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Distractor effect and saccade amplitudes: Further evidence on different modes of processing in free exploration of visual images

Sebastian Pannasch and Boris M. Velichkovsky

Applied Cognitive Research/Psychology III, Technische Universitaet Dresden, Germany

In view of a variety of everyday tasks, it is highly implausible that all visual fixations fulfil the same role. Earlier we demonstrated that a combination of fixation duration and amplitude of related saccades strongly correlates with the probability of correct recognition of objects and events both in static and in dynamic scenes (Velichkovsky, Joos, Helmert, & Pannasch, 2005; Velichkovsky, Rothert, Kopf, Dornhoefer, & Joos, 2002). In the present study, this observation is extended by measuring the amount of the distractor effect (characterized as a prolongation of visual fixation after a sudden change in stimulation; see Pannasch, Dornhoefer, Unema, & Velichkovsky, 2001) in relation to amplitudes of the preceding saccade. In Experiment 1, it is shown that retinotopically identical visual events occurring 100 ms after the onset of a fixation have significantly less influence on fixation duration if the amplitude of the previous saccade exceeds the parafoveal range (set on 5° of arc). Experiment 2 demonstrates that this difference diminishes for distractors of obvious biological value such as looming motion patterns. In Experiment 3, we show that saccade amplitudes influence visual but not acoustic or haptic distractor effects. These results suggest an explanation in terms of a shifting balance of at least two modes of visual processing in free viewing of complex visual images.

Keywords: Ambient processing; Distractor effect; Fixation duration; Focal processing; Intermodal processing; Saccade amplitude; Scene perception; Two visual systems.

Please address all correspondence to Sebastian Pannasch, Applied Cognitive Research/Psychology III, Technische Universitaet Dresden, Helmholtzstrasse 10, 01069 Dresden, Germany. E-mail: pannasch@applied-cognition.org

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The importance of eye movements for visual perception and cognition is undisputable (Buswell, 1935; Stratton, 1906; Yarbus, 1967). During the inspection of complex scenes, we perform on average three to four saccadic eye movements per second, which implies that neural processing operations aimed at scene segmentation, feature binding, and identification of image components are accomplished in about 200 ms. However, individual fixations greatly vary in their duration as do conditions and requirements of everyday tasks. This makes it highly improbable that the same neural computations are taking place during different fixations. This aspect of active vision has for a long time been neglected by the students of perception. Despite the fact that pioneering work on the understanding of the role of eye movements was often focused on the investigation of scenes and pictures, most of the influential research contributions in the last decades dealt with simple stimuli and artificial viewing tasks of the "fixate-and-jump" type (e.g., Deubel & Schneider, 1996; Findlay & Walker, 1999).

Although research on tasks such as reading (Rayner, 1978, 1998) and visual search (Vaughan, 1982) has resulted in a number of models explaining the control of fixation duration, recent efforts were focused on understanding of the spatial target selection (Foulsham & Underwood, 2008; Hayhoe & Ballard, 2005; Itti & Koch, 2001; Tatler, Baddeley, & Vincent, 2006; Torralba, Oliva, Castelhano, & Henderson, 2006). One exception is a study by Henderson and Pierce (2008), who tested whether fixation duration is under direct or indirect control of the visual scene. In their experiments a scene onset delay paradigm was used, in order to investigate the degree to which fixation durations are under control of the availability of the current scene. The authors described two populations of fixations. Whereas a certain proportion of fixations was prolonged with respect to the scene onset delay, other fixations remained unaffected by the display change. The findings for the first group are interpreted as evidence for mechanisms of direct control of fixations. This investigation however leaves a number of questions open. One is the baseline probability for the survival of fixations, e.g., 100 or 800 ms after their beginning. When this baseline information is taken into account, the delay of scene onset results in a less dramatic prolongation of fixations than one reported in the study. Second, the authors do not provide an independent description of features that would enable to differentiate fixations under direct and indirect control. Finally, it remains unclear what neurophysiological mechanisms are or could be responsible for the existence of different groups of fixations.

In search of factors that may clarify the control mechanisms of fixations, we attempted to differentiate classes of fixations based on the existence of two basic modes of visual processing. Though earlier statements can be found (Bernstein, 1947), this distinction came to prominence with a special issue of *Psychologische Forschung* in 1967 (Ingle, Schneider, Trevarthen, & Held, 1967). Succeeding approaches emphasized two distinct cortical mechanisms of primates' vision, dorsal and ventral pathways (Milner & Goodale, 1995, 2008; Ungerleider & Mishkin, 1982). Accordingly, dorsal stream activity can be related to spatial localization and sensorimotor coordination, whereas the ventral visual pathway is involved in identification (e.g., Norman, 2002). One of the recent developments in the field is an emphasis on the role of the frontoparietal feedback system in the active programming of the spatial exploration of the scene contrasted with more stimuli-driven analysis of features of visual input by the structures of occipital and temporal cortex (Corbetta, Patel, & Shulman, 2008).

In line with this neurophysiological concept, we demonstrated in several studies that a combination of fixation durations and saccade amplitudes strongly correlates with the probability of recognition of scene fragments in both static and dynamic settings. This was shown for the correct reaction to hazardous events in a virtual driving simulation (Velichkovsky, Rothert, Kopf, Dornhoefer, & Joos, 2002), and for the recognition of cut-outs of natural images (Velichkovsky, Joos, Helmert, & Pannasch, 2005). In the latter study, the recognition of cut-outs of a previously seen visual scene was distinguished according to the fixation duration and the saccadic amplitude during the inspection. Correct answers were given with a higher probability if the part of the scene was inspected by relatively long fixations ($>$180 ms) accompanied with saccades of less than 5 deg. It was concluded that combining fixation duration and saccadic amplitude can provide indications of the processing mode: "Ambient processing mode" characterized by short fixations and long saccades is related to the overall spatial orientation in a scene, whereas long fixations—often accompanied by short saccades—are expressions of "focal processing" serving the identification of objects.

