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Control of fixation duration in a simple search task

I. T. C. HOOGE and C. J. ERKELENS
Helmholtz Institute, Utrecht University, Utrecht, The Netherlands

To obtain insight into the control of fixation duration during visual search, we had 4 subjects perform simple search tasks in which we systematically varied the discriminability of the target. The experiment was carried out under two conditions. Under the first condition (blocked), the discriminability of the target was kept constant during a session. Under the second condition (mixed), the discriminability of the target varied per trial. Under the blocked condition, fixation duration increased with decreasing discriminability. For 2 subjects, we found much shorter fixation durations in difficult trials with the mixed condition than in difficult trials with the blocked condition. Overall, the subjects fixated the target, continued to search, and then went back to the target in 5%–55% of the correct trials. In these trials, the result of the analysis of the foveal target was not used for preparing the next saccade. The results support a preprogramming model of the control of fixation duration. In a simple search task, control of fixation duration appears to be indirect.

In daily life, the oculomotor system and the visual system work in close cooperation. On the one hand, eye position determines the part of the environment that is accessible to visual perception. On the other hand, visually perceived information is essential for making goal-directed eye movements. Extensive visual search and reading are good examples of this cooperation. In both tasks, a sequence of eye movements is required to gather visual information from a display that exceeds the area covered by a single glance. During periods of fixation (intersaccadic intervals), at least three processes relating to vision may occur. These processes are samplings of the visual field, analysis of the foveal part of the visual field, and planning of the next eye movement (Viviani, 1990). These three processes take time. Analysis of the foveal target takes at least 100 to 150 msec (Eriksen & Eriksen, 1971) and eye-movement programming takes about 150 to 200 msec (Becker & Jürgens, 1979). These two processes are assumed to act in parallel, but not much is known about the amount of overlap (Viviani, 1990). In this visual-search study, we were interested in the relationship between the analysis of the foveal target and the control of fixation duration. In other words: Is the result of the analysis of the foveal target used in the planning of the next eye movement?

Two models have been proposed. The first is the process-monitoring model (Rayner, 1978), in which the analysis of the foveal target is monitored by the mechanism that controls the fixation duration. The planning of the saccade starts after the analysis of the foveal target has been completed. Analysis of the foveal target and planning of the following saccade do not overlap. In this model, fixation duration reflects the processing time that is needed for the analysis of the foveal target. This model implies dead time in the intersaccadic intervals, that is, periods which, because of the saccadic latency, are not used for visual processing.

The second model is the preprogramming model (Vaughan, 1982), in which the fixation duration is preprogrammed and independent of the visual processing time. In this model, analysis of the foveal target and planning of the saccade may overlap. The preprogramming model implies that the stimulus may not have been completely analyzed when the planning of the following eye movement started. Such saccades are not based on the analysis of the foveal target carried out during the preceding fixation. Two visual-search studies report the occurrence of this kind of eye movement. Engel (1977) found that in a search task in which subjects were asked to respond by fixating the target, search continued after subjects had fixated the target. Engel concluded that recognition took place at a stage later than the selection of a potential target for eye movement. Gould (1973) reported many refixations of targets and nontargets in a visual- and memory-search task. In that study, subjects were also asked to respond by fixating the target.

In an experiment in which we want to study the control of fixation duration, we have to be aware of the fact that subjects may follow a specific strategy for the control of saccade amplitude and fixation duration. If fixation duration is the variable of major interest, dense displays should be avoided (Moffit, 1980). In the case of a dense display, depending on stimulus material and strategy, there may be a tradeoff between fixation duration and saccade amplitude. Jacobs (1986) describes three possible strategies for controlling fixation durations. First, given a certain saccade amplitude, the fixation duration depends on the amount of visual information that has to be analyzed. Second, fixation duration is fixed and sac-

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cade amplitude decreases as the increasing amount of visual information to be analyzed increases. The third strategy involves a combination of the first and second strategies. In the third strategy, fixation duration increases and saccade amplitude decreases with increasing amount of visual information. An example of the second strategy is demonstrated in Gordon's (1969) study, in which subjects had to look for an "a" (the target) in a list of characters. He found almost equal fixation durations for easy tasks (nontargets of one kind) and difficult tasks (nontargets of two or four kinds). In the easy task, saccade amplitudes were large. In the difficult task, saccade amplitudes were small. Jacobs (1986) found evidence for the third strategy. He investigated the factor determining saccade amplitude in a search task. Subjects had to look for a character in lines of the letter x. He analyzed saccade amplitude and fixation duration only for lines that did not contain targets. If he instructed subjects to look for a difficult target (a z among xs), he found variable saccade amplitudes and long fixation durations. Saccade amplitudes were larger and fixation durations were shorter when the subjects were instructed to look for an easy target (a C among xs). He found that saccade amplitude depended on the expected difficulty of the task. Jacobs suggested that *control of saccade length* is not determined by the stimulus alone.

