

Lateral information transfer across saccadic eye movements

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Our perception of the visual world remains stable and continuous despite the disruptions caused by retinal image displacements during saccadic eye movements. The problem of visual stability is closely related to the question of whether information is transferred across such eye movements—and if so, what sort of information is transferred. We report experiments carried out to investigate how presaccadic signals at the location of the saccade goal influence the visibility of postsaccadic test signals presented at the fovea. The signals were Landolt rings of different orientations. If the orientations of pre- and postsaccadic Landolt rings were different, the thresholds of the test signals were elevated by about 20%-25% relative to those at the static control condition. When the orientations were identical, no such elevation occurred. This selective threshold elevation effect proved to be a phenomenon different from ordinary saccadic suppression, although it was closely related to the execution of the saccadic eye movement. The consequences for visual stability are discussed.

Our active perception of the visual environment is accompanied by saccadic eye movements by which objects of interest are successively mapped onto the fovea so that we can achieve a detailed and consistent view of the visual world. Despite these fast ballistic eye movements, which occur at a rate of about 3/sec, with each one changing the retinal image drastically, the impression of the world remains stable and unified. The well-known effect of saccadic suppression alone cannot account for this phenomenon, since it explains only the reduced sensitivity to retinal smear during the eye movement, thus leaving the problem of unifying pre- and postsaccadic perception into one coherent view.

As a solution to this problem, a temporal integration of visual information bridging the saccade has been proposed. The underlying notion for this hypothesis is that of a buffer organized in spatiotopic coordinates where retinal information is temporally accumulated in an integrative manner after having been transformed from retinotopic to spatiotopic coordinates. This view may be regarded as a generalization of classical iconic memory concepts (Neisser, 1967). It leads to the important testable hypothesis of a spatiotopic superposition of pre- and postsaccadic perception and has been put to test in a number of studies (Bridgeman & Mayer, 1983; Irwin, Yantis, & Jonides, 1983; Jonides, Irwin, & Yantis, 1983; Rayner & Pollatsek, 1983). In the typical experimental paradigm

used in these investigations, 12 dots out of a 5×5 dot matrix were parafoveally presented to the subject. When the observer saccaded to the location of these dots, they were replaced by another subset of 12 dots of the matrix during the eye movement. The task was to indicate the location of the missing dot which had been presented in neither the first nor the second presentation. This obviously requires the fusion of the pre- and postsaccadic stimulus configuration in spatial coordinates that is assumed by the buffer hypothesis. However, no evidence was found for this hypothesis, and the results could be reinterpreted in a way that did not involve spatiotopic fusion. Another experiment arguing against spatiotopic fusion was reported by O'Regan and Lévy-Schoen (1983), who used two sets of line segments which, when superimposed, formed letter strings. However, subjects again proved to be unable to perform this spatiotopic integration, if one half of the stimulus was presented before the saccade and one half after it.

On the other hand, there is experimental evidence that peripheral and foveal vision can efficiently cooperate during a saccade in the sense that postsaccadic image processing is facilitated by presaccadic information at the locus of the saccade goal. This facilitative effect has been demonstrated in reading (McConkie & Zola, 1979; Rayner, McConkie, & Ehrlich, 1978) as well as in picture naming (Pollatsek, Rayner, & Collins, 1984; Pollatsek, Rayner, & Henderson, 1990) and in visual search (Rayner & Fisher, 1987). In general, these experiments yielded a shortening of response times in the case of the semantic identity of the previewed object and the saccade target. This is to say that in this context "identity" does not necessarily mean physical identity but rather identity in a semantic sense. In reading, for instance, the response behavior remains unaffected if only letter case is altered during the saccade flight but the word meaning remains

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the same (Rayner, McConkie, & Zola, 1980). This finding supports the idea of a cooperation of presaccadic and postsaccadic information processing on a level where physical and semantic stimulus features are yet separated.

Another experimental paradigm concerning transsaccadic information processing was introduced by Wolf, Hauske, and Lupp (1978, 1980). They measured the visibility of sinusoidal gratings presented on the fovea after a saccade as a function of the spatial frequency of a peripheral grating presented immediately before the saccade. Only for gratings of medium spatial frequency was an improved visibility found, provided that pre- and postsaccadic stimuli had the same spatial frequency and the same spatial coordinates. This result was interpreted as suggesting a transsaccadic integration of spatial frequency filtered versions of the pre- and postsaccadic retinal images within a spatiotopic coordinate frame. More recently, Irwin, Zacks, and Brown (1990) failed to replicate the results of Wolf et al. in a similar experimental situation. However, the presentation time of their postsaccadic target was much longer than that used by Wolf et al. (250 vs. 20 msec). Given the typical average fixation duration of about 300 msec, this difference might be critical for the outcome of the experiment if the processes bridging pre- and postsaccadic perception are active only during a fractional part of the intersaccadic period. Hence, the direct comparability of these studies remains questionable.

Motivated by the divergent findings outlined above, we performed an experiment in which we used Landolt rings with different orientations in order to investigate how presaccadic signals at the spatiotopic position of the saccade goal influence the visibility of postsaccadic foveally presented test signals. We considered these Landolt rings simply as letter-like figures, whose information content was given by their orientations. Our choice of this type of stimuli resulted from the intention to have signals that on the one hand were geometrically similar to letters but, on the other hand, should be free from the peculiarities of letter recognition and reading. Thus, our experiment should be less problematic for the attempt to generalize from experimental to natural viewing situations (see Loftus, 1983, for this problem). As an index for visibility, we determined the threshold contrasts for the different orientations of the Landolt rings.

METHOD

Subjects

Four subjects (C.S., M.H., M.J., and T.K.) with normal or corrected-to-normal vision, three of whom (C.S., M.H., and T.K.) were naive with respect to the aim of the study, participated in the study.

Apparatus

Stimulus generation and presentation were controlled by a color pattern generator (see Gerber, 1987, for details) that permitted the generation and manipulation of two-dimensional 256 × 256 × 10 bit patterns in real time at a frame rate of 50 Hz. The stimuli were presented on a Barco CDCT 6151 monitor (Hitachi 510 CKB 22; P22 phosphor with a 10% decay rate of less than 1 msec; see Skol-

nik, 1970). The mean luminance of the screen was adjusted to 20 cd/m². The modulation of the signals presented on the screen did not exceed 6% of the mean luminance. The screen subtended 28° × 21° of visual angle at the viewing distance of 0.8 m. Eye movements were recorded using an infrared scleral reflectance technique with a horizontal resolution of 0.1°. The sampling rate for the eye position signal was restricted to 50 Hz, owing to the synchronization given by the frame rate of the pattern generator. Saccade onset was determined by applying an eye position change criterion of 1° in 20 msec. Stimulus presentation, eye movement tracking, and response acquisition were controlled by a PDP-11/24 minicomputer.

