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CHAPTER 8

Blinks, blanks and saccades: how blind we really are for relevant visual events

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Abstract: We report on a study in which subjects viewed color video stills of natural traffic situations while eye movements were recorded. A display change could occur randomly during three different occlusion modes — blinks, blanks and saccades — or during a fixation. These changes could be either relevant or irrelevant with respect to the traffic safety situation. Furthermore we contrasted insertions and deletions. All occlusion modes appeared equivalent concerning detection rate and detection time, and only differed from the fixation condition. The results also show that the detection of relevant changes was more likely and faster than that of irrelevant ones. However, even relevant insertions, which were almost always detected, were around 180 ms longer to report when they occurred during an occlusion. Furthermore, the detection of relevant changes was fairly stable across a wide range of the visual field, whereas irrelevant changes were less well detected, the further away from the fovea they occurred. We close with an outlook on a follow-up study where only relevant insertions and the blank occlusion were used in a driving simulator environment. Surprisingly, we found an advantage in change detection rate and time with blanks compared to the control condition. Change detection was also good during blinks, but not in saccades.

Introduction and overview

The variety of functional blindness phenomena

When viewing a scene we actually see far less than we think (e.g. Dennett, 1991; Wolfe, 1999a). Although this fact can be demonstrated with any crowded picture, it is particularly pronounced if there are some changes in either observed or in background events. The first demonstration of functional change blindness goes back to the 19th century (Baxt, 1871). For decades, it was studied in the context of *masking effects*: a target that is clearly visible when briefly presented alone can be rendered invisible by the subsequent presentation of a non-target object in the nearby spatial location (see Enns and Di Lollo, 2000).

Ulric Neisser (1979) contributed to a better ecological validity of the experiments by proposing the 'selective looking' paradigm, an analogue to the 'dichotic listening' from investigations of selective attention. He presented a video with superimposed films of two different teams playing basketball. When monitoring only passes of one team and ignoring passes made by the other team, observers often failed to perceive a continuous irrelevant event — a woman with an umbrella walking across the scene (see also Simons and Chabris, 1999). In another famous study, professional pilots were instructed to land an aircraft in a flight simulator under conditions of poor visibility using a head-up display (Haines, 1991). Two of ten tested pilots were not aware of a

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large airplane on the runway although it was clearly visible and located directly ahead of them. Being functionally blind to the unexpected obstacle, they simply landed their aircrafts 'through' it.

This inability to perceive unexpected events has been labeled '*inattentional blindness*' (Mack and Rock, 1998). Wolfe (1999b) however argues that these phenomena are rather evidence of '*inattentional amnesia*', because the changes might have been perceived, but not remembered (in the direct, explicit sense of the word). These change detection failures have recently been investigated in studies focusing primarily on a phenomenon known as '*change blindness*', which we discuss and investigate in this chapter. There are a few other variants of the change blindness phenomenon worth mentioning, though we will not specifically address them: they include the '*attentional blink*' (Shapiro et al., 1997), '*repetition blindness*' (Kanwisher, 1987) and '*comparison blindness*' (Scott-Brown et al., 2000).

A review of the current explanations (Simons, 2000) demonstrates that the field is in need of more systematic experimental studies before a theoretical synthesis can be provided. Noticing a changing object may be an automatic achievement with respect to detection and localization, but it assumes focused attention and effortful encoding of features if identification is demanded (Velichkovsky, 1982; Rensink et al., 1997). A lack or a re-direction of attention therefore often causes failure to perceive changes to scenes.

How to produce change blindness

Change blindness typically occurs when a global disruption of the retinal image, such as *saccades* (due to saccadic suppression) or *eyeblinks*, obscure the local transient caused by a change. Grimes (1996), for example, demonstrated that people often do not detect large changes to scenes occurring during saccades. In his experiments, observers studied everyday scenes presented on a computer monitor for a later recognition. While they freely explored the scenes, some details were changed in a gaze-contingent manner (e.g. two people exchanging heads or a prominent building in a skyline becoming 25% larger). A considerable number of changes (67%), that could cover one fourth of the picture, sometimes in the center of visual field, were missed. The same changes were easily detected when they occurred during a fixation. These striking results are consistent with earlier studies on the failure to integrate information across saccades (e.g. Irwin et al., 1983; Rayner and Pollatsek, 1983). O'Regan et al. (2000) obtained similar effects when they changed aspects in everyday visual scenes every time an eye blink occurred.