To investigate whether the *control of fixation duration* depended on the result of the visual recognition task or on the expected difficulty of search, we engaged subjects in a search task in which we systematically varied the discriminability of the target. To prevent the subjects from using different strategies in the tradeoff between saccade amplitude and fixation duration, we designed the stimulus in such a way that only one target could be analyzed during one period of fixation. Our experiment was performed in a blocked design in which the difficulty of the task was predictable and in a mixed design in which it was not. If the control of fixation duration behaved like a process monitoring model, we expected that fixation duration as a function of discriminability of the target would be unaffected by the presentation order of the trials (blocked or mixed).

METHOD

Subjects

Four male subjects participated in this experiment (aged 24 to 45 years). They were experienced with eye-movement recordings. Subjects C.G., I.H., and H.T. had normal vision without correction. C.E. wore contact lenses. C.E. and I.H. were the authors. C.G. and H.T. were not familiar with the goals of the experiment. C.G. and I.H. had had some practice inasmuch as they were involved in the pilot experiments. C.E. and H.T. had had no practice at all before they participated in the experiment.

Apparatus

The subjects sat in front of a large screen at a distance of 1.50 m in a completely darkened room. To prevent head movements, the subject's head was kept steady by a chin- and headrest. The stimuli were generated by an Apple Macintosh IIci personal computer (refresh rate 66.7 Hz, resolution 640 × 480 pixels) and rear-projected on a translucent screen by a Barco Data 800 projection television. The screen measured 1.9 × 2.4 m. Eye movements of the right eye were measured using an induction coil mounted in a scleral annulus in an a.c. magnetic field. This method was first described by Robinson (1963) and refined by Collewijn, van der Mark, and Jansen (1975). The dynamic range of the recording system was from direct current to 100 Hz (3 dB down), with a noise level of less than 10' of arc. Deviation from linearity was less than 1% over a range of ±20°. The horizontal and vertical eye positions of the right eye were measured at a sampling rate of 500 Hz using a National Instruments 12-bit NB-MIO16h analog-to-digital converter. Data was stored on disk for further analysis.

Data Analysis

Data were analyzed off line by a computer program that ran on an Apollo 10000 system. In the analysis, saccades were detected by a velocity threshold. The velocity threshold was 150°/sec. After detection of a saccade, the program searched for the onset and offset of that particular saccade. The program marked the onsets and offsets of the saccades, and from these markers it computed fixation durations and the number of saccades per trial. We used an amplitude threshold of 1° to remove small-correction saccades. Velocity and amplitude thresholds adequately removed noise and blinks from the analysis. Using the marked data points, the program also plotted the scan path and computed search times and the number of detected targets. The scan paths were used mainly to examine repeated fixations of objects.

Procedure

To investigate the control of fixation duration during visual search, we designed a search experiment in which eye movements were required for finding the target. We ensured that subjects could not discriminate the target while periodically fixating nontargets. To achieve this, we separated the objects in such way that, for nonfixated objects, the difference between target and nontargets was below the threshold of visual acuity (Drasdo, 1991). The stimulus consisted of seven objects that were positioned equidistantly on an invisible circle (radius 15°). The objects were six Landolt Cs (the nontargets) and one circle (the target). Every stimulus contained one circle. The green circle and the green Landolt Cs were projected on a black background. They had diameters of 2.1° of visual angle. Gaps in the Landolt C measured 0.15°, 0.30°, or 0.60° of visual angle. Orientation of each C was randomly chosen from the directions: "0°, 90°, 180°, and 270°."

A trial started with the presentation of only the target. The target marked the starting position and appeared randomly at one of the seven object positions. The subjects were asked to fixate this target. After 1 sec, the complete stimulus, in which one target was randomly positioned at one of the seven object positions, appeared on the screen and remained visible for 2 sec. The subjects were allowed to make eye movements and were asked to find the target within the presentation time of 2 sec. If the subject found the target, we asked him to continue fixating it until the end of that particular trial.