Stimuli

The stimuli were Landolt rings of four possible gap orientations: 0°, 90°, 180°, and 270° (Figure 1). By definition, both line width and gap width equal 0.2 times the outside diameter of the Landolt ring. Usually all rings appeared under a visual angle of 1.7°. Only in one experimental condition (Persistence Control II) were Landolt rings of 2.1° also used. Parafoveally presented Landolt rings had contrast values of 0.16 log units, so that they could be easily identified in peripheral vision. For the test stimuli, four different contrast levels near threshold (-0.04, 0.04, 0.10, and 0.16 log units) were selected and kept fixed over the experiments. Thus the number of test stimuli amounted to 16 (4 orientations × 4 contrast levels). Small black dots of 0.1° diameter served as fixation points.

Procedure

The subjects viewed the screen monocularly with the left eye, the head being fixed with a bite bar. All room lights in the experimental area were turned off during the experimental sessions. There were three experimental conditions. They will be denoted, following the terminology of Wolf et al. (1978), as the resting eye, saccading eye, and control conditions. In addition, we performed two experiments to determine the possible influence of persistence effects. This seemed necessary, since phosphor persistence is known to have plagued other researchers in this field (Jonides, Irwin, & Yantis, 1982). The two experimental conditions will be denoted Persistence Control I and Persistence Control II. The conditions were blocked: Subjects C.S. and M.H. started with the resting eye condition, followed by the control condition, the saccading eye condition, Persistence Control I, and Persistence Control II; for Sub-

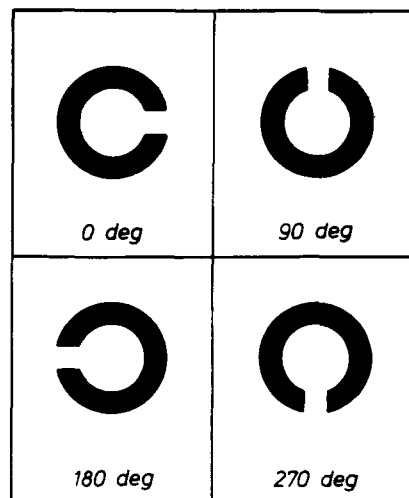


Figure 1. Landolt rings of gap orientations 0°, 90°, 180°, and 270°, serving as stimuli in the experiments.

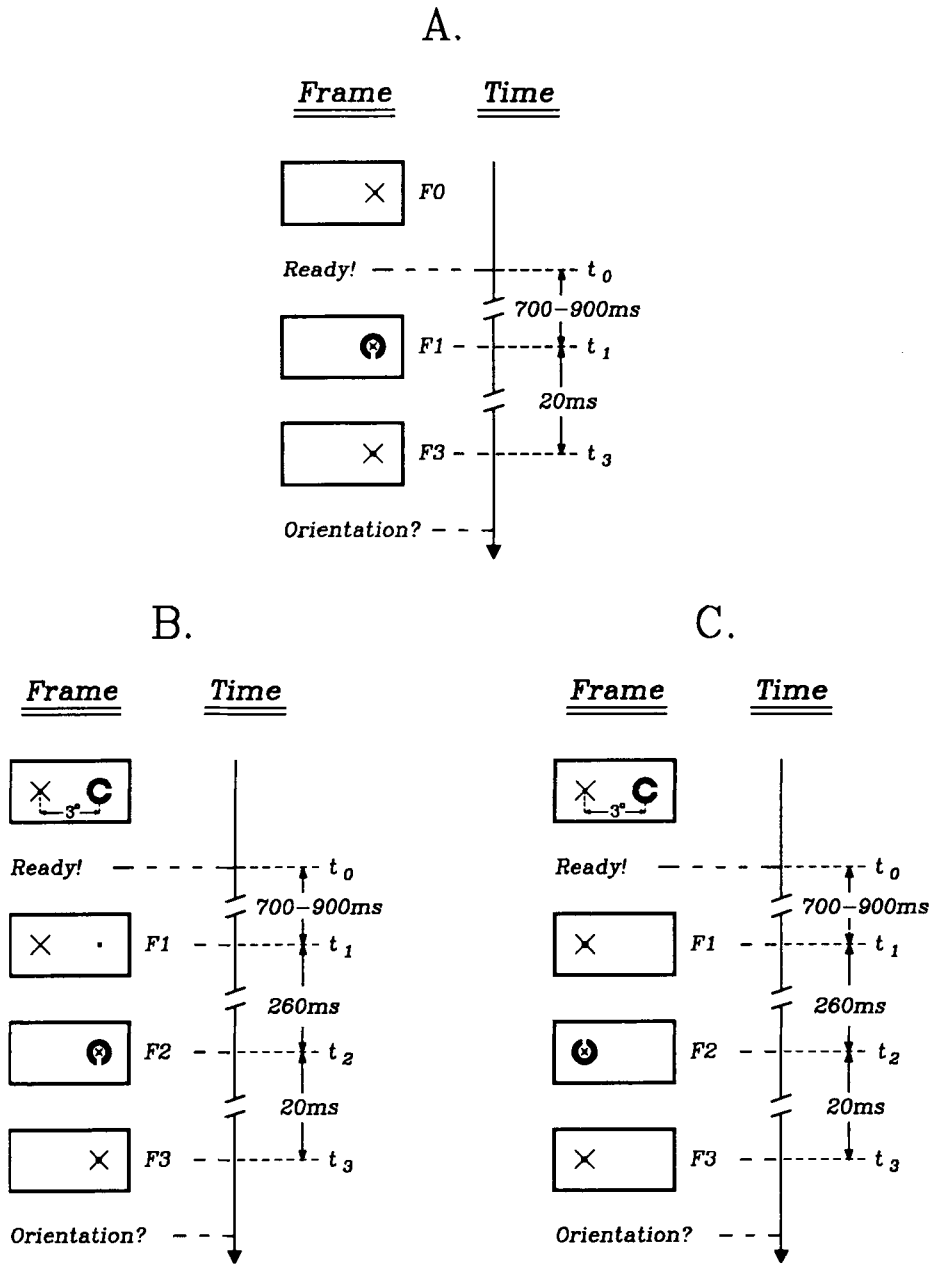


Figure 2. (A) Stimulus sequence in the resting eye condition. After the observer had initiated the trial, the test stimulus was presented for 20 msec after a foreperiod of 700-900 msec. The test stimulus was centered at the location of the fixation dot, with orientation and contrast both randomly selected. The subject had to indicate the orientation. Note that the crosses in the diagram symbolize the subject's eye position and do not belong to the stimuli on the screen. (B) Stimulus sequence in the saccading eye condition. The subject started to fixate a dot in the left half of the monitor. At a distance of 3° of visual angle, the presaccadic stimulus was presented. It consisted of a Landolt ring with weak suprathreshold contrast and randomly selected orientation. After the observer had signaled his or her readiness, the parafoveal stimulus disappeared after 700-900 msec. At the same time, the fixation dot jumped to its position. The subject had to saccade to the fixation point within a time window of 200 msec, and after an interstimulus interval of 260 msec, the test signal was presented. The rest of the sequence is identical to that in A. (C) Stimulus sequence in the control condition. In contrast to B, the eye position of the observer remained constant and the displacement effect of the eye movement was simulated.

jects M.J. and T.K., the order of control condition and saccading eye condition was reversed, whereas the rest of the sequence remained unchanged.

