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The omnipresent prolongation of visual fixations: saccades are inhibited by changes in situation and in subject's activity

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Abstract

Presenting a distractor prolongs not only saccadic reaction times in paced tasks but also fixation durations in unpaced tasks. To investigate whether the effect of a distractor is a pure optomotor reflex, we used both visual and auditory distractors in an unpaced picture-viewing paradigm. Results show a distractor effect for both modalities. Analysis of data from previous studies showed similar effects, even in amodal shifts of attention. These findings challenge the hypothesis that the effect is modality-specific and suggest that the distractor effect may be another expression of the orienting reflex. © 2001 Published by Elsevier Science Ltd.

Keywords: Opotomotor reflex; Auditory distractors; Distractor effect; Visual distractors; Saccade latency; Saccade inhibition

1. Introduction

When two stimuli are presented in parallel, one of which is the target and the other a distractor, a significant increase in saccadic reaction time is usually found (Lévy-Schoen, 1969; Findlay & Walker, 1999). This 'remote distractor effect' is at its maximum when the distractor appears around 100 ms before target onset (Walker, Kentridge, & Findlay, 1995) and leads to a maximal increase in saccadic latency when the distractor is presented centrally (Walker, Deubel, Schneider, & Findlay, 1997). Taking the reciprocal stance, one may state that the duration of fixations is prolonged. The effect is phasic in nature, meaning that it occurs primarily during the ongoing fixation in a range of 80–120 ms following the distractor (Unema & Velichkovsky, 2000). The implication of this viewpoint is not just a semantic reversal, but a reorientation to the effects of various 'distractors' on the natural, i.e. continuous viewing activity.

Reingold and Stampe (2000) already pointed out that McConkie, Reddix, and Zola (1992) found a similar increase in fixation durations in reading, when non-fixated words were altered in a gaze contingent masking paradigm. McConkie et al. interpreted this increase as the result of a disruption of automatic, parallel processes. This interpretation, the 'process disruption hypothesis' (henceforth PDH), heavily draws upon the effect being time-locked to the beginning of a fixation. However, since the effect can be elicited at virtually any time during a fixation, this hypothesis seems untenable.

The 'saccade inhibition hypothesis' (henceforth SIH), as described by Reingold and Stampe (2000), assumes that it is an oculomotor reflex elicited within the superior colliculus (SC). The SIH seems eligible in view of the extremely short latency of the distractor effect and its insensitivity to cognitive task variables (Dornhoefer, Pannasch, Velichkovsky, & Unema, 2000; Reingold & Stampe, 2000). If non-visual influences were to indicate effects on the dynamics of visual fixations, however, the SIH would be less plausible.

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2. Method

2.1. Subjects

Sixteen students from the Dresden University of Technology (12 female, four male, age range = 19–39) participated in the experiment for course credit.

2.2. Apparatus

Eye movements were recorded at 250 Hz, using the Eyelink™ System with online detection of saccades and fixations. Fixation onset was detected and transmitted to the presentation system with a delay of approximately 12 ms. Images were displayed using an ATI 3D Rage Pro card and a 17-inch (43 cm) ViewSonic monitor at 640 by 480 pixels at 72 Hz. Viewed from a distance of 60 cm, the screen subtended an angle of approximately 31° horizontally and 26° vertically.

2.3. Stimuli and design

Stimuli consisted of 16 pictures by 17th century painters and were presented in a counterbalanced order, each for 90 s. During each trial, visual and auditory distractors were presented at a stimulus onset asynchrony (SOA) of either 100 or 300 ms from the fixation onset. Distractor rates were set to meet the (un)likelihood of a fixation lasting longer than SOA. Thus, at a SOA of 100 ms, there was a 1:7 chance of a fixation being presented with a distractor. A software-based random generator (C++ library) decided which of every 7th fixation was suitable for distractor presentation. Similarly, at a SOA of 300 ms, every 1:2 of a fixation lasting longer than 300 ms was eligible. As soon as the subsequent saccade was initiated, the distractor was removed. The visual distractor consisted of a 1° black circle presented at 2.3° to the right of the fixation, and the auditory distractor was a 1000 Hz tone presented through pc-loudspeakers on both sides of the screen. All subjects reported the signal to be audible but not startling.