Under one condition, we presented the stimulus in three blocks, each consisting of 123 trials (blocked condition). In each block, Landolt Cs, with one of the three selected gap sizes, were used. Thus, the difficulty of the discrimination task did not change within a block. Under the second condition, we mixed the trials of the three blocks. Mixed trials were also presented in three blocks of 123 trials (mixed condition). In this condition, the difficulty of the discrimination task varied from trial to trial.

RESULTS

Scan Patterns

Figure 1 shows four examples of scan patterns. Subjects fixated the objects one at a time (Figure 1A). We did not

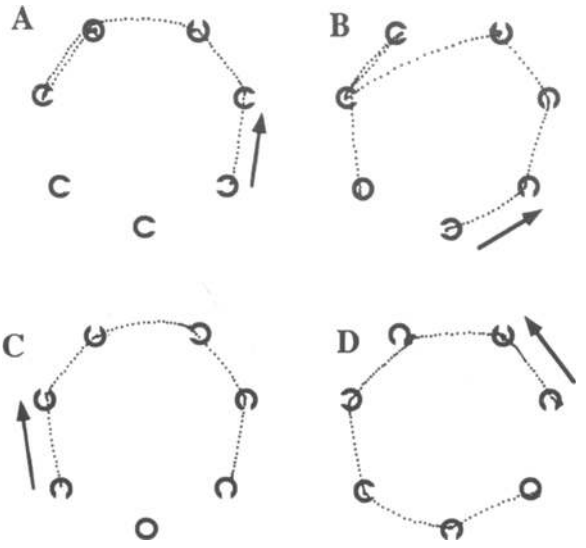

Figure 1. Scan patterns. (A) Finding the target after a return saccade, (B) changing direction and skipping an object, (C) not reaching the target because out of time, and (D) a correct trial.

find many fixations that were positioned between two objects. Generally they scanned systematically in either a clockwise or a counterclockwise direction. Occasionally, they skipped an object or changed direction (Figure 1B). The subjects were not always successful in finding the target: (1) They ran out of time because they fixated at each position for too long (Figure 1C). (2) They made mistakes because they did not recognize the target when they fixated it; they just went on making eye movements. In some cases a target was recognized during fixation, but recognition came too late to cancel the following eye movement. Then they made another one or two eye movements before returning to the target (Figure 1A). These eye movements we will call return saccades. (3) Subjects misjudged nontargets. This type of error was characterized by continued fixation of a nontarget. When this occurred, we were not able to distinguish between errors of Type 1 and Type 3. So we will not make any distinction between these two types of errors in any further analysis.

The distribution of saccade amplitudes provides insight into the way in which scanning takes place. The occurrence of saccades larger than the distance between objects points to a skipping of objects. Figure 2 shows a representative example of the distribution of saccade amplitudes. A large peak is seen for amplitudes between 11° and 13°. These are amplitudes of saccades made from one object to an adjacent object. The shortest distance between the objects was 13.3°. We do not find many saccades with amplitudes of 27°, which is about the shortest distance between two objects that are not adjacent. These results show that objects are mainly inspected piecewise and one after the other.

If during fixation, recognition of the target came too late to cancel the following eye movement, the subject made one or more additional eye movements, followed by a return saccade. In Figure 3, we have plotted the fraction of return saccades against gap size. By "fraction of return saccades," we mean the number of return saccades divided by the number of correct trials. A correct trial is a trial in which the target is found. There are large differences among subjects. Within a subject, the fraction of return saccades is independent of gap size. It is difficult to draw any conclusion from the fraction of return saccades. Other experiments will be necessary to determine the relationships between fixation duration, processing time, and the occurrence of return saccades.

Fixation Durations

In Figure 4, fixation duration and initial fixation duration are plotted against gap size under mixed and blocked conditions. Initial fixation duration is the duration of the first fixation of each trial. We plotted initial fixation duration separately because, in general, we found bimodal distributions of fixation duration (Figure 5). The second peak of the distribution represents the initial fixation durations. The first peak of the distribution represents the remaining fixation durations. In the majority of the trials, the initial fixation durations were longer than the remaining fixation durations.

Fixation durations ranged between 150 and 450 msec and decreased with increasing gap size. This means that fixation duration increases with increasing difficulty of the discrimination task.

The results for Subjects I.H. and C.E. show a slight increase in both initial and remaining fixation duration with decreasing gap size. Fixation durations do not differ much in blocked and mixed conditions. In general, Subject I.H. has shorter fixation durations than Subject C.E.

The results for C.G. are similar to those for I.H. and C.E. in trials with gap sizes of 0.60° and 0.30°. The results for C.G. differ from those for I.H. and C.E. for trials with the smallest gap size. C.G. has long fixation durations under the blocked condition and much shorter fixation durations under the mixed condition.