Resting eye condition. This condition (Figure 2A) served as a reference condition in our experiments. Here the test signal was presented without any preceding saccade and without any parafoveal stimulation. The subject started to fixate a dot in the right half of the monitor. The cross in Figure 2A symbolizes the subject's eye position and does not belong to the frame itself. When the observer had achieved fixation he/she pressed a button. After a delay of 700–900 msec, the test stimulus was presented for 20 msec, centered at the location of the fixation dot. Both orientation and contrast of the test stimulus were randomly selected from the corresponding sets of four possible values, respectively. The subject had to indicate the orientation by pressing a button on a keypad (i.e., a four-alternative forced choice was employed). This keypress ended the trial and the next cycle started. Each session consisted of 20 presentations per stimulus, resulting in 320 trials per session. The data of five sessions were pooled. Hence, the database in this condition consisted of 100 presentations per stimulus. The performance of the subject was calculated in terms of frequency of correct responses. From the data, we calculated threshold values for each orientation by means of a probit analysis (Finney, 1971).

Saccading eye condition. The stimulus sequence of this experimental condition is shown in Figure 2B. Again the subject started to fixate a dot, this time in the left half of the monitor. At a distance of 3° of visual angle, the presaccadic stimulus was presented; it consisted of a Landolt ring with randomly selected orientation. After the observer had signaled his/her readiness, the parafoveal stimulus disappeared after 700–900 msec. At the same time, the fixation dot jumped to its position. The subject had to saccade to the fixation point within 200 msec. Both the eye movement and the preceding fixation period after the ready signal were checked for correct execution. Trials with fixation errors above 1° or with improper execution of the saccade were discarded. In this case, the subject was informed by an acoustical signal and the disqualified trial was repeated later. After a total interstimulus interval of 260 msec, the test signal was presented for 20 msec, centered at the new position of the fixation point. Orientation and contrast were again randomly selected and the subject had to indicate the orientation of the test signal. Hence, the resting eye condition and the saccading eye condition differed only to the extent that in the latter, the presentation of the test signal was preceded by the presentation of a parafoveal signal. The latter shared the same spatial coordinates but was separated in time by a saccadic eye movement and, therefore, also in space with respect to the retinal frame of reference. Since a trial in the saccading eye condition was determined by three parameters (orientation of the presaccadic signal, orientation of the test signal, and contrast of the test signal), each of which had four possible values, the total number of stimulus configurations amounted to 64. Thus, one 320-trial session in the saccading eye condition had five presentations per configuration, and we pooled the data of 10 sessions in order to receive 50 presentations per configuration as a database for the threshold calculations.

Control condition. Moreover, we tested a situation in which the displacement effect of the saccade in the saccading eye condition was simulated by an appropriate step of the locus of presentation of the test signal leading to the sequence depicted in Figure 2C. A comparison with Figure 2B demonstrates that both the control and the saccading eye conditions had the same spatiotemporal stimulus sequence in the retinal coordinate system but not with respect to the spatiotopic reference frame. Data collection and evaluation in the control condition were the same as for the saccading eye condition.

Persistence Control I. In this experiment, a program-controlled electromagnetic shutter was mounted in front of the display. The shutter closed at the beginning of the trial; a prime signal was pre-

sented on the screen simultaneously. After 700–900 msec, the shutter opened again, and at the same time the prime signal was extinguished. The rest of the sequence, consisting of the interstimulus interval and the presentation of the test signal, was identical to that in the regular conditions outlined. The prime and test stimuli were presented at identical locations on the screen. In order to see whether the prime stimulus had any effect on the perception of the test signal, we compared the calculated threshold values with those of a reference condition in which no prime stimulus was presented behind the closed shutter device.

Persistence Control II. As another type of control definitively excluding phosphor persistence effects, we performed an experiment in the saccadic condition, where a presaccadic Landolt ring was presented, whose diameter was a factor of 1.25 larger than the test signal. Owing to the geometry of the Landolt ring, this resulted in a complete spatial decorrelation of the two signals, which now appeared successively concentric to each other without any pixel overlap.

RESULTS

Saccading Eye and Resting Eye Conditions

Figure 3 shows for 4 subjects the quotients Q_{SR} of the thresholds measured in the saccading eye condition and the reference values in the resting eye condition for each of the four possible orientations of the test signal. The parameter of each partial diagram is the orientation PSO of the presaccadic Landolt ring. The plots show a striking increase in contrast threshold when the orientations of the pre- and postsaccadic Landolt rings were different. Consider, for example, the upper right diagram for the data of Subject C.S. showing the threshold quotients for presentations in which the presaccadic stimulus had a 90° orientation. The threshold elevation consequently affects all orientations of the test signal that are different (i.e., 0°, 180°, and 270°). The same applies in an analogous manner to the other orientations of the presaccadic signal. The average threshold elevation amounts to about 25%. However, in the case of identical orientations of pre- and postsaccadic signals, the threshold values remained unchanged. This result is summarized in Table 1, where the threshold quotients were pooled into two subgroups referring to the cases of same orientation of pre- and postsaccadic signal (Subgroup S) and different orientation (Subgroup D), respectively, and the mean values of each group were calculated.

Since threshold values represent only averages of visibility over the spectrum of contrast levels, the question arises of how the observed interference effect depends in detail on contrast. Figure 4 shows the relative frequency of correct responses, P_{corr} , as a function of contrast. The diagram shows the psychometric functions of the pooled response data for Subgroups S and D in the saccading eye condition. For comparison, the corresponding function in the resting eye condition is also plotted. As already observed in the threshold representation of Figure 3, performance is poorest for Subgroup D when the orientation of the test signal is different from that of the presaccadic parafoveal presented signal. In contrast, the data of Subgroup S do not differ significantly from the reference con-