2.4. Procedure

A nine-point calibration routine was performed at the beginning of each block of trials. Calibration was repeated if any point was in error by more than 1°, or if the average error for all points was above 0.5°. Before each trial, a drift correction was performed. In order to study the influence of both stimulus modalities on the duration of fixations, distractors were presented during fixations in an unpaced picture-viewing task. Subjects were aware that distractors were presented but instructed to ignore them. Subjects were asked to study the picture in order to be able to recognize sections from it in a follow-up multiple-choice test.

3. Results

Fixation durations over 1500 ms (0.7%) were excluded from further analysis. The means of fixation durations for each condition are displayed in Table 1 and Fig. 1. Fixations in the no-distractor condition were selected as the average over the three fixations preceding and the three fixations following the one during which the distractor appeared.

The data obtained in the experiment demonstrate a robust effect of distractors on the fixation duration at both SOAs ($F_{1,15} = 1285.68$, $P < 0.001$) and both modalities of distractors ($F_{1,15} = 11.67$, $P = 0.004$), with no interaction ($F_{1,15} = 0.13$, $P = 0.753$). Fig. 2 demonstrates the instantaneous prolongation of fixations for both modalities collapsed over both SOAs.

Interestingly, not the whole distribution of fixation durations is affected by the distractor presentation. Fig. 3 shows an underrepresentation of fixations in the interval 80–120 ms following distractor onset for both visual and (less prominent) auditory distractor conditions and for both SOAs.

Differences in expected and observed frequencies in the range of 80–120 ms after distractor presentation proved significant for both sensory modalities collapsed over SOAs ($F_{1,15} = 6.20$, $P = 0.025$). No interaction between modality and distractor was found ($F_{1,15} = 1.17$, $P = 0.296$). The auditory effect seems weaker than the visual effect, however.

Since testing the means does not reveal very much about the changes in the shape of the distribution, a survival analysis was performed in order to test the effect of visual and auditory distractors on the 'survival' rate of fixations. The use of a Cox proportional hazards regression analysis allowed us to estimate the hazard of a fixation terminating at a given time from distractor onset. In contrast to other methods of survival analysis, the Cox regression offers the possibility of a multivariate comparison of hazard rates. In this way, the scope of the effect of the auditory and visual distractors can be limited to a predefined period follow-

Table 1
Means of fixation durations (ms) per condition

	Mode	No distractor (S.D.)	Distractor (S.D.)
SOA 100	Auditory	326.79 (38.83)	341.83 (41.60)
	Visual	340.01 (29.46)	357.14 (26.06)
SOA 300	Auditory	470.76 (30.86)	479.80 (25.71)
	Visual	484.73 (34.74)	501.13 (31.87)

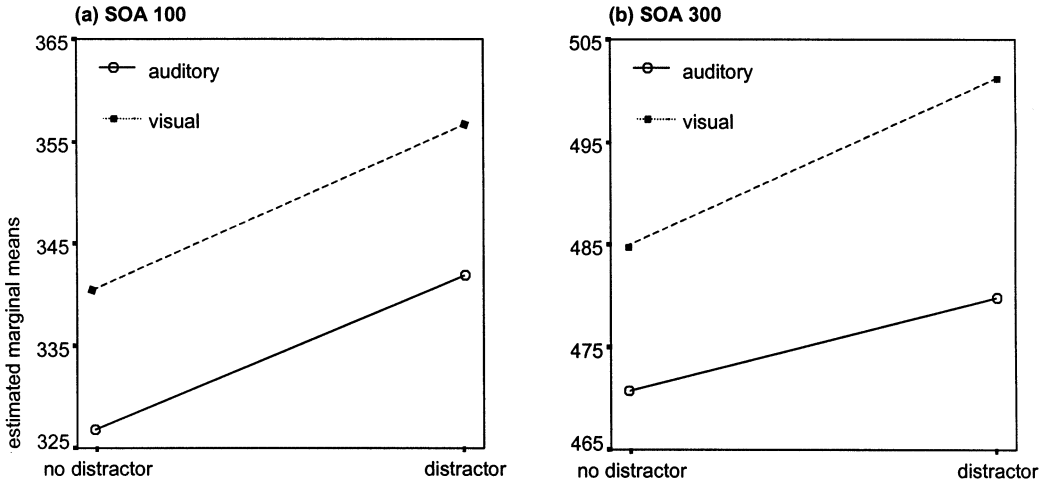

Fig. 1. (a, b) Mean estimated fixation durations (as determined by the repeated-measures MANOVA from the SPSS package) by distractor (absent/present), SOA (100/300 ms) and distractor modality (auditory/visual).

ing distractor onset, thus accounting for both conduction delays and effect duration. For both the visual and the auditory distractors, time-dependent concomitant variables were computed in two intervals: the first interval was set between 50 and 150 ms (V_{down} and A_{down}), the second between 150 and 300 ms (V_{up} and A_{up}), reflecting the fact that the distractor effect is due around 100 ms following distractor onset, and a possible recovery phase after 200 ms. The analysis yielded the regression coefficients shown in Table 2.