The results for Subject H.T. show large differences between the blocked and the mixed condition. Under the

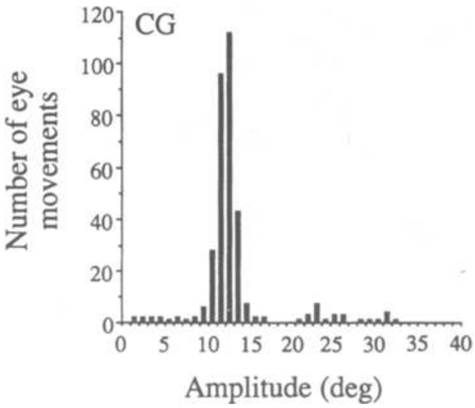

Figure 2. The distribution of the saccade amplitudes of Subject C.G. under the blocked condition. Gap size was 0.15° and bin width was 1°. (We did not plot saccades having amplitudes smaller than 1°.)

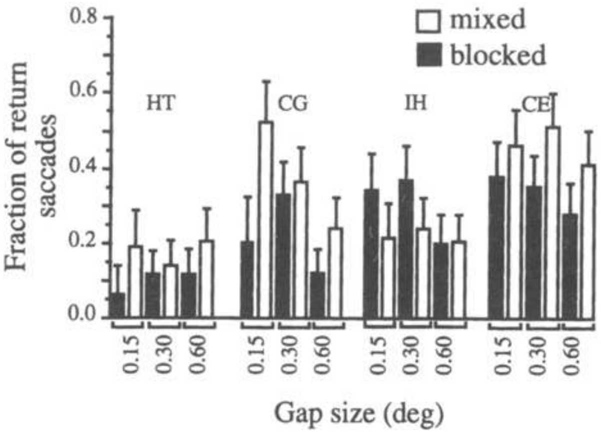

Figure 3. Number of return saccades divided by the number of correct trials against gap size. The white bars denote the mixed condition; the black bars denote the blocked condition. Error bars represent the 95% confidence intervals.

blocked condition, fixation duration is strongly related to gap size. Under the mixed condition, fixation durations in trials with a gap size of 0.60° are longer than they are under the blocked condition. Fixation durations in trials with a gap size of 0.15° are shorter than they are under the blocked condition.

Search Time

Search time depends on the number of fixations and on the fixation durations. In our experiment, fixation duration depends on gap size and condition (mixed or blocked). We limited presentation time to 2 sec. In the case of many fixations and long fixation durations, 2 sec is not long enough to find the target.

Figure 6 shows the cumulative fraction of correct trials in relation to search time. We define fraction of correct trials as the number of trials in which a target was found divided by the total number of trials. We define search time as the time from stimulus onset to the moment at which a subject starts to maintain fixation at the target position. Our definition of search time differs from that used in experiments in which subjects respond by pushing a button. By our definition, search time is slightly shorter than the "real" search time, because we do not take into account the time that is needed for analysis of the last object. Search times of 0 msec may occur when the target appears at the starting position and is recognized quickly. The usual "push button" search time is longer than the "real" search time because it includes the reaction time of the push.

Slopes of the cumulative curves increase with gap size. The slope is proportional to search speed, so search time increases with decreasing gap size. When search was slow, the fraction of detected targets did not reach a value close