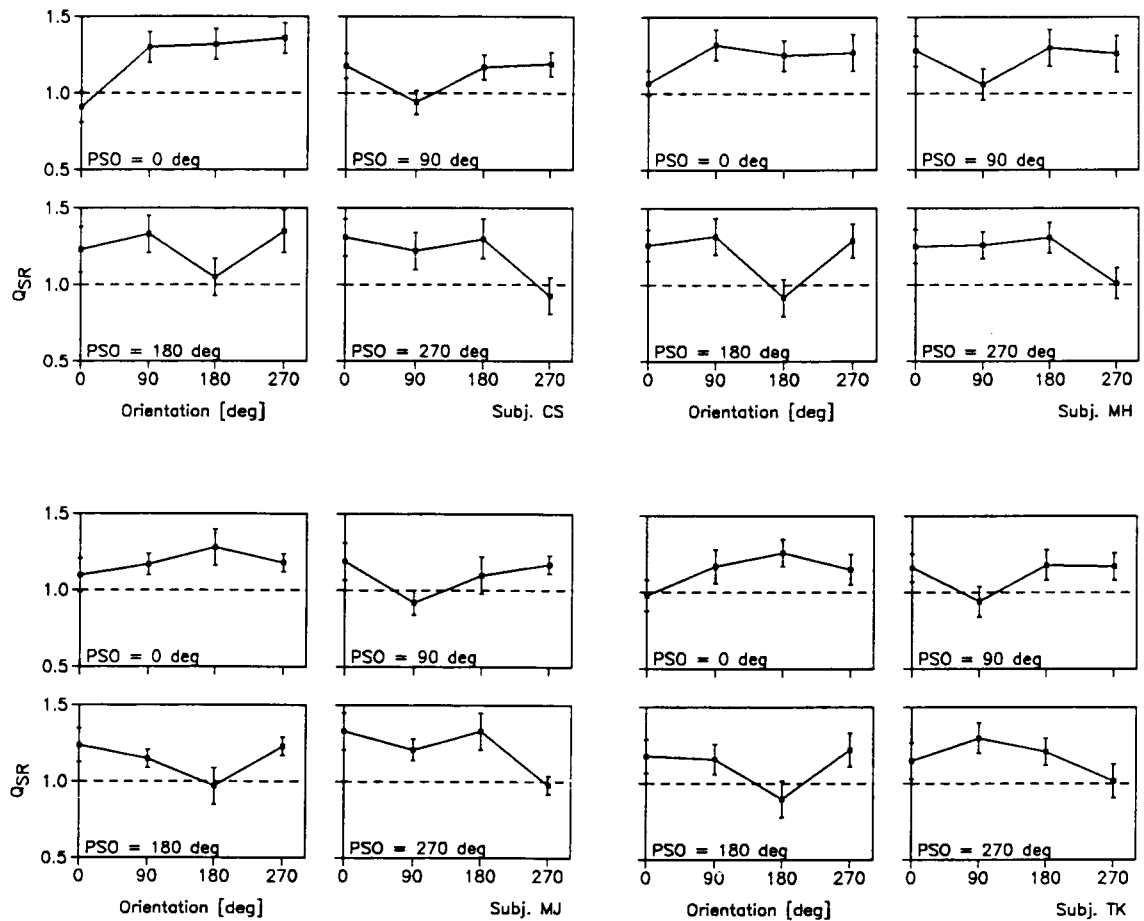


Figure 3. Quotients Q_{SR} of the estimated thresholds in the saccading eye condition and in the resting eye condition as a function of the orientation of the test signal. The parameter of each partial diagram is the orientation PSO of the presaccadic Landolt ring. The error bars represent $\pm 1 SE$ of the quotients.

dition without saccades. Interestingly, the interference effect appears to be most pronounced for low contrasts when signal identification is difficult. With increasing signal strength, the effect decreases as the influence of the presaccadic parafoveal signal becomes weaker. Of course, for contrast levels far above threshold, the psychometric functions for all three conditions converge to their common asymptotic value of one.

Control Experiments

In a first control experiment, we checked to see whether the timing of the stimulus sequence for the saccading eye condition excluded effects that are commonly referred to in the literature as saccadic suppression. Given an inter-stimulus interval of 260 msec and a time window of 200 msec for the completion of the saccade, there was a minimum delay of 60 msec between the cessation of the eye movement and the presentation of the test signal. However, it is well known that saccadic suppression may

Table 1
Mean Threshold Quotients Q_{SR} for Subgroups S (Same Orientation of Pre- and Postsaccadic Signals) and D (Different Orientations)

Condition	Subject			
	C.S.	M.H.	M.J.	T.K.
Saccading Eye Condition				
S	0.95	1.02	0.99	0.96
D	1.27	1.28	1.22	1.19
Control Condition				
S	0.99	0.97	1.03	1.02
D	1.00	1.02	1.01	0.99
Persistence Control I				
S	1.01	1.01	0.95	1.00
D	0.99	1.03	0.99	1.02
Persistence Control II				
S	1.02	0.98	0.99	0.96
D	1.25	1.22	1.25	1.24

Note— $SE < 0.07$.

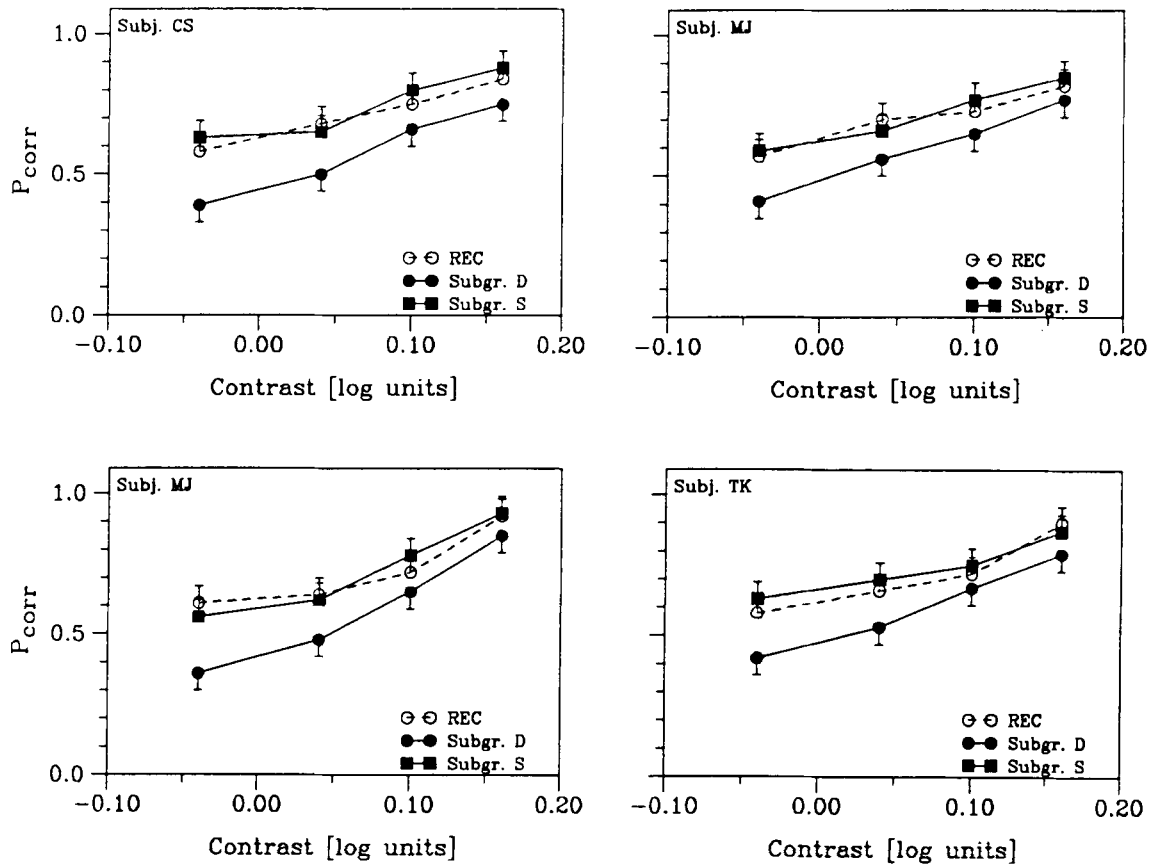


Figure 4. Relative frequency of correct responses P_{corr} as a function of contrast of the test signal. The diagram shows the psychometric functions of the pooled response data for Subgroup S (same orientation of pre- and postsaccadic signal) and Subgroup D (different orientation) in the saccading eye condition. For comparison, the corresponding function in the resting eye condition REC is also plotted. The error bars represent ± 1 SD.

outlast the time during which the eye is moving by a certain period (Matin, 1974; Volkman, Schick, & Riggs, 1968). To see whether postsaccadic suppression affected our results, we performed an experiment in the saccading eye condition without parafoveal stimulation (i.e., the contrast of the presaccadic signal was set to zero). The results are shown in Figure 5. The value one for the threshold quotients lies well between the standard error bars. Hence, no rudimentary effects of ordinary postsaccadic suppression were present.