The goal of the present investigation is to contribute to this discussion using a simpler paradigm based on the presentation of distractors in relation to the fixation onset. Since the first report by Lévy-Schoen (1969) a large body of data demonstrated an increase in saccadic reaction time when a target stimulus appears together with a visual distractor (Walker, Kentridge, & Findlay, 1995). In most of the experiments, saccadic latencies were analysed within a "fixate-and-jump" paradigm: Subjects had to fixate a designated point on the screen and execute a single saccade once the target (and distractors) appeared. The gaze-contingent paradigm (McConkie & Rayner, 1975) allows distractor experiments in continuous tasks such as reading and free picture viewing (Pannasch, Dornhoefer, Unema, & Velichkovsky, 2001; Reingold & Stampe, 2000). Furthermore, it has been shown that the resulting effects are modulated by the neurophysiological level of processing (Reingold & Stampe, 2002) and can be partially explained within a framework of novelty-based reactions such as the orienting response (Graupner, Velichkovsky, Pannasch, & Marx, 2007).

For the present purpose it is important to note that the magnitude of the distractor effect can be related to differences in the experimental manipulation (e.g., eccentricity of distractor). This effect can also be interpreted—in free viewing—as a prolongation of the actual fixation. Finding differences in the amount of the distractor effect can be understood as a nearly online indicator of information processing in contrast to previous studies where a differentiation was only possible with a post hoc analysis of recognition (Velichkovsky et al., 2002, 2005). More specifically, we aimed to investigate the modulation of the distractor effect in relation to the amplitude of the preceding saccade, which has never been reported before. In our previous work, the distinction between processing modes was based on the combination of fixations and subsequent saccades. This differentiation cannot be applied in the current study since presenting a distractor affects the ongoing fixation and might also influence the following saccade. Therefore the classification of processing modes is based on the last eye movement parameter unaffected by a distractor—the amplitude of the preceding saccade.

It could be expected that ambient (directed at the spatial layout) and focal (directed at the objects and their features) processing differentially modulates the detection of visual sensory events. Both, our previous results (Velichkovsky et al., 2002, 2005) and newly revisited neurophysiological models (Corbetta et al., 2008) suggest that under dominance of the dorsal pathway, i.e., during ambient exploration, the processing of visual input, including distractors, would generally be diminished. One special case could be distractors of obvious biological significance, e.g., stimuli imitating a rapidly approaching object. In other words, one can expect that some resources of attentive processing are preserved even during ambient mode for dealing with biologically important information (Kahneman, 1973). Another hypothesis that had to be verified in the experiments concerns the question about the locus of the visual distractor effect: Is it more “visual” or more “distractor” effect, i.e., related to amodal mechanisms of the novelty-based responses? The answer to this particular question could be given by using distractors of different modalities.

In a more technical vein, experiments like this demand definition of several parametric values; first of all, the range of saccade amplitudes that can be considered as dividing the domains of ambient and focal processing. A simple rule of thumb that was validated in previous studies with static images is to take saccadic amplitudes at around 5° as the criterion to differentiate between the relative dominance of ambient or focal processing modes (Velichkovsky et al., 2002, 2005). This is a measure that also corresponds to the anatomical data on the parafoveal area of the adult human eye (Polyak, 1941; Wyszecki & Stiles, 1982) and to electrophysiological indicators (Billings, 1989; Thickbroom, Knezevic, Carroll,

& Mastaglia, 1991). The second parameter that was kept constant across the experiments was the delay of distractor presentation after the beginning of fixation. The selected delay was 100 ms. It is therefore larger than the temporal zone of saccadic suppression (Vallines & Greenlee, 2006). At the same time, the delay is short enough to test the majority of initially selected fixations, even if nearly 100 ms are additionally required for the full evolving of the distractor effect (Graupner et al., 2007; Reingold & Stampe, 2000).

EXPERIMENT 1

By distinguishing fixations in relation to the preceding saccadic amplitude, we expect stronger distractor effects for fixations in the focal mode rather than those related to ambient processing. To study this hypothesis it is necessary to control for the distractor's eccentricity as increasing the spatial distance between a distractor and the current fixation location reduces the influence of the distracting event (Honda, 2005; Walker, Deubel, Schneider, & Findlay, 1997). Since this observation was made in simple fixate-and-jump experiments, it is important to study if a similar relationship can be identified during free visual exploration.

Method

Subjects. Sixteen healthy volunteers (11 females and 5 males) with a mean age of 25.3 years ($SD = 4.9$) took part in this experiment. All subjects had normal or corrected to normal vision and received either course credit or €7 for participation in the study conducted in conformity with the declaration of Helsinki.

Apparatus. Participants were seated in a dimly illuminated, sound-attenuated room. Eye movements were sampled monocularly at 250 Hz using the EyeLink I eyetracking system (SR Research, Ontario, Canada) with online detection of saccades and fixations and a spatial accuracy of $< 0.5^\circ$. Fixation onset was detected and transmitted to the presentation system with a delay of approximately 12 ms. A 9-point calibration and validation was performed according to the guidelines outlined by Stampe (1993) before the start of the first trial and after the break. Saccades were identified by deflections in eye position in excess of 0.1°, with a minimum velocity of $30^\circ/s^{-1}$ and a minimum acceleration of $8000^\circ/s^{-2}$, maintained for at least 4 ms. The minimum fixation duration threshold was set to 100 ms. The first fixation in each trial was defined as the first fixation that began after the onset of the image. Pictures were displayed using a GeForce2 MX card and a CRT display (19-inch Iiyama Vision Master 451) at 1152 × 864 pixels at a refresh rate of 100 Hz. Viewed from a distance of

90 cm, the screen subtended a visual angle of 25.7° horizontally and 19.3° vertically.