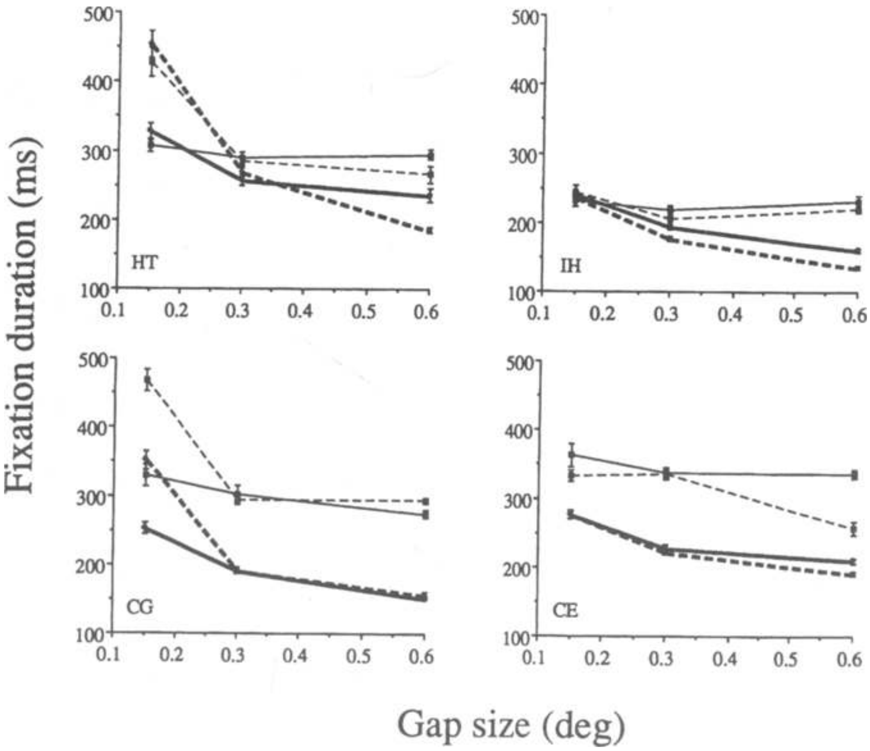

Figure 4. Fixation duration against gap size. Thin lines denote the initial fixation durations of each trial; thick lines denote the other fixation durations. Solid lines denote the mixed condition, and dashed lines denote the blocked condition.

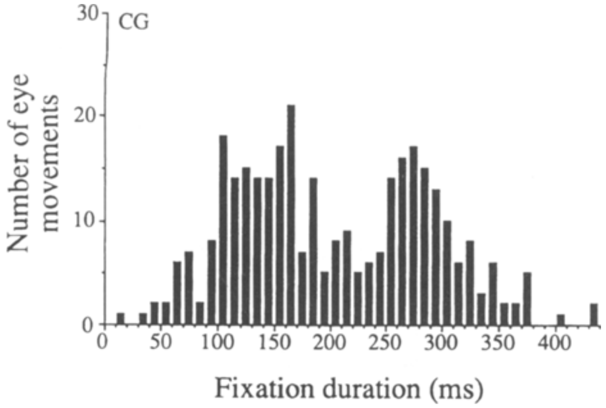

Figure 5. The distribution of fixation durations of Subject C.G. under the blocked condition. The second peak represents the initial fixation durations. The first peak represents the other fixation durations. Gap size is 0.15°, and bin width is 10 msec.

to 1.0, because presentation time was limited to 2 sec. This is mainly the case in trials with a gap size of 0.15°.

For a certain gap size, the cumulative curve reaches the highest level in the condition in which subjects had the highest fixation rate. The results for Subject H.T. are a good illustration of this observation. For trials with a gap size of 0.15°, fixation durations were longer under the mixed condition than under the blocked condition. Under the blocked condition, the cumulative curve has a larger slope and reaches a higher level. The opposite was found for trials with a gap size of 0.15°. Fixation durations were longer under the blocked condition than under the mixed condition. Under the mixed condition, the slope was larger and a higher level of correct responses was reached.

In one-seventh of the trials, the target appeared at the position of the fixation marker. In other words, the fixation marker (a circle) remained at the same position and six Landolt Cs appeared elsewhere. The subjects did not have to make any eye movement, because they had already fixated the target position. But subjects did not always recognize the target or they recognized it too late to cancel the following eye movement. For this reason, Figure 6 shows that cumulative curves do not intersect the fraction-correct axis at the one-seventh fraction of detected targets. An illustrative example is Subject I.H.; he always missed the target when it appeared at the starting position. The initial fraction of detected targets is about zero. Inspection of initial fixation durations shows that Subject I.H. always briefly fixated the first object (Figure 4).

DISCUSSION

Initial Fixation Durations

The results for 3 subjects show that the initial fixation durations were longer than the subsequent fixation durations. To explain why initial fixation durations were longer than the subsequent fixation durations, Zingale