From the previous results arises the question of whether the observed selective threshold elevation has to be attributed to the stimulus sequence on the retina (i.e., the parafoveal stimulation) or whether the active execution of the saccade is a necessary prerequisite for this phenomenon. In the control condition, we simulated the displacement effect of the saccade by an appropriate stimulus step without changing the temporal and spatial stimulus sequence in the retinal frame of reference. As is demonstrated in Figure 6 and Table 1, the threshold quotients remained unchanged with respect to the reference values in the resting eye condition without preceding parafoveal

stimulation. Consequently, the active execution of the saccade must be considered a necessary condition for the selective threshold elevation.

Persistence Control Experiments

Two experiments were run in order to study the effect of phosphor persistence. The results of the condition Persistence Control I are summarized in Figure 7 and Table 1. The plot shows the quotients of the thresholds measured in the primed condition and the reference values in the nonprimed condition. The parameter of each partial diagram is the orientation of the prime Landolt ring. Obviously the plots show no significant influence of the prime signal and therefore no evidence of even a rudimentary influence of phosphor persistence. In the second experiment, Persistence Control II was based on the standard saccadic condition, which was modified only by rescaling the presaccadic Landolt ring by a factor of 1.25 to prevent any pixel overlap of pre- and postsaccadic signals on the screen. However, as is depicted in Figure 8, this modification did not alter the characteristic finding of selective threshold elevation in the case of different

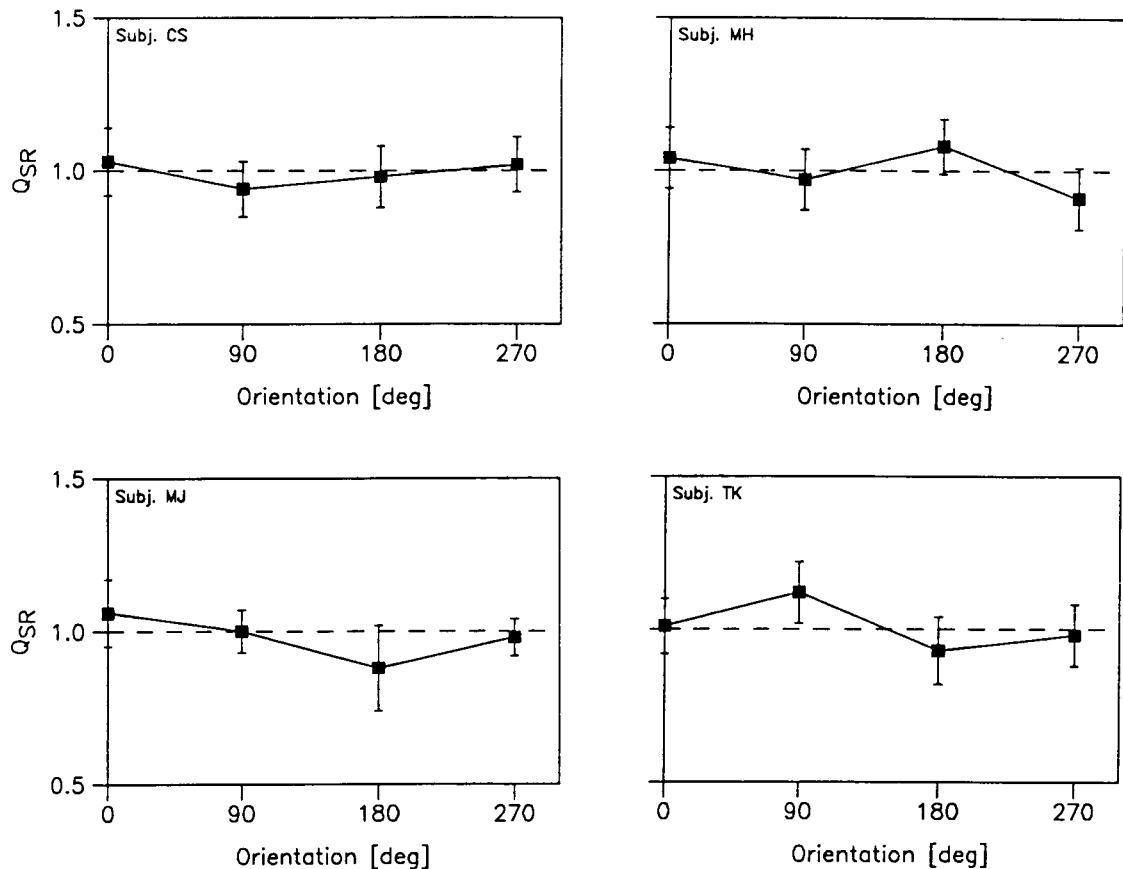


Figure 5. Quotients Q_{SR} of the estimated thresholds in the saccading eye condition without parafoveal presaccadic stimulation and in the resting eye condition, as a function of the orientation of the test signal. The error bars represent ± 1 SE of the quotients.

orientations of pre- and postsaccadic signals. This is confirmed by the means of the threshold quotients in Table 1, which do not significantly differ from those for the saccading eye condition. Hence, both experiments suggest that the idea of phosphor persistence as an explanation for the selective threshold phenomenon has to be rejected.

DISCUSSION

Our experiments have shown that perception immediately after the termination of a saccadic eye movement is influenced by the stimulus pattern that exists at the spatial position of the saccade goal prior to the saccade. The contrast threshold for postsaccadic test signals that are incompatible with presaccadic stimuli appearing to have the same spatial coordinates is distinctly elevated relative to the reference condition without saccades and without parafoveal stimulation.

What conclusions might be drawn from this finding for visual information processing? First, it should be noted that the two persistence control experiments concerning phosphor persistence failed to reveal any phosphor artifact. The persistence tables in the literature (Skolnik,

1970) give a decay rate of less than 1 msec to 10% of peak luminance for the P22 phosphor used in our cathode-ray tube.¹ If we assume an exponential decay characteristic, this means a 1% decay within 2 msec. Small residues of persistence due to the long-lasting tail of this decay may be observable in the dark, but hardly under the conditions of our experiments, in which the mean luminance of the screen was adjusted to 20 cd/m² and the modulation of the signals was less than 6%. The observed absence of phosphor persistence effects also appears plausible if one compares the temporal characteristics of the P22 phosphor with the interstimulus interval of 260 msec used in our stimulus sequence.