The coefficients for V_{down} and A_{down} have a negative sign, indicating that the visual distractor reduces the likelihood of fixation termination by 26%, while the auditory distractor reduced the likelihood of fixation termination by 5%. The coefficients for the upbeat phase (V_{up} and A_{up}) did not reach significance, implying that the effect of presenting a distractor is monophasic in nature—that is, the overshoot of fixation terminations beyond the local minimum in the frequency distributions (Fig. 3a) is not due to some kind of excitatory 'recovery-effect' following the inhibitory effect from the distractor. Since the time scale represented the fixation duration minus SOA, the SOA coefficient should not be interpreted.

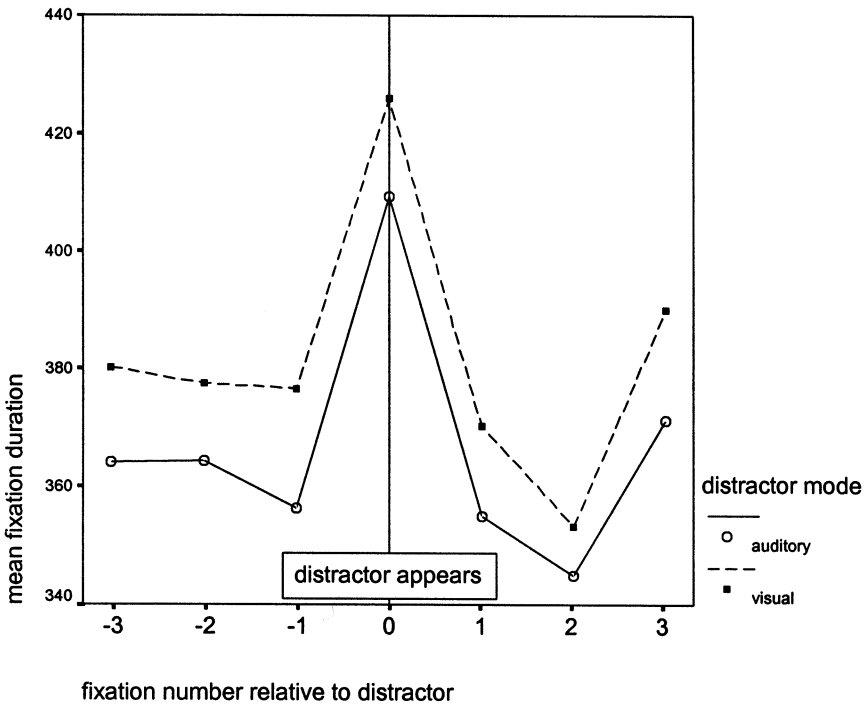

Fig. 2. Instantaneous fixation duration by modality of distractors.