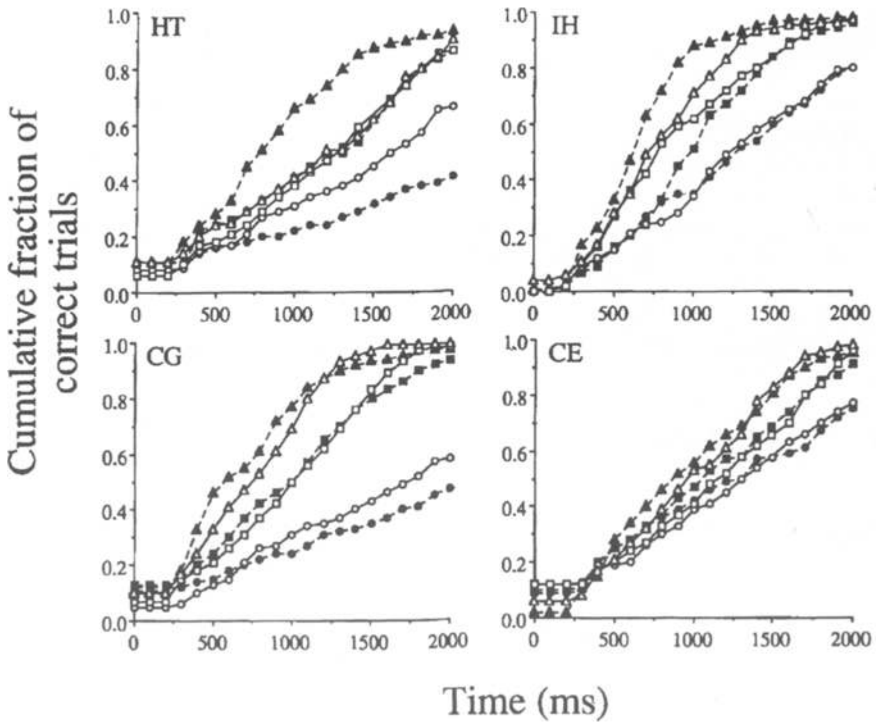

Figure 6. Cumulative fraction of correct trials against search time. Open symbols denote the mixed condition; filled symbols denote the blocked condition. Circles indicate a gap size of 0.15°, squares indicate a gap size of 0.30°, and triangles indicate a gap size of 0.60°.

and Kowler (1987) suggested that a sequence of eye movements is programmed during the first fixation. In our experiment, subjects had to make eye movements to circles and Landolt Cs which were placed at the same grid in every trial. In our experiment, subjects did not have to use the actual visual-position information of the potential targets to make eye movements. Eye movements could also be based on remembered locations. Zingale and Kowler found longer initial fixation durations in an experiment in which they asked a subject to scan, as quickly as possible, a number of circularly positioned targets. Initial fixation duration increased with the number of eye movements the subject made. Subsequent fixation durations decreased with the number of eye movements. In trials in which the subject made five eye movements, the initial fixation duration was about 100 msec longer than the subsequent fixation durations. This difference between the initial and the subsequent fixation durations is comparable to the differences in fixation times that we found in our experiment.

Another explanation for the longer initial fixation durations is that they were the result of a special strategy accorded only to the first fixation, that is, the subjects' treatment of the first fixation was different from that of the other fixations. In an attempt to determine the reason for the advantage of longer fixation durations, we plotted the number of times that subjects maintained fixation at the initial fixation position for trials in which the target appeared at the starting position against initial fixation duration for the difficult tasks (gap size 0.15°). In one seventh of the trials, the target appeared at the starting position. To fixate the target, the subjects did not have to make an eye movement. When the eye started on the target and moved to a nontarget, the result of the analysis of the foveal target was not used for preparing that particular eye movement. At least 150 msec is needed (latency of a fast regular saccade; Fischer & Ramsperger, 1984) to plan an eye movement. If a subject wants to use the result of the analysis of the foveal target for the next eye movement, we assume that the fixation duration has to be longer than 150 msec. Figure 7 shows a decreasing number of eye movements from the target with increasing fixation duration. Subject I.H. used a strategy with respect to the first object which differed from that used by the other 3 subjects. Subject I.H. briefly inspected the first object and therefore made many mistakes. This means that at least 100 msec is needed for the analysis of the foveal target. If fixation duration is too short, the result of the analysis of the foveal target comes too late and cannot be used for canceling the next saccade. This corroborates the findings of Engel (1977), who found that search continued after fixation of the target due to a lag in recognition.

A third possibility is discussed in the following section. We suggest a model that describes control of fixation duration. In this model, analysis of the foveal target during the initial fixation plays an important role. During the initial fixation of a trial, a subject estimates the time needed to analyze the foveal target.