Change blindness is not specifically related to saccades or blinks, however: it can also occur during an artificial global occlusion, such as a *blank screen*, where the disruption of the retinal image by an eye movement is simulated by a brief *blank screen* that is inserted between the original and the modified picture — using either a 'one-shot' (Pashler, 1988; Blackmore et al., 1995; Simons, 1996) or a 'flicker' paradigm (Rensink et al., 1997). In one-shot tasks, the original and the modified picture are each presented for one view before the observers have to guess whether a change has occurred. In the flicker paradigm (it has a less natural character and may interfere with different aspects of perceptual processing, e.g. Macknik et al., 1991), the original picture A alternates with the modified picture A′, each time separated by a brief blank field. A random order of presentation is often used to create temporal uncertainty about the change.

Other global disruptions that have been used in investigations of change blindness are *picture shifts* (Blackmore et al., 1995), *film cuts* in motion pictures (Levin and Simons, 1997) or *physical occluders* in real world situations (Simons and Levin, 1998). Furthermore, change blindness can also occur when the change takes place in full view, namely if a multitude of distracting local transients (often called '*mudsplashes*') are presented parallel to that produced by the change (O'Regan et al., 1996; Enns and Di Lollo, 2000), or when *gradual changes* occur slow enough not to give rise to the activation of the visual transient channels (Simons et al., 2000).

Factors affecting change blindness

Various factors have been found to modulate change detection. In particular, recent studies have shown that the *relevance* of a change plays an important role in the detection probability. According to Rensink et al. (1997) and O'Regan et al. (1999), changes to objects of central interest (as determined in independent ratings) are detected more readily than changes to objects of marginal interest. Even when eccentricity relative to the eye position is controlled, an advantage in detectability for objects of central interest remains (O'Regan et al., 2000). In a driving simulator study, however, Shinoda et al. (2001) found that task variables interfere with relevance and can modulate detection probability: the highly traffic-relevant replacement of a No-Parking sign by a Stop sign during a blank screen was rarely detected if subjects were asked to follow a lead car and keep a constant distance.

In their elaboration of the classical Neisser experiments, Simons and Chabris (1999) showed that unexpected changes are more likely to be detected the higher the *similarity* between the currently attended and the unexpected events is. In an attempt to replicate these results, Most et al. (2001) demonstrated that the change detection has to be attributed not as much to similarity with attended events, but rather to dissimilarity with the unattended, to-be-ignored stimuli. According to data from the investigations of picture memory, schema-inconsistent changes are more likely to be detected than schema-consistent ones, albeit only in recognition, not in recall tasks (Friedman, 1979; Henderson, 1992).

Focused *attention* may be the single most important factor in change blindness studies. Newby and Rock (1998) found that detection is the better the closer an unexpected stimulus is to the center of attention — not necessarily to the center of fixation. The position that attention mediates change detection is further supported by the findings that verbal (e.g. Rensink et al., 1997) or spatial (Enns and Di Lollo, 2000) cueing improves detection rate. Considering the support for the notion of attention as a necessary condition for change detection, it seems reasonable to assume that, in fact, relevant objects simply are more likely to attract attention than irrelevant ones. This would be in line with Henderson and Hollingworth (1999), who found that fixating an object immediately before or after a change correlates with detection rate. Nevertheless, several recent studies provide evidence that change detection can take place *without awareness* (Hayhoe et al., 1998; Fernandez-Duque and Thornton, 2000; Smilek et al., 2000; Henderson and Hollingworth, 2002), causing Rensink (2000) to point towards the hypothesis, that "conscious visual experience of change is mediated by focused attention, whereas unconscious perception of change is not".

Change detection is further a function of *knowledge* and *expertise* of observers. Archambault et al. (1999) report that the *level of categorization* at which an object has been learned (general vs. specific) interacts with change detection. In an expert–novice comparison of change detection in football images, Werner and Thies (2000) showed that domain-specific expertise attenuates change blindness. Reingold et al. (2001) found experts' advantages in detection of changes to meaningful chess configurations and proved the long-lasting hypothesis that experts work with larger cognitive templates. These findings are consistent with studies showing that the visual scanning strategies evolve with expertise (in the case of road traffic see, e.g., Mourant and Rockwell, 1972; Crundall and Underwood, 1998): experts search a larger visual area more efficiently and with fewer eye movements than novices.