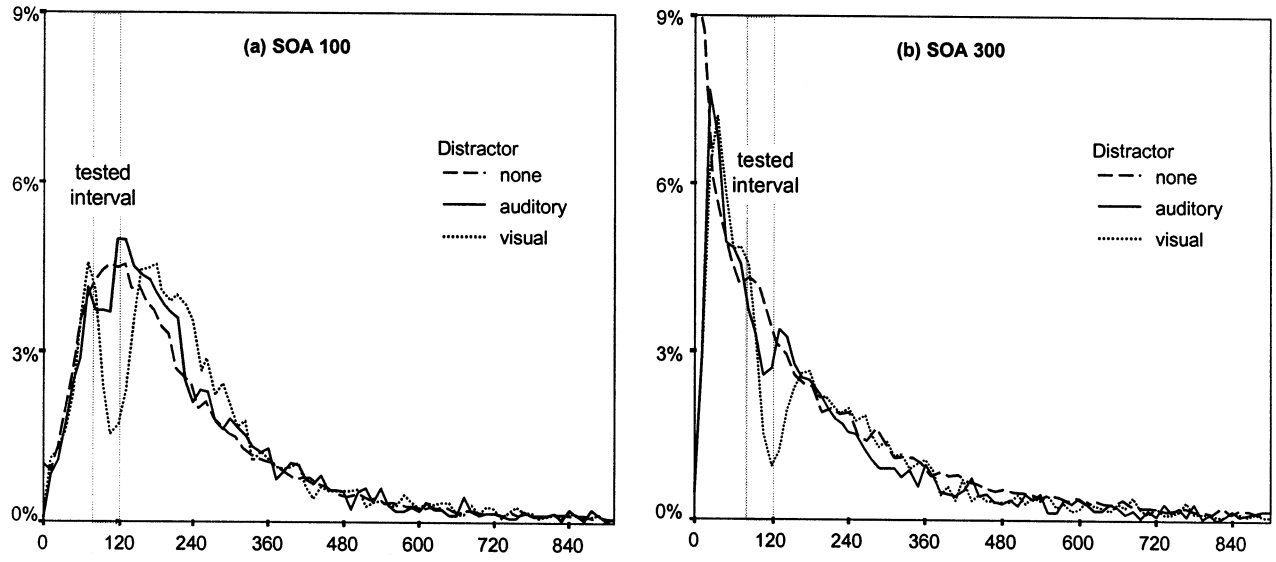

Fig. 3. Frequency distribution of fixation termination latencies (fixation duration minus SOA) for (a) SOA 100 and (b) SOA 300.

Table 2
Variables in the Cox regression model

	B	S.E.	Wald	df	Sig.	Exp(*B*)
VDOWN	−0.298	0.028	112.988	1	0.000	0.742
VUP	0.017	0.024	0.512	1	0.474	1.018
ADOWN	−0.052	0.026	4.096	1	0.043	0.949
AUP	−0.012	0.027	0.187	1	0.665	0.988
SOA	0.000	0.000	60.676	1	0.000	1.000

4. Discussion

The present results demonstrate that presenting a distractor prolongs fixations in unpaced tasks. This 'evoked fixation response' is elicited by both visual and auditory distractors and appears to take effect within approximately 100 ms from the onset of a visual, and slightly less ($\sim$80 ms) from an auditory distractor. Although equating prolonged fixation durations with increased saccadic latency may seem inappropriate, both may well have a common cause—as illustrated by the size of the effect (some 20 ms, see Table 1 and Fig. 1a and b) on fixation durations, which agrees well with the effect sizes found in saccade latencies (e.g. Walker et al., 1997). The PDH suggested by McConkie et al. (1992) seems to be questionable, as the effect appears at both SOAs. Alternatively, the SIH, as put forth by Reingold and Stampe (2000), suggests this 'visually evoked saccade inhibition' as being the result of lateral inhibitory connections within the intermediate layer of the SC. Newly arriving input may inhibit saccadic build-up activity, either through competing activity in other saccadic build-up neurons or through increased activity of fixate neurons. In either case, a low latency inhibitory effect ensues. The intermodal character of the effect seems to contradict its interpretation qua SIH, however. Although the effect may not simply be an *opto*motor reflex, its locus of effect may well lie in the SC.

The literature shows several examples of the integrative function of the SC for several sensory modalities. Wallace and Stein (1996, 1996), for example, pointed out that in cat, 49%, and in monkey, 36% of the deep SC cells respond to auditory stimuli, only 13% and 18%, respectively, respond *exclusively* to auditory signals (unimodal cells), and only 23% and 37% respond exclusively to visual signals. They further showed that when bimodally presented stimuli are in a spatial register, there is a significant enhancement of cell response that clearly exceeds the sum of two unimodally presented stimuli, whereas there is no enhancement or even a significant depression of cell response when bimodal stimuli are presented in different receptive fields. Frens and Van Opstal (1998) also found significant interactive effects between auditory and visual stimuli on saccade latency.