Stimuli and design. Forty digitized paintings by European seventeenth- to nineteenth-century artists were used as stimuli with a size of 1152 × 864 pixels and 24 bit colour depth. During each trial, visual distractors were presented 100 ms after the fixation onset with a duration of 75 ms. Distractors were of circular shape with a size of 50 pixels (~1.38°). They were implemented as a colour inversion for chromatic and luminance values of the designated image region (RGB values for each pixel were transformed into the equivalent value on the colour scale, e.g., a value of 5 was converted to 250). Distractors were shown at 11 different horizontal positions in relation to the current fixation location (0, 2, 4, 6, 8, or 10° to the left or to the right of it). Within one trial 22 distractors were presented in randomized order, resulting in two presentations at each position per trial.

Procedure. Each subject was informed of the purpose of the study as an investigation of eye movement patterns in perception of art. Participants were asked to study the images in order to answer five questions regarding scene content after the picture offset (e.g., "Was there a painting on the wall?"). They were aware of the distractor presentations, but instructed to ignore them. The experimental session was run in four consecutive blocks, each containing 10 pictures with 5 min break after the second block. In total, the session took 90 min to complete. Before each trial, a drift correction was performed. Picture presentation began with an initial 5 s period without distractors, followed by the relevant experimental presentation. After an intervening delay of 2 s, questions regarding the picture content were shown. Within the experiment, distractors were presented at every fifth fixation. They were triggered by the fixation onset with a stimulus–onset asynchrony (SOA) of 100 ms. If a fixation was terminated before reaching the SOA, the program waited for the next suitable fixation resulting in more then five fixations between the distractors in such a particular case. The presentation algorithm also considered the relative position of the fixation on the image, i.e., if the fixation-distractor distance would result in a distractor outside the image, the direction was switched and the distractor appeared at the opposite position. The image presentation lasted until the respective number of distractors of each category was presented (on average, about 55 s).

Data analysis. Data analyses were carried out using SPSS 14.0 and MATLAB 7.1. Raw eye movement data were preprocessed before statistical analysis. All fixations shorter than 100 ms or outside the presentation screen were excluded from analyses. According to earlier findings (Harris, Hainline, Abramov, Lemerise, & Camenzuli, 1988; Velichkovsky, Dornhoefer, Pannasch, & Unema, 2000), fixations were expected to reveal a right skewed distribution where the median represents a more reliable value than the mean. Therefore, for statistical testing the respective median values were subjected to repeated measures analyses of variance (ANOVA). Partial eta-squared values were additionally reported in order to provide indicators of the potential practical significance of differences. For data analyses only the fixations and saccades at the time of distractor presentation and the two adjacent to this event were considered. Accordingly, 50.5% ($N = 76547$) of the overall dataset were used for subsequent statistical analyses.

Results

To investigate the effects of the distractors at the different positions, fixation durations of the baseline and the distractor condition were compared. As baseline we used the median duration of the two fixations preceding and following the distractor. A $2 \times 6 \times 2$ repeated measures ANOVA was conducted on the medians of fixation duration with direction (left vs. right), eccentricity (0, 2, 4, 6, 8, and 10° distance from the fixation location) and distractor (distractor vs. baseline), all serving as within-subjects factors. No effect was found for direction, $F < 1$, but for eccentricity, $F(5, 75) = 16.45$, $p < .001$, $\eta^2 = .523$, and for distractor, $F(1, 15) = 245.66$, $p < .001$, $\eta^2 = .942$. Furthermore, a significant interaction was obtained for Position × Distractor, $F(5, 75) = 30.53$, $p < .001$, $\eta^2 = .671$, demonstrating a larger influence of distractors within the foveal and parafoveal range (up to 5° away from the fixation location, within a range of 317–357 ms). For distractors appearing in the periphery (further away than 5° from the fixation location) the effect remains relatively stable (within a range of 300–308 ms; see Figure 1). No further interaction was found.

Since a prolongation of fixations was obtained, we were interested if this distractor effect is also modulated by processing mode. A distinction was made between fixations preceded by saccades with amplitudes of less or equal than 5° and fixations with preceding amplitudes of larger than 5°. As described earlier, the first category was assumed as belonging to focal processing (henceforth focal), whereas the second was referred to ambient processing (henceforth ambient). According to this definition, distractor and baseline fixations were classified. Subsequently, the difference values (distractor minus baseline fixations) for each category were computed. Because no differences were obtained concerning the location of distractors to the left or to the right from fixation position, this factor was not further considered. The resulting differences are shown in Figure 2.

Difference values were applied to a 6×2 repeated measures ANOVA with eccentricity (0, 2, 4, 6, 8, and 10° distance from the fixation location) and

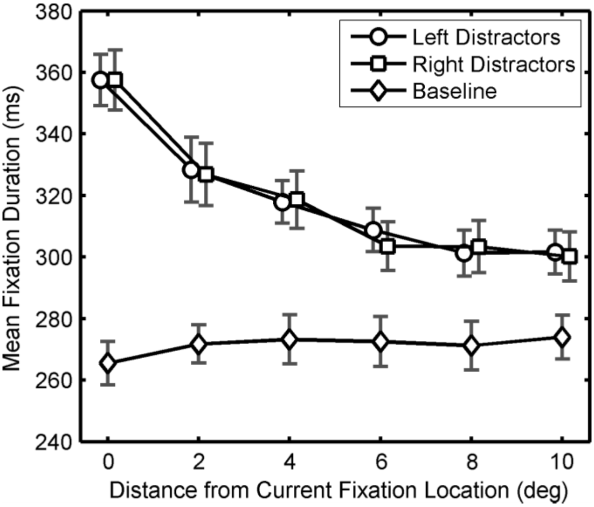

Figure 1. Mean durations and standard errors for distractor fixations and the baseline in respect of the distractor distance from the fixation position.

