may at least contribute to the explanation of his results.

A second series of experiments stems from Rayner (1978), who studied the relation between eye movements and reading. Readers tend to pick up word length, word shape and even specific letter information from the nonfoveal areas. Again, the general contention is that this information is acquired only during eye fixations. In one particular study, Rayner and Morrison (1981) presented an asterisk at varying distances from the fixation point. During the saccade toward this asterisk, it was replaced by a word. For all visual angles tested, they found the same lexical decision time for the word, suggesting that no useful information was obtained during the saccade. Yet this result may be typical for

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the fairly small visual angles that are common in reading and not be valid for larger saccades. In addition, the results may depend on stimulus complexity. Words are perceptually more complex than patterns such as a single digit or a column of dots.

In the present experiment, the essentials of Rayner's paradigm were used (see also Rayner, McConkie, & Ehrlich, 1978), but with considerably larger visual angles and with less complex signals, namely, single digits instead of words. Following Sanders' (1963, 1970) paradigm, two signals were presented on each trial, one to the right and one to the left of the subject's meridian, constituting either an eye field (45 deg) or a head field (100 deg) display. The task was to compare the two signals through successive inspection of the left and the right ones and to decide whether they were the same or different. Thus at presentation, subjects fixated the left signal and, subsequently, shifted to the right signal, which was presented at various intervals before, during, or after the completion of the saccade. The question, obviously, is whether under these conditions information about the right signal is acquired during the saccade.

METHOD AND PROCEDURE

Task Conditions

The experiment took place in a sound-attenuated and air conditioned cubicle (Amplifon) that was illuminated by a dimmed light source from behind the subject's head. Subjects sat at a table in front of a curved white screen, enclosed by a black nonreflecting ceiling and base. The distance between the subject's eyes and the screen was approximately 70 cm.

An experimental trial started with a 1-sec warning tone of 1,000 Hz. One second after the offset of this tone, two stimuli were presented until the subject responded, but with a maximal duration of 2 sec. After a response, there was a 5-sec interval between the offset of the two stimuli and the onset of the next warning tone. A stimulus consisted of the digit 4 or 5 formed by dots within a rectangular frame (7.5 x 6.5 cm), also consisting of dots. Stimuli were projected on the screen by way of back projection. All dots had a diameter of 7 mm, a midpoint distance of 14 mm, and a brightness of .3 cd/m^2 on a background of .05 cd/m^2.

On every trial, two stimuli were presented on the screen at eye level, one at either 22.5 deg or 50 deg to the left and the other at the same distance to the right of the subject's meridian. As a result, the digits were separated by binocular visual angles of either 45 deg or 100 deg. The left stimulus always appeared 1 sec after the offset of the warning tone, and the right stimulus appeared at irregular intervals after the left one. These intervals varied in steps of 20 msec between 0 and 520 msec in the case of the 100-deg visual angle and between 0 and 420 msec in the case of the 45-deg visual angle. There were red fixation lights at the positions of the left and right stimuli that disappeared as soon as the actual stimuli could be seen. Subjects were instructed to fixate the left fixation light at the start of a trial. Viewing the left stimulus was followed by a shift to the right stimulus. The right fixation light indicated the position of the right stimulus in trials in which the eye arrived there before the stimulus had actually been presented. The task was to decide whether the digits were same (4-4, 5-5) or different (4-5, 5-4) and to press a "same" or "different" response key. Subjects were instructed to keep their index fingers on top of the keys throughout an experimental session and to respond as fast as possible while keeping errors to a minimum.

One experimental variable was the binocular visual angle (45 deg, 100 deg). These values were chosen to create one condition in the eye field (45 deg) in which eye movements but not head movements are necessary when reorienting from left to right, and one condition in the head field (100 deg) in which eye movements must be supplemented by head movements. No constraints were made on eye and head movements, except for the requirement that at the moment of presentation the left stimulus must be fixated. Visual angle was kept constant within an experimental session.

Recording of Eye and Head Movements

Throughout all sessions, horizontal eye movements were recorded by the EOG technique: Two Beckman minielectrodes were attached to the lateral side of the right and left eyes. Head movements were measured by a variable potentiometer connected to a helmet that subjects wore during a session. This helmet was fixed to the ceiling, enclosing the screen, and so had the additional advantage of keeping the position of the subject's head constant.

Both eye and head movements and the moments at which the left and right stimuli were presented and the response key was pressed were graphically recorded (speed = 100 mm/sec). In this way, separate analyses were possible of (1) the fixation time of the left signal (t_1: from the onset of presentation of the left signal to the onset of the eye movement), (2) the movement time of the eye (t_m), and (3) the time elapsing from the onset of fixation of the right signal until completion of the response (t_r). All data were hand scored to the nearest 10 msec. Occasional trials in which the movement was divided into two or more parts or in which the subject moved his eyes back to the left signal after fixating the right one were excluded from the analysis.

The a priori defined classes of stimulus onset asynchronies were compressed into five categories: In Category L_1, the right digit was presented during the first half of t_l. In Category L_2, the right digit was presented during the second half of t_l. In Category M_1, the right digit was presented during the first half of t_m. In Category M_2, the right digit was presented during the second half of t_m. In Category R, the right digit was presented after completion of the eye movement.

Procedure

Six male and two female students (16-25 years of age, with normal vision) served as subjects and were paid for their participation. Subjects were tested two at a time in alternating sessions of approximately 30 min during a full day. A subject performed two 45-deg sessions, each consisting of three blocks of 50 trials, and two 100-deg sessions, one consisting of three and the other consisting of two blocks of 48 trials. Hence, there were 300 trials in the head field and 240 trials in the eye field. Within a session, the interval between presentation of the left and right stimuli was varied pseudorandomly, so that each interval occurred three times for each stimulus combination (4-4, 5-5, 4-5, 5-4).