As still another group of factors, the spatial–temporal variables of presentation have to be mentioned. According to Henderson and Hollingworth (1999), change detection decreases with the *foveal distance* from the location of change. They assume that there is a significant role for fixation position in the maintenance of information processing across discrete views of a scene, and that allocation of attention cannot be the sole determinant of detection performance. O'Regan et al. (2000) showed that beyond 2° of visual angle, detection rate remains fairly stable up to at least 8°, with a slight advantage for changes of central interest. With respect to time, the longer an occlusion lasts, the worse subjects perform at change detection: Rensink et al. (2000) report that performance deteriorated as blank durations increased from 40 ms to 320 ms. Phillips and Singer (1974) found a non-monotonous influence of the interstimulus interval (ISI): with a zero-length ISI, changes were detected easily, growing increasingly difficult as the ISI approached 80 ms, beyond which detection became stable up to ISI of over 300 ms (see also Enns and Di Lollo, 2000). Rensink et al. (2000) examined whether extended viewing time of the initial image improves change detection. They provided an uninterrupted preview of the original image of 8 s before starting an AAA′A′-flicker sequence (with following image durations of 240 ms each). Observers were asked to remember as much of the image as possible. A comparison with a study using the same flicker sequence without an additional preview (Rensink et al., 1997) revealed no effect of previewing time. Rensink et al. (2000) therefore conclude that change blindness is not caused by an insufficient time to construct a coherent representation.

Finally, the *type of change* seems to play a role. According to Simons (1996), the appearance of an object in a previously empty array is more likely to be detected than the replacement of one object by another. Phillips and Singer (1974) as well as Stelmach et al. (1984) also found that adding an item to the visual array was more likely to be detected than deleting one. Henderson and Hollingworth (1999) found better detection rates for deletions compared to rotations. In the study, a 90° rotation was detected only 10% of the time, when neither the pre- nor the post-saccadic fixation landed on the change location, while deletions were detected in the same conditions 40% of the time. In Grimes' experiment (1996), changes to object properties (color, rotations) were detected more easily than layout and semantic category changes.

An experiment on variation of relevance and type of occlusion

In the light of the discussed data, which demonstrate an abundance of situations and factors inducing change blindness (saccades, blinks, blanks, mudsplashes, gradual changes), the question arises how serious these effects are in everyday life. Let us consider the mere number of blinks and saccades made during the day: someone who makes an average of 12–15 blinks per minute (Barbato et al., 2000) lasting 150 ms on average while making an average of 4 saccades per second with an average duration of 35 ms, experiences a global occlusion 17–18% of the time. Thus, although it has well been established that blanks, blinks and saccades are effective in eliciting change blindness, a direct comparison is necessary to determine whether the respective influences are comparable. Considering this, we were interested to find out to what extent the types of occlusion occurring in everyday life may contribute to the failure of detecting relevant and irrelevant changes in realistic traffic scenes.

Method

Stimuli and design

The experiment involved 60 digitized color stills taken from a video containing a variety of real traffic scenes recorded from the vantage point of the driver through the windshield of a car. The stills were digitized to 800 × 600 pixel bitmaps with a color resolution of 24 bits per pixel. To each of the images, four different manipulations could occur, resulting in a set of 240 trials.

A complete-within-subjects design was used to study the effects of occlusion type and relevance on detection probability and detection latency. Stimuli were presented in random order in three sets of 100 trials, each containing an equal number of trials of each condition. The changes could be executed during either of four conditions: a screen blanking, which lasted 112 ms, an eye blink, a saccade or a fixation (as non-occlusion condition). Subjects were asked to respond by pressing a button as soon as they noticed a change. In contrast to the endogenous occlusions (blinks and saccades) external blanks may serve as a cue. Therefore, in order to avoid guessing, 60 blank screen catch trials were added to the 240 trials, i.e. no changes were made. Presentation of the 300 trials occurred in any of four predetermined quasi-random orders. A trial started with a blank screen for 1500 ms. The unchanged image was shown for 4000, 4500, 5000, 5500 or 6000 ms before a change was initiated. In the blank condition, this meant that the image was changed at the end of the above-mentioned period. In the blink, saccade, and fixation conditions, the image was changed immediately upon next occurrence of the event. When a blink trial was up and no blink occurred during the following 6 s, the trial was aborted and discarded from further analysis. The trial ended when the button was pressed or when it was not pressed within 5 s following the change. Reaction times were measured from the moment of de-occlusion. Thus, in the blank- and the fixation-condition, reaction time was measured from the moment of image change, in the saccade condition reaction times were measured from the start of the next fixation, and in the blink-condition reaction times were measured either from the moment the blink was over (when the blink occurred during a fixation) or from the start of the next fixation in case the blink occurred during a saccade.