The results cannot be explained by assuming that the subject adjusted his or her response to the more easily detectable presaccadic stimulus rather than to the test stimulus. Any strategy of this kind would finally result in a more symmetrical change in threshold—that is, an elevation for different orientations of the pre- and postsaccadic stimulus and a threshold decrease for identical orientations. This is because the overall performance (i.e., the number of correct responses) cannot be improved by a strategy that is uncorrelated with the actually presented

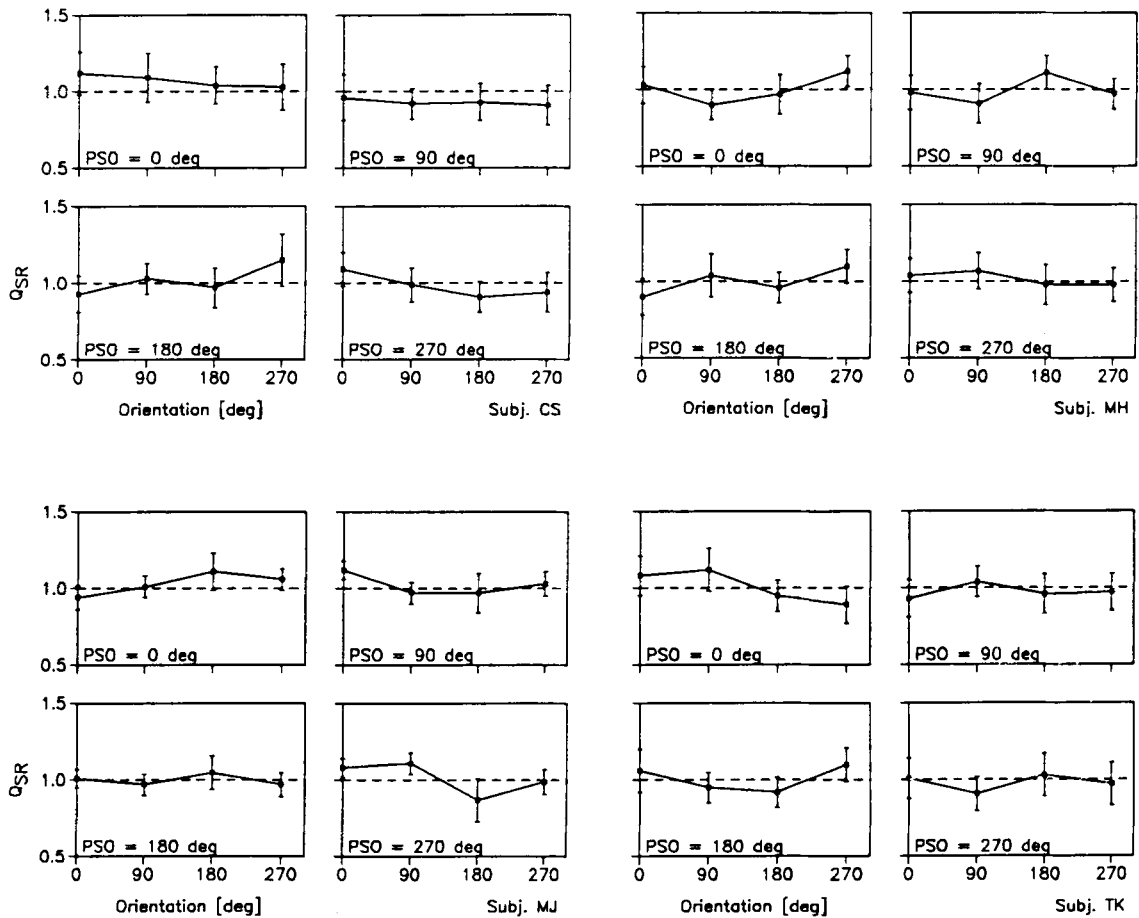


Figure 6. Quotients Q_{SR} of the estimated thresholds in the control condition and in the resting eye condition, as a function of the orientation of the test signal. The parameter of each partial diagram is the orientation PSO of the presaccadic Landolt ring. The error bars represent ± 1 SE of the quotients.

test signal. However, such a prediction stands in contrast to our findings, where only a threshold elevation, but no decrease in threshold, was observed.

We conclude that the selective threshold elevation may reflect an influence of the saccadic eye movement on information processing of the visual system. The interesting fact that this phenomenon of transsaccadic interference proved to be robust against the spatial decorrelation introduced by the different sizes of pre- and postsaccadic Landolt rings in the condition Persistence Control II might signify a size invariance property, although this point still has to be investigated for a larger range of scales. This result suggests that the semantic content of pre- and postsaccadic signals is the critical parameter, not their exact spatial correlation. Hence, our experiments do not support the notion of the integrative buffer hypothesis, but they demonstrate in a more general sense that parafoveal and foveal vision can cooperate during a saccade.

The fact that the interference effect requires the active execution of the saccade raises the question of how the two phenomena are interconnected. The preparation of

a voluntary saccade involves different processes (cf., e.g., Becker & Jürgens, 1979; Fischer, 1987). One concerns the disengagement and shift of attention; another, the extraction of the target and the evaluation of its coordinates; a third, the decision to initiate the eye movement; and finally, the control of the actual motor response is needed. From these processes, attention appears to be a good candidate to explain the differences in the results of saccading eye and control conditions. The only assumption that has to be made is that allocation of attention differs in the two experimental conditions, which is plausible since the sessions were blocked. If attention is shifted to the parafoveal signal before the saccade is initiated and the interference effect is a direct consequence of this attentional allocation, then in the control condition no such effect should be expected, since attentive fixation is not disrupted and no attentional shift occurs.

The selectivity of the threshold elevation shows that immediately after the termination of a saccadic eye movement sensory events that indicate changes in the visual field are processed in a different way from those that sig-