Fendrich, Hughes, and Reuter-Lorenz (1991) showed that the gap effect (a reduction of saccadic latency upon removing the fixation stimulus before the target appears) may also be elicited by acoustic targets. They

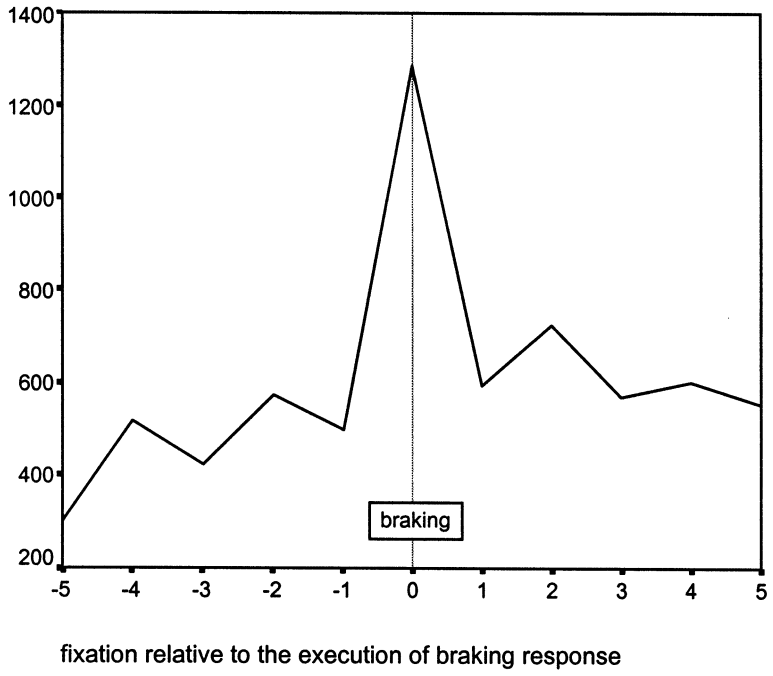

Fig. 4. Instantaneous fixation duration during self-initiated brake responses.

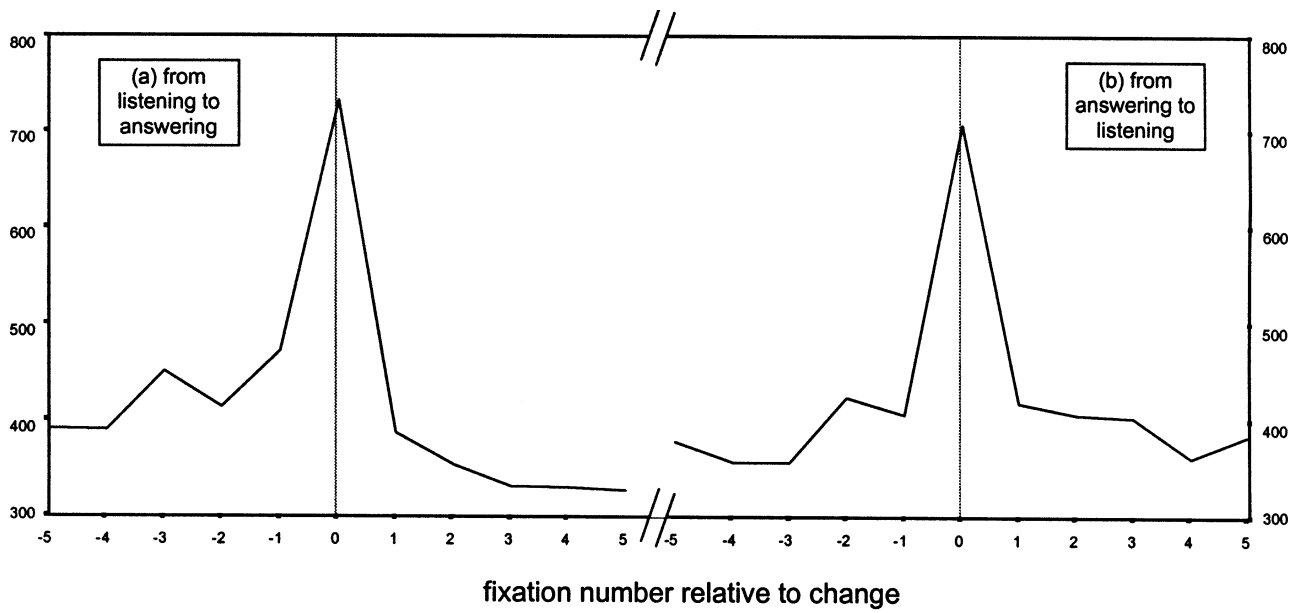

Fig. 5. Instantaneous fixation duration while switching from (a) listening to answering and (b) vice versa.