processing (ambient vs. focal) serving as within-subjects factors. A significant main effect was found for eccentricity, $F(5, 75) = 17.62$, $p < .001$, $\eta^2 = .540$. Post hoc testing revealed reliable differences between distractors at 0° and those that appeared at 4° and further away, $p < .05$. Also a

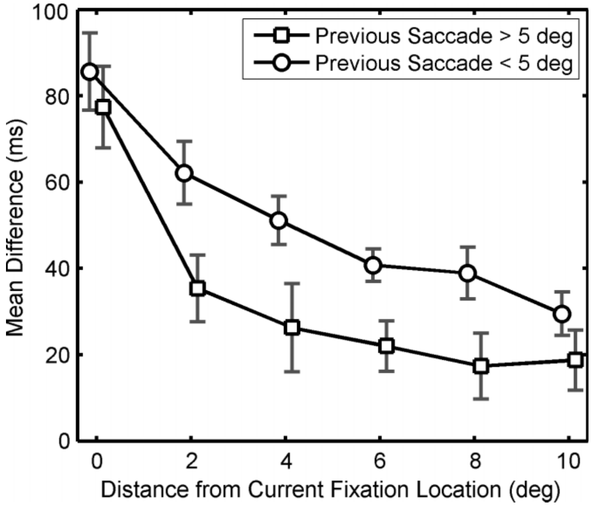

Figure 2. Mean differences and standard errors for fixation durations with respect to the amplitudes of the previous saccade.

significant difference was obtained for the factor processing, $F(1, 15) = 14.160$, $p = .002$, $\eta^2 = .486$, with no further interaction, $F < 1$. The main effect was largest for distractors at the current fixation location (82 ms at 0° eccentricity) and became smaller with increasing eccentricity (24 ms at 10° eccentricity). Single paired *t*-tests on the difference values of distractor effects with respect to the previous saccadic amplitude revealed significant differences for distractors shown in the range of 2–8°, $t(15) \geq 2.43$, all $ps < .028$ (Bonferroni corrected).

Discussion

Our results are in line with earlier reports on differences in the influence of visual distractors in relation to their eccentricity. For four out of six eccentricities, in the range from 2° to 8°, we also found the expected differences of the distractor effect depending on the amplitude of the preceding saccade. This latter effect was absent at the foveal location of distractors leading to a steeper decline of distractor effect with increasing eccentricity of presentation when the tested fixations followed long-range saccades.

The notable exception of the distractor effect at the foveal location is similar to the picture of saccadic recalibration of presaccadic positions for shortly presented stimuli (Bischof & Kramer, 1968; McConkie & Currie, 1996; Müsseler, van der Heijden, Mahmud, Deubel, & Ertsey, 1999). However these effects were observed at earlier temporal intervals than 100 ms after the beginning of a new fixation as it was in our experiment. The same can be said about saccadic suppression. One possible explanation is related with the double nature of our stimuli used as distractors. They consisted of changes of both colour and luminance within the picture. It is known that the locus of interference of large saccades is the magnocellular pathway which is responsible to luminance variation in space and time (Burr, Morrone, & Ross, 1994; Vallines & Greenlee, 2006). Accordingly, saccades have a relatively weak influence on chromatically modulated components of distractors that can be efficiently processed in the foveal region.

EXPERIMENT 2

A nearly neglected aspect of the distractor effect is its dependency on dynamic parameters of the distractors. Because all existing studies are limited to the presentation of single simple stimuli, almost nothing is known about possible effects of the presentation of biologically important stimuli. This question is of particular interest from the perspective of the distinction of two modes of visual processing. While ambient processing can be generally connected with a shallower processing, according to the classical theory of attention as mental effort (see Kahneman, 1973), some residual resources may always be preserved for an in-depth processing of a limited set of stimuli with an a priori biological value. A looming optical pattern that normally signifies an approaching visual object is an example of such a stimulus. In the following experiment we compared the prolongation of visual fixations in dependence on the presentation of three types of distractors. We used single static stimuli as well as shrinking and expanding optical patterns.

Method

Subjects. Sixteen healthy volunteers (6 females and 10 males) with a mean age of 22.5 years ($SD = 2.9$) took part in this experiment. All subjects had normal or corrected to normal vision and received either course credit or €7 for participation in the study conducted in conformity with the declaration of Helsinki.

Apparatus and stimuli. Experiment 2 used the same apparatus and stimuli as described in Experiment 1.

Design. During each trial, visual distractors were presented in relation to the fixation position; 100 ms after the fixation onset and with duration of 75 ms. In contrast to Experiment 1, three subsequent distractors were shown during one fixation, resulting in a total distractor presentation time of 225 ms.

The distractors consisted of circular rings of three different sizes. The inner radius of the ring was always 0.375° but the outer radius could be either of 0.45°, 0.525°, or 0.60°. They were centred to the actual coordinates of the fixation and implemented by inverting the colour of the region between the inner and the outer radius. If a fixation was selected for the distractor presentation (see Experiment 1 for details) two different distractor sequences were possible. Distractors were presented in either an expanding or a shrinking manner. In the first case, it started with the smallest outer radius and expanded to the largest outer radius (i.e., from 0.45° to 0.60°), whereas in case of shrinking distractors the sequential procedure was the other way round. In addition, single distractors (circular ring with an inner radius of 0.375° and an outer radius of 0.45°) were presented (instead of three subsequent distractors) in order to test for the general distractor effect compared to Experiment 1. Within one trial 25 distractors (20 of the respective distractor type and 5 single distractors) were presented.