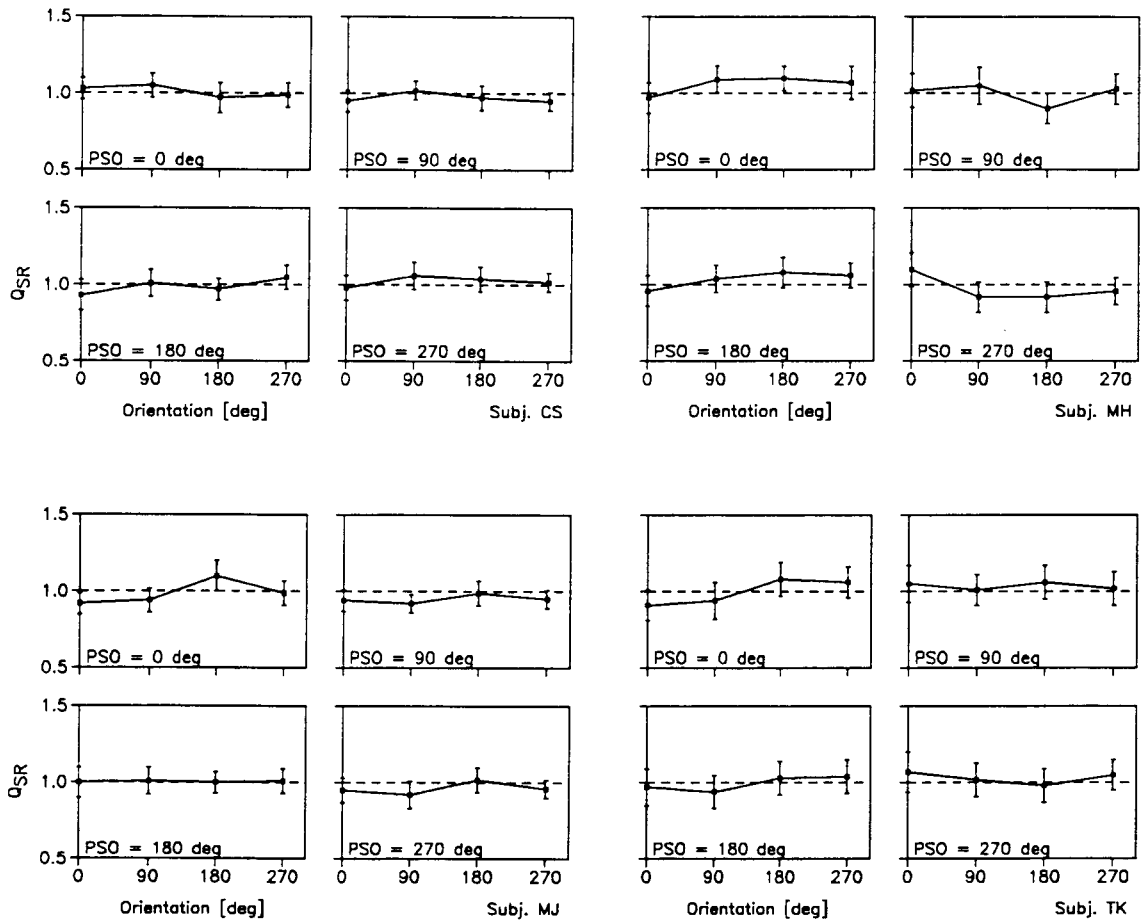


Figure 7. Quotients Q_{SR} of the estimated thresholds in the Persistence Control I condition (with prime signal) and in a reference condition (without prime signal) as a function of the orientation of the test signal. The parameter of each partial diagram is the orientation PSO of the prime signal. The error bars represent ± 1 SE of the quotients.

nify a stationary world. As is obvious from Figure 4, the interference between pre- and postsaccadic signals is largest for weak postsaccadic signals, when the available stimulus information is ambiguous with respect to its correct identification. With increasing signal strength, the effect declines, and this suggests that the identification of the orientation of the test signal is achieved mainly on the basis of the postsaccadic stimulus information. The fact that the observed phenomenon of interference seems to be restricted to signals near contrast threshold could also explain the discrepancies between our results and those of Rayner et al. (1978) and McConkie and Zola (1979), who observed a response facilitation. However, this facilitation concerned stimuli (letter strings and words) that were presented far above threshold, owing to the experimental paradigm. Moreover, the same effects could be found if the saccade was simulated, contrary to our observation of a transsaccadic interference, which is ultimately linked to the eye movement. Hence, we think that the two types of experiments cannot be compared in a straightforward way.

How can our results be related to the problem of visual stability? MacKay and Mittelstaedt (1974) proposed a theory of visual stability that is based on the assumption of the existence of an internal representation of the visual world that is independent from the retinal image per se. This representation is considered to be stable a priori, and sensory signals are used for a permanent update of this representation. The central component of this scheme is a process of evaluation comparing the actual visual input and the internal representation to decide whether the latter needs revision. The criteria for this comparison are continuously varied according to current motor activity, and especially to eye movements. As a consequence, this should lead to a conservative system behavior concerning the perception of changes in the visual world during saccadic eye movements. Experimental evidence for this notion comes from the observed insensitivity to stimulus displacements during saccades (e.g., Bridgeman, Hendry, & Stark, 1975; Whipple & Wallach, 1978). The importance of a process of updating by comparison rather than one of spatiotopic fusion has also been emphasized by Ir-

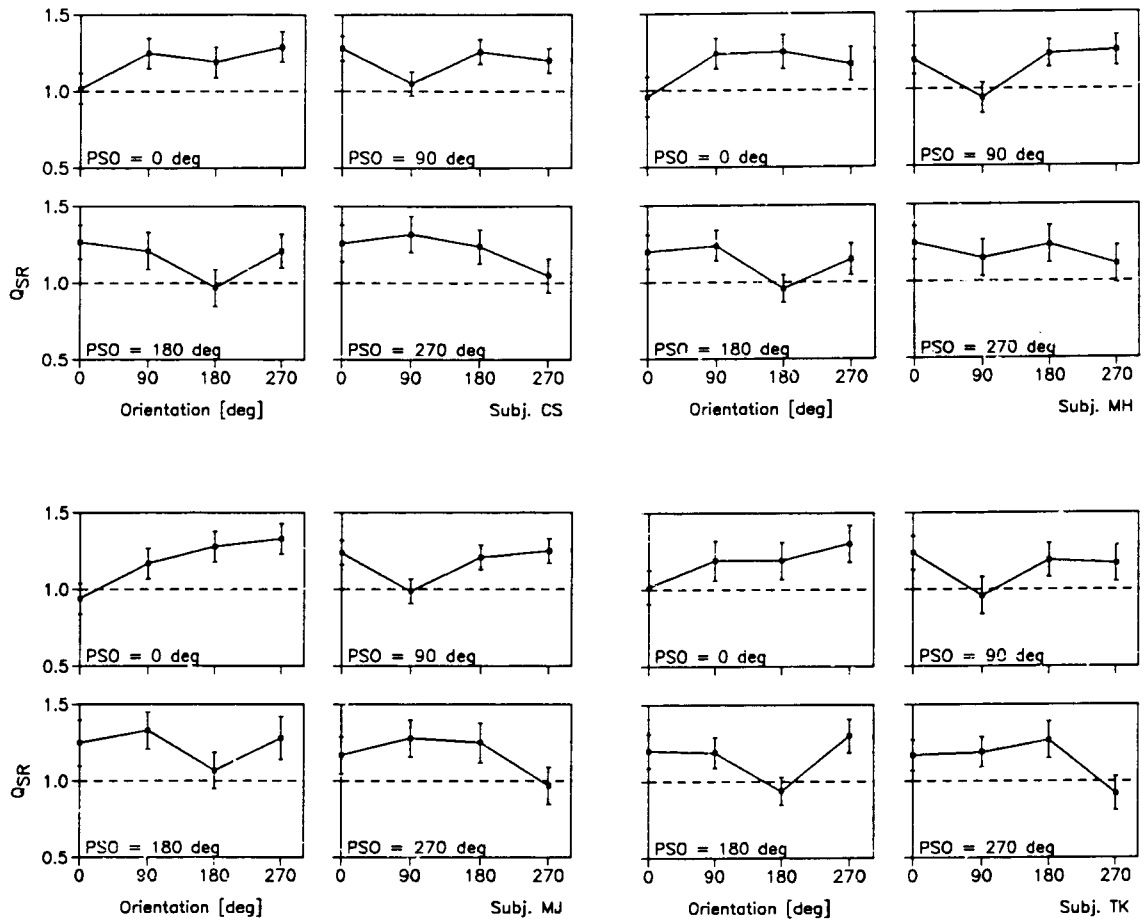


Figure 8. Quotients Q_{SR} of the estimated thresholds in the Persistence Control II condition and in the resting eye condition as a function of the orientation of the test signal. The parameter of each partial diagram is the orientation PSO of the presaccadic Landolt ring. The error bars represent $\pm 1 SE$ of the quotients.