conclude that the gap effect is probably due to a facilitation of motor or premotor processes rather than enhanced visual processing (Reulen, 1984) and that the most likely locus of the effect would be the deep layers of the SC. Reuter-Lorenz, Nozawa, Gazzaniga, and Hughes (1995) argue that in fact the stimuli onset or offset anywhere in the visual field can provide the alerting information that seems to speed up saccadic reaction time. Similarly, Corneil and Munoz (1996) showed that both visual and auditory distractors affect saccadic performance. Moreover, they came to the conclusion that, depending on temporal and spatial register, 'alerting effects represent a spatially independent mechanism by which any stimulus, either aligned or misaligned with the target, can lower reaction times to a target' (p. 8204).

Thus, auditory stimulation may equally lead to a reduction of saccade latency. In our study, however, inhibitory effects of auditory distractors on saccades also occurred. Whereas the onset of a distractor takes effect within 100 ms, the gap effect is maximal when the fixation point is offset 200–300 ms prior to target appearance (Fischer & Ramsperger, 1984). The apparent discrepancy between inhibitory and facilitatory influences may be reconciled if we also take the time course into account: by the time the gap effect occurs, any inhibitory effects may already have passed over. This does not imply that the gap effect and the distractor effect are identical, but rather that they seem to have some collicular processes in common. One serious problem with this interpretation of the auditory inhibitory effect remains: the auditory distractor effect also occurs in the absence of spatial information. Although the speed of the behavioral response hardly leaves room for mechanisms other than subcortical mechanisms, a broader explanation of its nature may be needed. In this vein, the distractor effect might also be considered as another expression of the general inhibition of motor functions in orienting and startle reactions (e.g. Sokolov, 1963; Graham, 1975). Following Reingold and Stampe (2000), cortical control structures may take advantage of the collicular inhibitory response and extend the duration of the inhibition, allowing for cancellation or redirection of the next saccade, depending upon the relevance of the event. The corresponding relevance effect has indeed been reported (Unema & Velichkovsky, 2000).

From a psychological point of view, this is a manifestation of a switch of attentional control mediated by an orienting reflex (OR) (Sokolov, 1963; Sokolov & Vinogradova, 1975; Näätänen, 1986). The situation is no different in the case of this distractor experiment: whenever something new enters any sensory channel, an OR-like response is produced. In the present investigation, subjects were asked to study the pictures accurately, so the distractor could be considered as a perturbation of the free viewing task. The presentation of the new stimulus slows the original task: the ongoing fixation is prolonged. Although, in the case of visual stimuli, the saccade inhibition might be considered as an oculomotor reflex, our study shows that this is insufficient as an explanation for auditory stimuli. A consideration of the following data may be of particular importance for a further clarification of the nature of the described effect.

We observed a significant ($F_{1,23} = 83.121$, $P < 0.001$) prolongation of visual fixations even in the absence of discrete physical stimulus events, e.g. upon self-initiated brake responses in a driving simulator (Fig. 4) (Unema, Dornhoefer, Steudel, & Velichkovsky, in press).

There are earlier reports on the inhibition of saccades (i.e. prolongation of fixations) during the execution of manual activities by moving a lever (Bujakas & Linde, 1974). But not even motor output seems to be of critical importance: in an unpublished study on the influence of different verbal communications on eye movements, we observed the discussed effect ($F_{1,6} = 17.973$, $P = 0.005$) when subjects switched from listening to answering and vice versa (Fig. 5a and b).

Thus, virtually any change in our immediate situation or in our activity (sensorimotor as well as cognitive) seems to lead to the phasic prolongation of visual fixations.

Summarized, our results demonstrate that the appearance of intermodal distractors is observable not only in saccade latency but also in fixation duration, and moreover, this effect is not restricted to sensory stimulation, but even extends to amodal shifts of attention. This brings the PDH back into play, albeit in a different way: since the effect needs no pertinence to the task at hand, an interpretation of the distractor effect as an orienting reaction rather than as an oculomotor reflex remains eligible. Our current research efforts aim at the accrual of more evidence for or against the interpretation of the distractor effect as an OR-like response, including both behavioral and electrophysiological habituation.