Procedure. Each subject was informed of the purpose of the study as an investigation of eye movement patterns in perception of art paintings before signing their consent. The viewing task and procedure was the same as in Experiment 1. The experimental session was run in two consecutive blocks, each containing 20 pictures. Within a block only one distractor type (expanding or shrinking) was shown together with the single distractors, but each subject received all distractor types within one session. The order of the distractor type presentation was balanced across the subjects. On average, the presentation of an image lasted for about 55 s. In total, the experimental session took 90 min to complete with a 5 min break between the blocks.

Data analysis. Eye movement data were preprocessed and filtered by the same routines as described in Experiment 1. Accordingly, 63.9% ($N = 59291$) of fixations and saccades of the overall dataset were used for subsequent statistical analyses.

Results

To investigate the effects of different distractor types, fixation durations of the distractor condition were compared with the baseline (median of the two fixations before and after the distractor presentation). A 3 × 2 repeated measures ANOVA was conducted on the median fixation duration with distractor type (single, expanding, and shrinking distractors) and distractor (distractor vs. baseline), both serving as within-subjects factors. We obtained significant differences for distractor type, $F(2, 30) = 5.72$, $p = .008$, $\eta^2 = .276$, and for distractor, $F(1, 15) = 58.88$, $p < .001$, $\eta^2 = .797$ (see Figure 3). Post hoc testing yielded significance only between the single distractors and the expanding distractors, $p < .001$. Moreover there was a significant interaction for Distractor type × Distractor, $F(2, 30) = 5.85$, $p = .007$, $\eta^2 = .281$, resulting from a smaller influence of single distractors ($M = 314$ ms) compared to shrinking and expanding distractors (Ms = 335 and 350 ms). The presentation of dynamic distractors within a fixation resulted in a stronger prolongation of the affected fixation (21–36 ms).

In order to investigate this effect on a finer grained level, we again distinguished distractor and baseline fixations on the basis of the amplitude of the preceding saccade (ambient vs. focal; see Experiment 1 for further description). Subsequent to this classification, differences between distractor and baseline fixations were calculated (see Figure 4). A 3 × 2 repeated measures ANOVA was conducted on the resulting values with distractor type (single, shrinking, and expanding) and processing (ambient vs. focal), both serving as within-subjects factors. A significant effect was found for

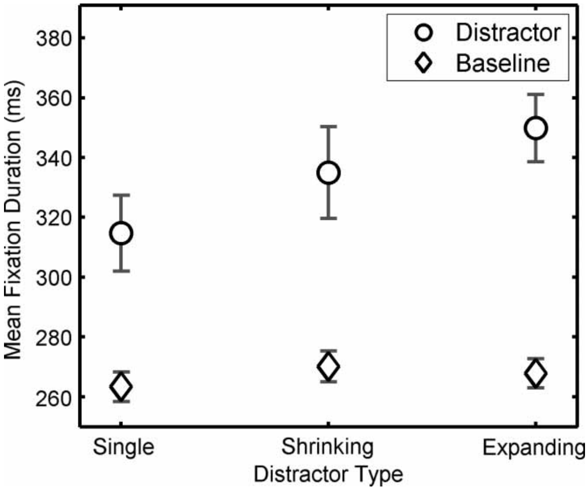

Figure 3. Mean fixation durations and standard errors for the different distractor types and the respective baseline.

distractor type, $F(2, 30) = 6.04$, $p = .006$, $\eta^2 = .287$. Moreover, a significant effect of processing was found, $F(1, 15) = 4.62$, $p = .048$, $\eta^2 = .235$, with no further interaction, $F(2, 30) = 2.62$, $p = .089$. Bonferroni corrected post hoc testing yielded stronger influences on fixations for expanding distractors than for single and shrinking distractors, $p < .05$ (*M*s = 79 vs. 52 and 53 ms).

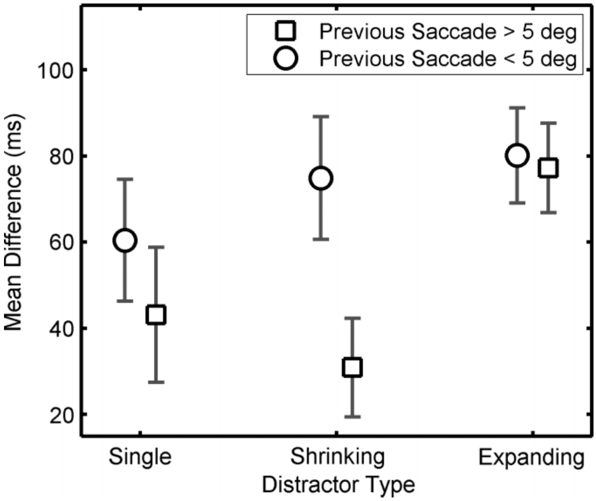

Figure 4. Mean difference values and standard errors for distractor types in relation to the amplitude of the previous saccade.

The results of this analysis demonstrate a distinct relationship between the effect of distractors and the mode of processing. For the focal processing, the outcome is similar to the results of the previous analysis for the general effect versus the baseline. Moreover, the effects for single distractors are similar to distractors that were shown at the eccentricity of 0° in Experiment 1. With dynamic distractors, a strong difference is found for shrinking (focal vs. ambient: *M*s = 75 vs. 31 ms) but not for expanding distractors (focal vs. ambient: *M*s = 80 vs. 77 ms).