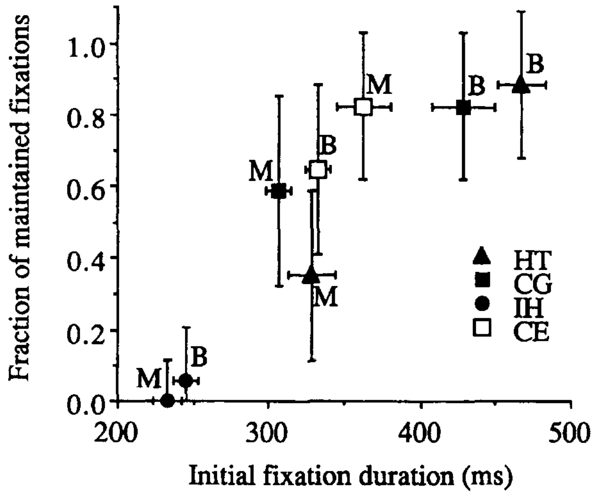

Figure 7. Fraction of trials in which the subjects fixated the target and did not make any eye movement when the target appeared at the starting position relative to duration of the initial fixation. Gap size is 0.15°. Two data points are plotted for each subject. M, mixed condition; B, blocked condition. Error bars represent the 95% confidence intervals.

Control of Fixation Duration

How is fixation duration controlled? To answer this question, we relate our results to four models: (1) the preprogramming-per-trial model, (2) the preprogramming-per-fixation model, (3) the strict process-monitoring model (Rayner, 1978), and (4) the mixed-control model (Rayner & Pollatsek, 1981).

If the fixation durations are preprogrammed, subjects have to estimate the time that is needed for the processing of the next foveal target. This estimation can be done only during previous fixations (Jacobs, 1986) or trials. Preprogramming models predict an adaptation of fixation duration to the difficulty of the discrimination task.

First, in the case of the preprogramming-per-trial model, we expect that fixation durations are influenced by the order in which the stimuli are presented. In a blocked-design experiment, only trials with the same gap size are presented in one session. Therefore, subjects should be more accurate in estimating the time needed to analyze the foveal target (Vaughan & Graefe, 1977) than they would be in a mixed design experiment in which the difficulty of the search task differs per trial. This model also predicts return saccades, which occur when the analysis of the foveal target is not completed when the planning of the next eye movement starts.

Second, in the case of the preprogramming-per-fixation model, the order of presentation will not have a large influence on the duration of fixations. Within a trial, there must be a correlation between successive fixation durations, which depend on an estimation of the time needed for an analysis of the foveal target. This estimation is done during a previous fixation. This model predicts the occurrence of return saccades for the same reason as the preprogramming-per-trial model predicts return saccades.

Third, we have the strict process-monitoring model, in which the fixation duration depends only on the processing time required for the actual fixated object. Fixation duration should be independent of fixation durations of previous fixations or trials. We expect fixation durations to be longer in difficult trials than in easy trials. The distribution of fixation durations reflects the distribution of the time needed to analyze the foveal target. If the control of fixation duration behaves as in a process-monitoring model, we can expect to find similar fixation durations in trials with a certain gap size under both the blocked and the mixed conditions. A strict process-monitoring model does not predict occurrence of return saccades, because the planning of an eye movement starts after the analysis of the foveal target has been completed.

Fourth, there is the mixed-control model, which is a combination of the preprogramming model and the process-monitoring model. The analysis of the foveal target is monitored. After a reasonable amount of processing, the planning of the next eye movement starts. This is not always the case; sometimes fixation durations are preprogrammed during a previous fixation or during the actual fixation without regard to the visual display. This model predicts return saccades if the analysis of the foveal target is not complete when the planning of the next eye movement starts. This model shortens the dead time that is involved in strict process monitoring.

We do not know the underlying distribution of time needed for the analysis of the foveal target. Distributions of fixation durations based on process monitoring models should in some way reflect the underlying distribution of analysis times.

The fixation durations of Subjects C.G. and H.T. seem to be more strongly related to gap size (difficulty of the search task) under the blocked condition than under the mixed condition. This suggests that fixation durations were more independent of the visual information presented during a fixation under the mixed condition than under the blocked condition. The results for Subjects C.E. and I.H. show little difference between the fixation durations of the blocked and mixed conditions. In both conditions, Subjects C.E. and I.H. had longer fixation durations in trials with small gap sizes than in trials with large gap sizes. But fixation durations for these 2 subjects differed less in the three kinds of trials under both conditions than they did for Subjects C.G. and H.T. All subjects showed initial fixation durations that were independent of gap size under the mixed condition.

We reject the strict process-monitoring model because return saccades occur. We also reject the mixed-control model because, first, in a mixed-control model there must be a relationship between the difficulty of the search task and fixation duration. The result for Subjects C.G. and H.T. showed large differences in fixation duration in both the blocked and mixed conditions for trials containing Cs with the smallest gap size. A mixed-control model cannot explain large differences in fixation duration between a mixed- and a blocked-design experiment. Second, a mixed-control model predicts, especially in a mixed-design experiment, a bimodal distribution of fixation durations. One peak of the distribution is due to preprogramming; the second is due to process monitoring. Neither in the mixed nor in the blocked condition did we find bimodal distributions of the remaining fixation durations.