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References

Bujakas, T. M., & Linde, N. D. (1974). Effect podavlenija saccadicheskikh dvizhenij glaz v prozesse dejatelnosti [Inhibitory effect on saccadic eye-movements in the process of activity]. In A. N. Leontiev, *Perception and activity* (pp. 68–86). Moscow: Moscow University Press.

Corneil, B. D., & Munoz, D. P. (1996). The influence of auditory and visual distractors on human orienting gaze shifts. *Journal of Neuroscience*, *16*(24), 8193–8207.

Dornhoefer, S., Pannasch, S., Velichkovsky, B. M., & Unema, P. J. A. (2000). 'Attentional landscapes' and phasic changes of fixation duration in picture perception. Perception, 29 (Supplement), 11 (Abstract).

Fendrich, R., Hughes, H. C., & Reuter-Lorenz, P. (1991). Fixation-point offset reduce the latency of saccades to acoustic targets. *Perception & Psychophysics*, *50*(4), 383–387.

Findlay, J. M., & Walker, R. (1999). A model of saccade generation based on parallel processing and competitive inhibition. *Behavioral & Brain Sciences*, *22*, 661–674.

Fischer, B., & Ramsperger, E. (1984). Human express saccades: extremely short reaction times of goal directed eye movements. *Experimental Brain Research*, *57*, 191–195.

Frens, M. A., & Van Opstal, A. J. (1998). Visual-auditory interactions modulate saccade-related activity in monkey superior colliculus. *Brain Research Bulletin*, *46*(3), 211–224.

Graham, F. K. (1975). The more or less startling effects of weak prestimulation. *Psychophysiology*, *12*, 238–248.

Lévy-Schoen, A. (1969). Détermination et latence de la réponse oculomotrice à deux stimulus. *L'Année Psychologique*, *69*, 373–392.

McConkie, G. W., Reddix, M. D., & Zola, D. (1992). Perception and cognition in reading: where is the meeting point? In K. Rayner, *Eye movements and visual cognition*: *scene perception and reading* (pp. 293–303). New York: Springer.

Näätänen, R. (1986). The orienting response: a combination of informational and energetical aspects of brain function. In G. R. J. Hockey, A. K. W. Gaillard, & M. Coles, *Energetics in human information processing*. Dordrecht: Martinus Nijhoff Publishers.

Reingold, E., & Stampe, D. (2000). Saccadic inhibition and gaze contingent research paradigm. In A. Kennedy, R. Raddach, D. Heller, & J. Pynte, *Reading as perceptual process*. Amsterdam: Elsevier.

Reulen, J. P. H. (1984). Latency of visually evoked saccadic eye movements I: saccadic latency and the facilitation model. *Biological Cybernetics*, *50*, 251–263.

Reuter-Lorenz, P. A., Nozawa, G., Gazzaniga, M. S., & Hughes, H. C. (1995). Fate of neglected targets: a chronometric analysis of redundant target effects in the bisected brain. *Journal of Experimental Psychology: Human Perception & Performance*, *21*(2), 211–230.

Sokolov, E. N. (1963). *Perception and conditionned reflex*. London: Pergamon Press.

Sokolov, E. N., & Vinogradova, O. (1975). *Neuronal mechanisms of the orienting reflex*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Unema, P. J. A., & Velichkovsky, B. M. (2000). Processing stages as revealed by dynamics of visual fixations: distractor versus relevance effects. *Psychonomic Society*, *5*(Supplement), 113 Abstract.

Unema, P.J.A., Dornhoefer, S. M., Steudel, S., & Velichkovsky, B. M. (in press). An attentive look at driver's fixation durations. In: A. G. Gale, I. D. Brown, C. M. Haslegrave, & S. P Taylor (Eds.), *Vision in vehicles VIII*. Amsterdam: Elsevier Science, North-Holland.

Walker, R., Deubel, H., Schneider, W. X., & Findlay, J. M. (1997). Effect of remote distractors on saccade programming: evidence for an extended fixation zone. *Journal of Neurophysiology*, *78*, 1108–1119.

Walker, R., Kentridge, R. W., & Findlay, J. M. (1995). Independent contributions of the orienting of attention, fixation offset and bilateral stimulation on human saccadic latencies. *Experimental Brain Research*, *103*, 294–310.

Wallace, M. T., & Stein, B. E. (1996). Sensory organization of the superior colliculus in cat and monkey. In M. Norita, T. Bando, & B. E. Stein, *Progress in Brain Research*, vol. 112 (pp. 301–311).