Discussion

As expected, we found a stronger distractor effect for the dynamic visual stimulation as compared with single stimuli. Of particular interest for the purpose of our study was the analysis of the amount of this effect depending on the amplitude of the preceding saccade. Such analysis revealed a picture of results, which dissociates influences of two changing optical patterns of stimulation on the duration of fixations. When in presumably focal mode of processing, immediately after short-range saccades, both types of dynamic distractors showed approximately the same effect on tested fixations, the results were quite different in what we consider to support the ambient processing mode, i.e., after long-range saccades. Here a much stronger distractor effect of expanding patterns was discovered.

The special quality of optically and acoustically looming stimuli has been shown in a number of psychophysical and neurophysiological studies (Bruce, Green, & Georgeson, 1996; Lappe, 2004; Maier, Neuhoff, Logothetis, & Ghazanfar, 2004). For the first time, this was demonstrated with respect to the oculomotor distractor effect. However a significant difference between shrinking and expanding distractors was found only in context of large-range saccades. As in the case of distributed attention (Treisman, 2006), ambient mode of visual processing implies a generally shallower processing of input by simultaneously preserving the alerting function of vision for a limited set of objects of potential biological significance.

EXPERIMENT 3

Considering the mechanisms of the distractor effect, one has to be aware of a number of components influencing the final picture of oculomotor behaviour. Besides initial stages of sensory information processing, there are several other important mechanisms; for example, the inhibitory networks at the levels of superior colliculus, amygdala, and perhaps the premotor cortex (Reingold & Stampe, 2002, 2004). Previous results suggest that the distractor effect should also be considered within a broader category of novelty-based reactions of organisms such as startle and orienting reaction (Graupner et al., 2007). In the following experiment, we attempted to clarify whether the relationship of saccadic amplitude and the distractor effect is specifically related to processes within visual systems or perhaps reflects some more general states and intermodal processing. The simplest way to differentiate visual and nonvisual components of processing is to use presentation of intermodal distractors. The bulk of evidence supports the possible effect of acoustic and somatosensory distractors on the latency of saccades and fixation duration (Amlot, Walker, Driver, & Spence, 2003; Pannasch et al., 2001). Based on these results, visual, auditory, and haptic distractors were investigated in the same setting of free exploration of complex visual images.

Method

Subjects. Sixteen healthy volunteers (7 females and 9 males) with a mean age of 23.6 years ($SD = 3.4$) took part in this experiment. All subjects had normal or corrected to normal vision and received either course credit or €7 for participation in the study conducted in conformity with the declaration of Helsinki.

Apparatus. Experiment 3 used the same apparatus for eye movement recording and stimulus presentation as described in Experiment 1.

Stimuli and design. Twenty of the pictures used in Experiment 1 were used as stimuli. During each trial, visual, auditory, or haptic distractors were presented 100 ms after a fixation onset with duration of 75 ms. Visual distractors had the same features as single distractors in Experiment 2. Auditory distractors consisted of pure sinusoidal 1000 Hz tones and were produced by a standard PC soundcard. The tones had a duration of 75 ms including 5 ms rise and fall time. They were presented at a sound pressure level of 70 dB binaurally via insert earphones (EartoneTM 3A). To generate haptic distractors, a custom-made stimulation device was produced that was controlled by a parallel input–output board (PIO-24 II, BMC Messsysteme, Maisach, Germany) which was connected to the PC running the experiment. Haptic distractors were implemented via a blunt metal pin which pushed against the left index finger for 75 ms. The stimulation was clearly perceivable but not painful. Visual distractors appeared on screen at the spatial location of the selected fixation; auditory and haptic distractors were presented without any spatial relation to the selected fixation.

Procedure. Each subject was informed of the purpose of the study as an investigation of eye movement patterns in perception of art. The viewing task and procedure was the same as in Experiment 1. The experimental session was run in four consecutive blocks, with a presentation of five pictures within each. Within three of the four blocks distractors of only one modality appeared; in the fourth block distractors of all modalities were mixed. The order of blocks was balanced across the subjects. During each trial 21 distractors of the same modality or in the mixed block 7 of each were shown (see Experiment 1 for a description of the distractor presentation). On average, each trial lasted for about 55 s. In total, the experimental session took 60 min to complete, with a 5 min break following the second block.

Data analysis. To ensure the comparability eye movement data of the current study was preprocessed and filtered by the same routines as described for Experiment 1. Accordingly, 57.4% ($N = 41738$) of fixations and saccades of the overall dataset were used for subsequent statistical analyses.

Results

To investigate the effects of distractors of different modalities, fixation durations affected by distractors of the different modalities (visual, auditory, and haptic) were compared with the respective baseline fixations (median of the two fixations before and after the distractor presentation). We were also interested if there is a difference for the continuous presentation of distractors of one modality within one block against the mixed presentation of distractors of different modalities within one block. A $2 \times 3 \times 2$ repeated measures ANOVA was conducted on the medians fixation duration with block (continuous vs. mixed), modality (visual, auditory, and haptic), and distractor (distractor vs. baseline) all serving as within-subjects factors. No effect was found for block, $F(1, 15) = 2.68$, $p = .122$, but for modality, $F(2, 30) = 39.05$, $p < .001$, $\eta^2 = .722$ and for distractor, $F(1, 15) = 83.81$, $p < .001$, $\eta^2 = .848$. Significant interactions were obtained for modality and distractor, $F(2, 30) = 31.15$, $p < .001$, $\eta^2 = .675$ (see Figure 5), as well as for block and distractor, $F(1, 15) = 8.61$, $p = .010$, $\eta^2 = .365$. This latter interaction is due to the difference in distractor fixations (continuous vs. mixed block; *M*s = 324 vs. 343 ms) since the baseline is the same (*M*s = 280 vs. 278). A closer look at the finding reveals that it is mainly based on the visual distractors (continuous vs. mixed block; *M*s = 387 vs. 428 ms). For other modalities the continuous vs. mixed presentation makes only marginal differences (auditory: *M*s = 301 vs. 312 ms; haptic: 284 vs. 289 ms, correspondingly). Moreover, Bonferroni corrected paired *t*-tests for modality and distractor effect revealed significant influences on the fixation