The results of our experiment cannot be described by a process-monitoring model. For this reason, we assume that fixation durations are preprogrammed. An important question remains. What information is used for the programming of fixation durations? A subject has to estimate the time required for the analysis of the foveal target. The estimation can be done on the basis of the result of one fixation (short time estimation) or on the basis of the results of more fixations of one or more trials.

Suppose the subject determines, in the case of each fixation, whether the duration of the previous fixation was long enough for the analysis of the foveal target (preprogramming per fixation). If fixation duration was too short to analyze the foveal target, the subject slows down his fixation rate. A preprogramming-per-fixation model predicts that a subject has the ability to change the fixation rate per fixation. This only makes sense if the time needed to analyze the foveal target is a constant (or has a very small deviation) and if the oculomotor system is able to make a saccade at a very precisely determined moment. If the analysis time is widely distributed, it makes no sense to estimate analysis time from one fixation. Let us therefore assume that the time needed to analyze a foveal target has a constant value. Then eye movements must be made at a precisely determined moment. If that is not possible, it makes no sense to preprogram fixation duration for each trial. Not much is known about distributions of the time needed to analyze a foveal target and about distributions of fixation durations.

Subjects C.G. and H.T. were not able to adapt their fixation rates to the difficulty of the search task for the difficult trials (gap size 0.15°) under the mixed condition. Therefore, it is unlikely that fixation durations were preprogrammed per fixation. Our experiment cannot prove that fixation durations are preprogrammed per trial, but it does show that control of fixation duration is not direct (like some kind of process-monitoring model).

How can we compare our results with those obtained by Vaughan and Graefe (1977), Vaughan (1982), and Rayner and Pollatsek (1981)? The main difference between our experiments and theirs is that they used a stimulus-onset-delay paradigm to investigate the control of fixation duration. In such an experiment, the onset of the fixated stimulus (a word or a target or nontarget) is delayed for a certain time. If a subject wants to analyze the fixated stimulus, he has to wait until the foveal target appears, and it appears after a certain delay. Vaughan and Graefe found evidence for preprogramming. In their *blocked*-design experiment (fixed onset delay during one block), stimulus onset delays ranged from 0 to 150 msec. Subjects increased fixation durations with onset delay. We suggest that their subjects were able to adjust the fixation rate to the stimulus-onset delay plus the time needed to analyze the foveal target. Vaughan (1982) and Rayner and Pollatsek (1981) found evidence for mixed control of fixation duration. Vaughan did not rule out the possibility that the control of fixation in search behaves like a preprogramming model. In his view, effects of stimulus onset delay on oculomotor latency were evidence for direct control. In a stimulus-onset-delay paradigm, subjects probably use a strategy that differs from that used in a normal search task. In a stimulus-onset-delay paradigm, subjects probably use the onset of the foveal target as a warning signal.

We suggest that control of the fixation duration in a simple search task like ours is indirect. Adjustment of fixation duration is based on the expected difficulty of the search task. The expected difficulty of the search task is estimated during previous fixations. During the initial fixation of each trial (which was much longer than subsequent fixations), the subject assesses the difficulty of the search task. The duration of the first fixation has to be long enough for the subject to be able to assess the difficulty of the search task. The subject then adjusts the fixation duration to the difficulty of the search task. The fixation has to be long enough for recognition of the target. Planning a saccade and recognition may overlap. Because presentation time was limited, subjects had to minimize dead time. This adjustment was subject dependent. This resulted in different fractions of return saccades per subject. We assume that the differences in fixation duration between the mixed and the blocked condition for Subjects C.G. and H.T. were due to the incorrect adjustment of the initial fixation duration. For all subjects, the initial fixation duration was almost independent of gap size under the mixed condition (Figure 5). Initial fixation durations of Subjects C.G. and H.T. in trials with a gap size of 0.15° in the mixed condition were shorter than remaining fixation durations of difficult trials of the blocked condition. This suggests that, under the mixed condition, in trials with a gap size of 0.15° during the first fixation, C.G. and H.T. adjusted a fixation duration that was not long enough for the discovery that the current trial was a difficult one. Fixation durations of Subjects C.E. and I.H. were less a function of gap size under the blocked condition, so in the mixed condition they adjusted a fixation duration that was long enough to assess the difficulty of the trial.

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