We contrasted two classes of change (Fig. 1). *Driving-relevant* changes were such changes that the driver of a vehicle in that situation would have to take action in order to avoid a dangerous or potentially dangerous situation. These changes included objects (e.g. pedestrians, vehicles or bicycles) that appeared or disappeared in front of the driver or changes within such objects — e.g. the (dis)appearance of braking lights. *Driving-irrelevant* changes could be any other kind of change — e.g. the (dis)appearance of a tree or a house's window. Five independent judges determined whether a change should be rated as driving-relevant or driving-irrelevant. Overall interrater agreement was better than 95%. Furthermore two kinds of changes, namely insertions and deletions were contrasted. Size, distance (with respect to the focus of extension) and color contrast of the changes were counterbalanced across all changes.

Subjects

Twenty-four subjects, 13 female and 11 male aged 20 to 30 years (mean = 23.25, SD = 2.64), volunteered for the study. All subjects were students of psychology at Dresden University of Technology and

Fig. 1. Sample image-pairs used in the experiment. (A) Relevant change: a bicyclist appears on the right side. (B) Irrelevant change: an advertisement object appears on the right side.

reported normal or corrected to normal vision. None of the subjects had participated in a change blindness study before. Furthermore all subjects were holders of a driving license.

Procedure

Subjects were seated in front of a 17" ViewSonic color monitor running at a vertical refresh rate of 100 Hz. Viewing distance was approximately 60 cm from the screen surface, resulting in a viewing angle of ~30° horizontally and 20° vertically. Subjects were instructed to watch the scenes while trying to imagine being the driver of a car approaching the scene and to press the left mouse-button as soon as they noticed a change. They were also asked not to be bothered by a blank screen that could sometimes appear. Before the eye tracking equipment was fitted to the subjects, a series of 20 test trials was presented to familiarize them with the procedure. After fitting and calibration of the eye tracker, subjects proceeded with the experiment. An automatic drift correction was performed every 5th trial, a recalibration took place every 30th trial. Subjects had a 5-min break after 100 and 200 trials. All participants saw the trials in one of four random orders of presentation. The whole experiment lasted approximately 75 min, including preparation and two 5-min breaks.

Apparatus

In order to perform eye-movement-contingent changes to the scenes, the SR-Research Eyelink™ I eyetracker was used. The system uses a headband holding a camera to compensate for head movements and one camera for each eye. Eye movements were recorded monocularly using the dominant eye, with an accuracy of less than 1°, sampled at 250 Hz. The eye tracking PC was interfaced by means of an Ethernet connection to a stimulus-presenting Pentium PC, which received the eye position data with an approximate delay of 8 ms. Eye movements larger than 0.3° per sample were considered to be saccades and detected by an online algorithm using four samples, resulting in a total delay of 24 ms. Fixations were identified as the absence of a saccade, unless missing pupil data indicated a blink — both, fixations and blinks, were also detected within 24 ms.

To avoid flicker, changes of the scenes were always performed during the vertical retrace and synchronized to the next vertical refresh (100 Hz), resulting in a potential further delay of 0 to 10 ms — thus an eye contingent display change was executed within 24 to 34 ms. The avoidance of flicker was considered to be more important than minimizing the delay, while choosing a relatively high cutoff criterion for minimal saccadic velocity to ensure that changes could be performed before a saccade was terminated. All stimulus data (scene, change location, change type, occlusion type and size) as well as all subject responses were sent time-stamped to the eyelink system in order to enable a retrospective in-depth analysis.