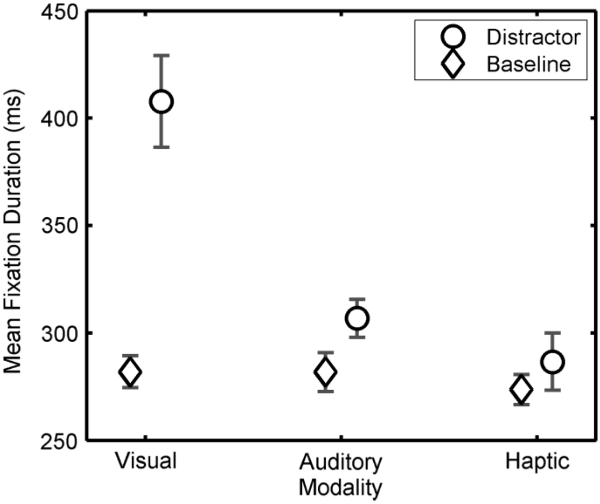

Figure 5. Mean fixation durations and standard errors for distractor and baseline fixation in relation to the modality of the presented distractor.

duration for visual and acoustic, *p*s < .001, but not for haptic distractors, $p = .065$.

Again, the distractor effect was investigated in relation to the amplitude of the previous saccade. Due to the nonsignificant main effect for block in the previous analysis, this factor was not further considered. We distinguished fixations in the baseline and those probed by distractors on the basis of the amplitude of the preceding saccade (ambient vs. focal; see Experiment 1 for further description). Subsequent to this classification, differences between distractor and baseline were calculated (see Figure 6).

Difference values were entered into a 3×2 repeated measures ANOVA with modality (visual, auditory, and haptic) and processing (ambient vs. focal), both serving as within-subjects factors. Significant main effects were found for modality, $F(2, 30) = 66.40$, $p < .001$, $\eta^2 = .816$, and for processing, $F(1, 15) = 7.68$, $p = .014$, $\eta^2 = .339$. Post hoc testing revealed stronger effects for visual distractors ($M = 108$ ms) compared to auditory and haptic distractors (*M*s = 21 and 11 ms, respectively). In addition, an interaction was obtained, $F(2, 30) = 9.00$, $p = .001$, $\eta^2 = .375$, resulting from the fact that the ambient-focal classification differentiated between fixations affected by visual distractors (about 47 ms). In the case of auditory and haptic modalities, any influence of saccadic amplitude is absent.

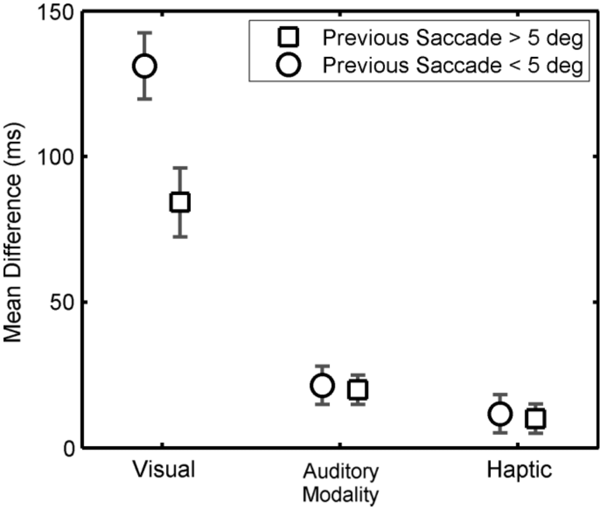

Figure 6. Difference values and standard errors for each distractor modality in relation to the amplitude of the preceding saccade.

Discussion

The results of this experiment demonstrate that the dependency of the distractor effect on the amplitude of preceding saccades is associated with the visual modality of presentation. Both auditory and haptic distractors had only a weak influence on the prolongation of fixations; moreover, this influence was independent of the saccadic context. Thus, the data from Experiment 3 testify that the visual distractor effect can be used for investigating differences in the mode of visual information processing, for example, in relation to the involvement of dorsal and ventral streams of visual processing in the regulation of eye movements (Burr et al., 1994; Velichkovsky et al., 2005).

Additional evidence for the locus of this effect could be collected with the repeated presentation of distractors and the analysis of habituation in the fixation duration (Graupner et al., 2007). In a preliminary way, one can predict no interaction of saccadic amplitudes and the rate of habituation, at least for fast habituation processes that seem to avoid cortical processing. At the same time, slow habituation, which usually develops over periods of minutes and hours, shows a correlation with the changes in visually evoked cortical ERPs and in that slow habituation might be related to one of the two modes of visual processing. A stronger overall effect for visual distractors was obtained in this experiment in comparison to Experiments 1 and 2. This might be due to the combined presentation of distractors of different modalities counteracting any form of habituation.

As demonstrated previously, habituation is more expressed in the case of homogeneous (unimodal) distractors (Graupner et al., 2007).

GENERAL DISCUSSION

Our goal in the study was a further analysis of information processing during separate visual fixations in a free viewing of complex images. In accordance with earlier findings on recognition performance (Velichkovsky et al., 2002, 2005) and recent neurophysiological models (Corbetta et al., 2008), we assumed a stronger influence of visual distractors during the focal as compared with ambient processing mode. This latter distinction was operationalized by taking into account the amplitude of saccades preceding the fixations in question: Fixations that resulted from saccades outside of the parafoveal range were considered as related to the ambient processing with its reliance on the global spatial layout of the environment. In this particular mode of processing, stimuli-driven influences such as additionally presented visual distractors could be of less importance.