The morning was devoted to instructions and practice sessions. It was emphasized that reactions should be fast, correct, and regular. Frequent feedback of results was given during the practice sessions. The afternoon was devoted to the experimental sessions.

The four experimental sessions (two for each visual angle) were run in a counterbalanced order. No feedback of results was provided during the experimental sessions. The first five trials of each block were considered warmup and excluded from analysis.

A PDP-11/03 computer was used for programming the sessions and recording reaction times and errors.

RESULTS

Fixation Time of the Left Signal (t_l)

An ANOVA was carried out on t_l, with visual angle (45 deg, 100 deg) and the moment of presentation of the right digit (L_1, L_2, M_1, M_2, R) as main independent

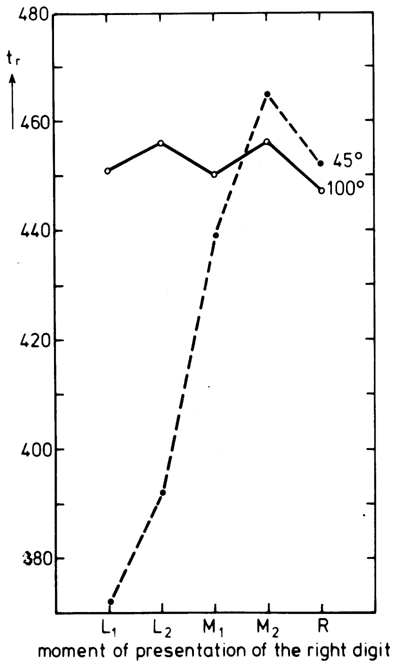

Figure 1. The right fixation time as a function of visual angle and moment of presentation of the right digit.

variables. There was a significant main effect of moment of presentation of the right digit [$F(4,28) = 14.4$, $p < .001$] and a significant interaction between visual angle and moment of presentation of the right digit [$F(4,28) = 7.04$, $p < .001$]. A Newman-Keuls analysis showed that both effects were caused by the L_2 condition, in which t_l was longer in the eye field than in the head field (210 vs. 192 msec). All other values of t_l were about 190 msec.

Movement Time (t_m)

An ANOVA on t_m showed significant main effects of visual angle [$F(1,7) = 358$, $p < .001$] and of moment of presentation of the right digit [$F(4,28) = 18.3$, $p < .001$].

In the head field, t_m was about 100 msec longer than it was in the eye field. The average t_ms were 119 msec and 217 msec for 45 and 100 deg, respectively. Furthermore, t_m was about 10 msec longer when the right digit was presented after the movement had started.

Fixation Time of the Right Signal (t_r)

An ANOVA on t_r showed significant main effects of visual angle [$F(1,7) = 14.7$, $p < .001$] and of moment of presentation of the right digit [$F(4,28) = 69.9$, $p < .001$] and a significant interaction between these factors [$F(4,28) = 24.7$, $p < .001$]. A Newman-Keuls analysis showed that the latencies in the head field were not significantly affected by the moment of presentation of the right digit, whereas those in the eye field appeared to depend strongly on the moment of presentation of the right digit (see Figure 1).

DISCUSSION

The results show that there is a pronounced difference between eye field and head field. In the head field, t_r appeared to be similar for the different presentation conditions. In other words, there was no evidence for any advance processing of the right signal, irrespective of whether that signal appeared during the preceding fixation pause or during the eye-head shift.

In the eye field, on the other hand, t_r was much shorter when the right signal was presented during the fixation of the left signal than when it was presented either during or after the eye movement. In the latter conditions, there was no systematic difference between t_r in the eye and head fields. This confirms Sanders' (1963, 1970) interpretation that information from the periphery of the visual field can be acquired only during a fixation pause and not during the eye shift, irrespective of whether such a shift is or is not accompanied by a head movement.

In the eye field, t_r was slightly shorter when the right signal was presented during the first half of the fixation of the left signal than when it was presented during the second half of the fixation of the left signal. In this last case, there may have been less opportunity to acquire information from the periphery, in particular when the peripheral signal appeared toward the end of the fixation of the left signal.

The results on t_l show that, except for the L_2 condition, t_l is similar in the eye and head fields. This deviates from the usual finding that the fixation time of the left signal is about 20 msec shorter in the eye than in the head field (Sanders, 1963; Sanders & Reitsma, 1982; Houtmans & Sanders, Note 1). The lengthening of t_l in the eye field in the present experiment might be explained by "waiting." Since subjects know that the right signal will be presented at any rate, they might use the strategy to postpone the eye shift in order to acquire peripheral information. This is consistent with the lack of acquisition during the eye shift. Postponing the eye movement would not make sense if peripheral information could be acquired during the eye movement.

In the eye field, t_m was slightly longer when the right signal was presented during or after the eye movement than when it was presented during the fixation of the left signal. The absence of the right signal at the start of the eye movement appears to slightly slow down the movement speed. It could be that when the right fixation point is indicated by only a fixation light, a slower speed is programmed. Yet this effect is secondary to the main finding that the acquisition of useful peripheral information is fully limited to the fixation pause.

In summary, these findings extend Rayner's (1978) results to conditions of much larger eye shifts as well as more simple peripheral signals. The results also confirm Sanders' (1963, 1966) interpretation that signals are not acquired during saccadic eye movements. They are also in line with strong saccadic suppression.

REFERENCE NOTE

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