Results

Data analysis

All received data were inspected offline to decide whether they were recorded correctly or should be discarded. Trials were discarded when at the time of image change the eliciting event (saccade, fixation, blink) was over or when (e.g. due to noise) the detection algorithm had proven incorrect with respect to the event. In particular when a blink was used as the intended occlusion and the maximal wait time of 6 s was exceeded, the trial was discarded in order to avoid systematic differences in exposure time. Five subjects with less than ten observations in any of six cells (occlusion types by relevance) were excluded from further analysis, resulting in a final data set of 19 subjects with a total of 4461 valid trials. Guessing did not to play a significant role in the blank condition: the average false alarm rate in the 'no change' condition was 5.3%, the highest individual rate among all subjects was 8.3%. The blink rate over all subjects was 14 per minute on average with an average duration of 140 ms. Saccades were made four times per second on average with an average duration of 43 ms. Two $3 \times 2 \times 2$ (occlusion $\times$ relevance $\times$ change-type) repeated measures anova's were performed to test significances of the experimental factors on detection rate and detection time, respectively. Fixation was used as a control condition. Since the occurrence of saccades, blinks and fixations cannot be exactly predicted, exposure times

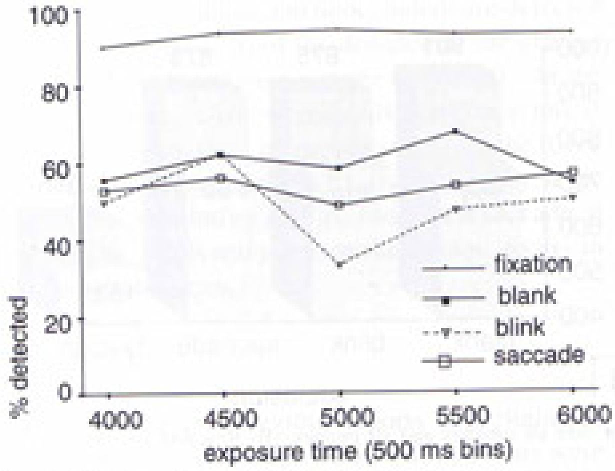

Fig. 2. Detection rate as a function of exposure time.

were not exactly matched. In order to test whether the analyses were possibly biased due to differences in exposure time, detection rate was plotted against exposure times in 500 ms bins per occlusion condition (Fig. 2).

Exposure time was measured as the time elapsed between first appearance of the original image and the initiation of the occlusion. As the figure shows, there is no systematic increase in detection rate as a function of exposure time. Analysis of variance using five bins of exposure time (4000 to 6000 ms) showed no effect of exposure time ($F = 1.076$, $df = 4$, $p = 0.369$) nor any interaction with occlusion mode ($F = 0.609$, $df = 8$, $p = 0.771$).

Occlusion type

The probabilities of detecting changes as a function of the type of occlusion are shown in Fig. 3A. Repeated measurement analysis of variance over the three occlusions showed no effect of occlusion on the detection probability ($F_{2,18} = 1.371$, $p = 0.257$). Pair-wise comparison using Bonferroni adjustment for multiple comparisons showed that the occlusion conditions only differed significantly from the (fixation) control condition (for all comparisons, $p < 0.001$).

Average reaction times were calculated from those trials in which a change was detected. Reaction times were measured as the interval between de-occlusion of the change and the button press. Fig. 3B shows the mean reaction times for each occlusion type and the control condition. The analysis of variance showed no effect of occlusion type ($F_{2,18} = 3.997$, $p = 0.116$). Pair-wise comparison showed that the differences between the occluded conditions and the fixation condition are highly significant (for all comparisons, $p < 0.001$), whereas none of the other comparisons yields significant differences.

Relevance

The probabilities of detecting relevant and irrelevant changes are shown in Fig. 4A for each occlusion condition, bar colors indicating the two levels of relevance. Relevance of change proves to have a large and significant ($F_{1,18} = 133.81$, $p < 0.001$)