We measured the influence of distractors on visual fixations effect depending on the retinotopic position of distractors (Experiment 1), their spatial-temporal patterning (Experiment 2) and the possible multimodality of the described effect (Experiment 3). In all three experiments, the differences in the size of the distractor effect in relation to the saccadic amplitude were confirmed. In terms of Henderson and Pierce (2008), fixation duration is under less direct control of the visual scene following saccade amplitudes outside the parafoveal range.

As every saccade is a complex biomechanical event changing conditions for visual information processing in a number of ways, alternative explanations for this basic result have to be considered. First of all, large saccades sometimes miss their targets, so that a short corrective saccade may follow after a preliminary stopping of eyes in the "undershot" position. However, precorrective fixations usually are of very short duration, substantially less than 100 ms (Otero-Millan, Troncoso, Macknik, Serrano-Pedraza, & Martinez-Conde, 2008; Velichkovsky et al., 2000; Yarbus, 1967). By presenting distractors 100 ms after the beginning of the selected fixations, we automatically excluded this possibility of explaining the results. Another explanation is the saccadic suppression (Dodge, 1900, Latour, 1962; Lee et al., 2007) that can be particularly pronounced in the case of large-scale saccadic eye movements. But an analysis of temporal relationships again makes this alternative a relatively unlikely explanation. Accordingly, suppression anticipates saccades by 50 ms, is maximal at the moment of saccadic onset, and outlasts saccades by nearly 50 ms at most (Vallines & Greenlee, 2006; Zuber & Stark, 1966). No saccadic suppression was discovered beyond this interval. This rules out an influence of saccadic suppression on the processing of distractors presented 100 ms after the saccade offset. Furthermore, one could argue that repetitive fixations (refixations) explain our findings. Regions of higher visual complexity are usually fixated with higher frequencies, longer durations, and the preceding saccades often are relatively short (Rajashekar, van der Linde, Bovik, & Cormack, 2007). Even if refixations are similar to focal fixations, this hypothesis alone does not explain the current findings, for instance, the differences of effects for expanding and shrinking distractors (Experiment 2). In addition, refixations were thoroughly controlled and excluded as a possible explanation in one of our previous studies (Velichkovsky et al., 2005).

Thus, the preferable hypothesis is that of a relation between eye movements and modes of visual processing. The conclusion is in general agreement with previous studies, which used such measures of visual performance as recognition (Velichkovsky et al., 2002, 2005) and, indirectly, with recent descriptive analysis of relationships between saccadic amplitudes and duration of fixations in visual processing of complex images (Tatler & Vincent, 2008; Unema, Pannasch, Joos, & Velichkovsky, 2005). Additionally it is supported by data from Experiment 3. Though the distractor effect (as a novelty-based reaction of the organism; see Graupner et al., 2007) has not only visual but also intermodal components, our data show that haptically and acoustically induced distractor effects show no interaction with parameters of preceding saccadic eye movements.

At the same time, overall results of the present study cannot be easily assimilated by the standard hypothesis of the two modes of visual processing, with its sharp distinction of perception for action and for consciousness (Milner & Goodale, 1995, 2008). In the case of active vision, involvement of saccadic eye movements seems to be rather a matter of balancing between complementary but closely interrelated modes of processing. In view of the contrasting influence of dynamic distractors found in Experiment 2, the difference reminds that of focused and distributed attention (Treisman, 2006). The exact nature of these mechanisms starts to be investigated by a simultaneous analysis of eye movements and neuronal activities (Cornelissen, Marsman, Renken, & Velichkovsky, 2008; Maldonado et al., 2008; Rajkai et al., 2008). Currently available information suggests that large-scale saccades selectively interfere with the magnocellular pathway. The latter is related to forms of global luminance-based processing of transient information, which is under control of dorsal stream structures (Bridgeman, van der Heijden, & Velichkovsky, 1994; Burr et al., 1994; Vallines & Greenlee, 2006).

From this perspective, eye movements have to be considered as a common output of several neurocognitive mechanisms. The neurophysiological data on contrasting functions of frontoparietal system and structures of occipital and temporal cortex (Corbetta et al., 2008; Faillenot, Toni, Decety, Gregoire, & Jeannerod, 1997) suggest two basic mechanisms at work in free exploration of visual images. It remains to be seen, whether the difference of processing in relation to the saccadic amplitude will generalise to different tasks, where other brain systems play a role. This may be the case of interpersonal communication where eye-to-eye contacts and the states of joint attention strongly influence the fixation duration (Schrammel, Pannasch, Graupner, Mojzisch, & Velichkovsky, in press; Velichkovsky, 1995). Another example is the comparative visual search: The spatial arrangement of two (nearly) identical parts of search space is well-defined here remaining constant during the task solution (Pomplun, 1998). Reading may be a similar case because in reading too the overall spatial arrangement is known before. Also known is the default saccade target, which normally is the next word. Even for static images, as in the present experiments, the time phase of perception may be of importance as the balance of ambient and focal processing is different at the beginning of scene inspection and after the initial 2–4 s (Pannasch, Helmert, Roth, Herbold, & Walter, 2008; Unema et al., 2005).

The methodological message of this study is therefore that visual processing during fixations has to be investigated in a variety of further conditions and tasks. Both amplitude of preceding saccade and the amount of distractor effect, as a dependent variable, seem to be well suited to testing hypotheses about the modes of visual processing during continuous visual activity in ecologically valid situations. By the beginning of a fixation its status with respect to the parameters of preceding saccade is known, which simplifies decisions on experimental manipulations and on the measures for baseline control. The distractor paradigm is relatively unobtrusive, involving a kind of background stimulation, which only weakly interferes with the task at hand. This makes it a promising instrument for studies of visual cognitive activities, also as a part of neurophysiological experiments with human and subhuman subjects.

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