win et al. (1990), who investigated the discrimination performance between dot patterns in successive fixations. Finally, in the context of our experiments, such a process would result in a certain loss in contrast sensitivity for signals that are incompatible with presaccadic perception.

As a matter of fact, retinal image changes due to saccadic eye movements require the visual system to perform more than the compensation of a pure image translation. Generally, for example, in the case of a simultaneous head movement, occlusion effects also have to be accounted for. In addition, there are changes of the boundaries of the visual field. Thus, we feel that our paradigm might lead to a better understanding of the phenomenon of visual stability, although the temporal and spatial boundary conditions of the observed selective threshold elevation effect still have to be determined (Jüttner & Röhler, 1992).

REFERENCES

BECKER, W., & JÜRGENS, R. (1979). An analysis of the saccadic system by means of double step stimuli. *Vision Research*, **19**, 967-983.
 BRIDGEMAN, B., HENDRY, D., & STARK, L. (1975). Failure to detect

displacement of the visual world during saccadic eye movements. *Vision Research*, **15**, 719-722.
 BRIDGEMAN, B., & MAYER, M. (1983). Failure to integrate visual information from successive fixations. *Bulletin of the Psychonomic Society*, **21**, 285-286.
 FINNEY, D. J. (1971). *Probit analysis*. Cambridge: Cambridge University Press.
 FISCHER, B. (1987). The preparation of visually guided saccades. *Reviews of Physiology, Biochemistry, & Pharmacology*, **106**, 1-35.
 GERBER, K. (1987). *Wechselwirkungen von globalen und lokalen Bewegungsreizen im visuellen System des Menschen*. Doctoral dissertation, University of Munich.
 IRWIN, D. E., YANTIS, S., & JONIDES, J. (1983). Evidence against visual integration across saccadic eye movements. *Perception & Psychophysics*, **34**, 49-57.
 IRWIN, D. E., ZACKS, J. L., & BROWN, J. S. (1990). Visual memory and the perception of a stable visual environment. *Perception & Psychophysics*, **47**, 35-46.
 JONIDES, J., IRWIN, D. E., & YANTIS, S. (1982). Integrating visual information from successive fixations. *Science*, **215**, 192-194.
 JONIDES, J., IRWIN, D. E., & YANTIS, S. (1983). Failure to integrate information from successive fixations. *Science*, **222**, 188.
 JÜTTNER, M., & RÖHLER, R. (1992). *Spatial, temporal and decision factors for transsaccadic information processing*. Manuscript submitted for publication.
 LOFTUS, G. R. (1983). Eye fixations on text and scenes. In K. Rayner

- (Ed.), *Eye movements in reading: Perceptual and language processes* (pp. 359-375). New York: Academic Press.
- MACKEY, D. M., & MITTELSTAEDT, H. (1974). Visual stability and motor control (reaffirmation revisited). In W. D. Keidel, W. Händler, & M. Spreng (Eds.), *Kybernetik und Bionik* (pp. 71-80). München: Oldenbourg.
- MATIN, E. (1974). Saccadic suppression: A review and an analysis. *Psychological Bulletin*, **81**, 899-917.
- MCCONKIE, G. W., & ZOLA, D. (1979). Is visual information integrated across successive fixations in reading? *Perception & Psychophysics*, **25**, 221-224.
- NEISSER, U. (1967). *Cognitive psychology*. Englewood Cliffs, NJ: Prentice-Hall.
- O'REGAN, J. K., & LÉVY-SCHOEN, A. (1983). Integrating visual information from successive fixations: Does trans-saccadic fusion exist? *Vision Research*, **23**, 765-768.
- POLLATSEK, A., RAYNER, K., & COLLINS, W. (1984). Integrating pictorial information across eye movements. *Journal of Experimental Psychology: General*, **113**, 426-442.
- POLLATSEK, A., RAYNER, K., & HENDERSON, J. M. (1990). Role of spatial location in integration of pictorial information across saccades. *Journal of Experimental Psychology: Human Perception & Performance*, **16**, 199-210.
- RAYNER, K., & FISHER, D. L. (1987). Letter processing during eye fixations in visual search. *Perception & Psychophysics*, **42**, 87-100.
- RAYNER, K., MCCONKIE, G. W., & EHRLICH, S. (1978). Eye movements and integrating information across fixations. *Journal of Experimental Psychology: Human Perception & Performance*, **4**, 529-544.
- RAYNER, K., MCCONKIE, G. W., & ZOLA, D. (1980). Integrating information across eye movements. *Cognitive Psychology*, **12**, 206-226.
- RAYNER, K., & POLLATSEK, A. (1983). Is visual information integrated across saccades? *Perception & Psychophysics*, **34**, 39-48.
- SKOLNIK, M. I. (1970). *Radar handbook*. New York: McGraw-Hill.
- VOLKMAN, F., SCHICK, A., & RIGGS, L. (1968). Time course of visual inhibition during voluntary saccades. *Journal of the Optical Society of America*, **58**, 562-569.
- WHIPPLE, W. R., & WALLACH, H. (1978). Direction-specific motion thresholds for abnormal image shifts during saccadic eye movement. *Perception & Psychophysics*, **24**, 349-355.
- WOLF, W. (1992). *Information transfer across saccades: The role of phosphor persistence*. Manuscript submitted for publication.
- WOLF, W., HAUSKE, L., & LUPP, U. (1978). How presaccadic gratings modify postsaccadic modulation transfer function. *Vision Research*, **18**, 1173-1179.
- WOLF, W., HAUSKE, L., & LUPP, U. (1980). Interaction of pre- and postsaccadic patterns having the same coordinates in space. *Vision Research*, **20**, 117-125.

NOTE

1. The published data on phosphor persistence concerning P22 seem to be somewhat contradictory. Two reviewers of the manuscript cite Hewlett-Packard Application Note 115 which states persistence values for P22 in the order of 25 msec. A recent analysis (Wolf, 1992) reveals that the measurement of persistence effects actually depends on the experimental conditions and the operation mode of the cathode-ray tube. This might explain the differences mentioned above.

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