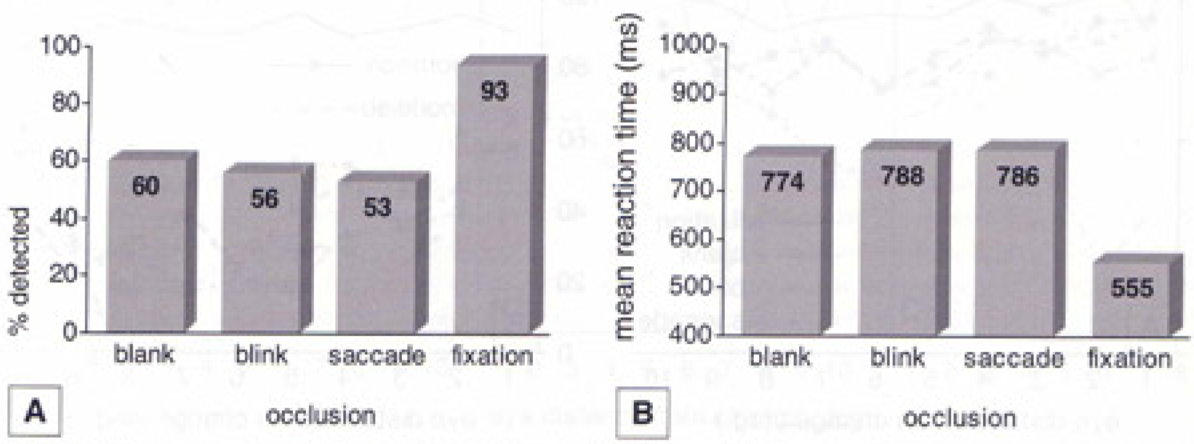

Fig. 3. (A) Mean percent detected by types of occlusion over all subjects and all images. (B) Mean reaction time by types of occlusion over all subjects and all images.

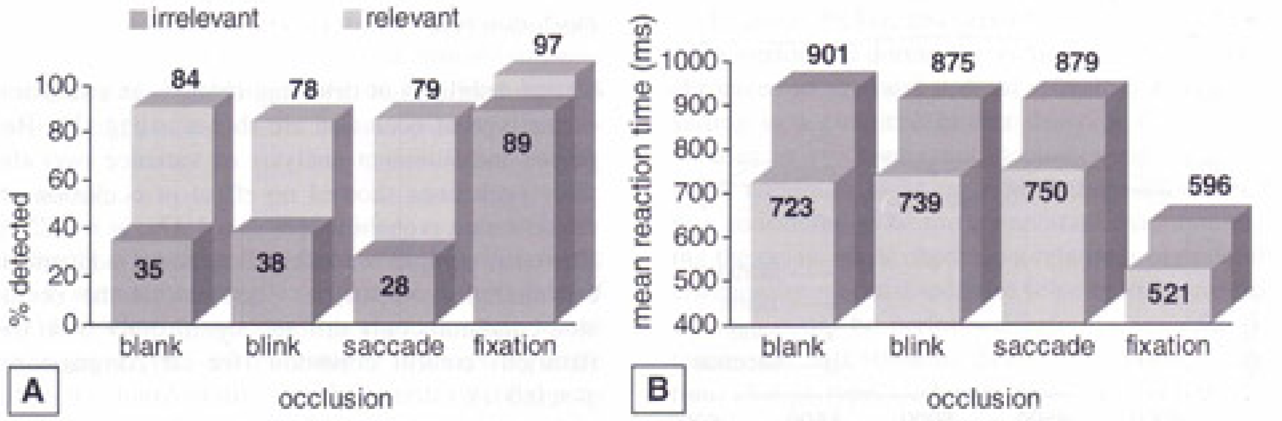

Fig. 4. (A) Mean percent detected by types of occlusion and relevance over all subjects and all images. (B) Reaction time by types of occlusion and relevance over all subjects and all images.

effect on detection rate in the expected direction. No further interactions were found.

Fig. 4B shows the estimated means of reaction times for each occlusion type, bar colors indicating the two levels of relevance. Analysis of variance showed a significant effect of relevance ($F_{1,18} = 24.22$, $p = 0.008$) on reaction time, but no further interactions.

Foveal distance

As visual acuity drops with increasing distance from the fovea, it seems reasonable to try to account for the decay of performance by a lack of visual resolution in the periphery. The distance from the fovea to the center of the change location was calculated at the moment of de-occlusion. In all cases, the average eye position during the fixation was taken as the point of reference. Fig. 5 shows the detection rate as a function of foveal distance and occlusion type, for relevant and irrelevant changes. Since the distance to change parameter was determined post hoc, the number of observations per distance category was not equal for all subjects, so a statistical analysis would contain the hazard of capitalizing on chance. There are, however, a number of stable tendencies in the data that we want to discuss.

In the first place, as can be seen in Fig. 5A, relevant

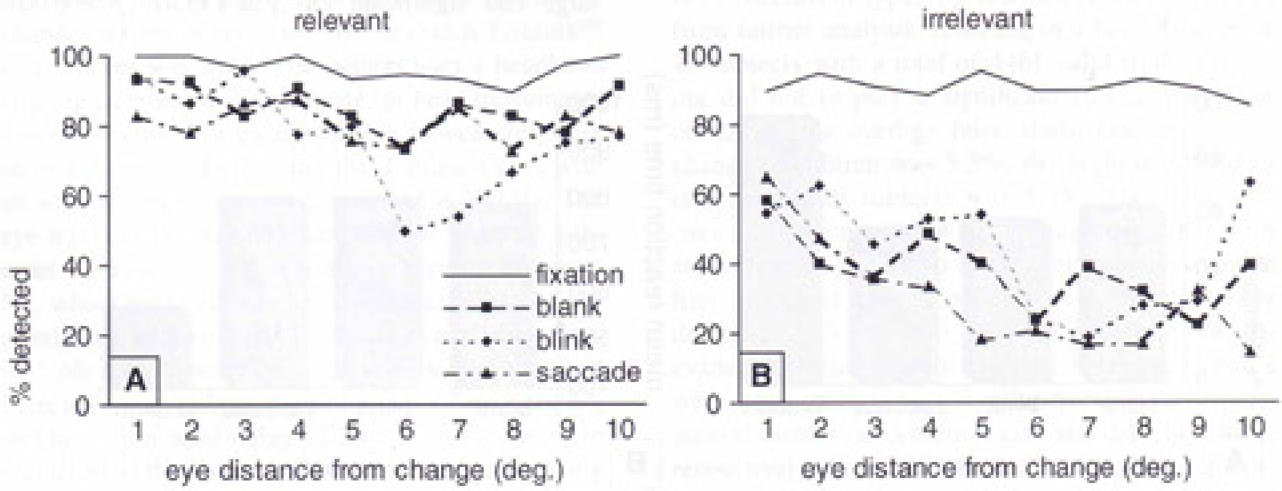

Fig. 5. Mean percent detected as a function of foveal distance and occlusion type over all subjects and all images: (A) relevant changes; (B) irrelevant changes.

changes (both occluded and unoccluded) are detected largely independent from the distance of the change location to the fovea over a range of 0 to 10°. In the case of irrelevant changes (Fig. 5B), detection rate is equally unaffected by change distance from the fovea if the change occurs during a fixation. However, if the change happens during a blink, blank or a saccade, it seems to be of advantage when the change occurs in the (para)foveal area.

Type of change

In line with several previous reports (e.g. Stelmach et al., 1984) we found that occluded insertions were detected significantly more often ($F_{1,18} = 633.22$, $p < 0.001$) and faster ($F_{1,18} = 12.94$, $p = 0.001$) than deletions (see also Velichkovsky et al., 2002). In particular we were interested to see if such differences would apply only to changes within the foveal range, or rather over the whole retinal array.

Fig. 6 clearly shows that insertions are detected considerably more often than deletions in our study. Moreover, the data also demonstrate that insertions are detected almost equally well over a large range of distances from the fovea, whereas detecting deletions gets worse as the distance between the fovea and the locus of a changing event increases.

General discussion and outlook

Blinks, blanks or saccades: it doesn't really matter

In the present study, we tested whether change blindness occurs equally often in three different situations containing a global temporary occlusion during which a change takes place. Our results show that all occlusion types have an essentially equal effect on change detection, also with respect to their interaction with other independent and dependent variables. This conclusion has an important implication for our understanding of change-blindness phenomena.

As a matter of fact, blanks, blinks and saccades represent different degrees of the subject's endogenous control over the global disruptions of visual stimulation. Recently, Shore and Klein (2000) compared a change detection study using the simultaneous inspection paradigm (a pair of photographic images presented next to each other) with a flicker study. Both paradigms showed an advantage for detection of central interest changes when the images were presented upright. When the images were inverted the advantage disappeared in the simultaneous condition — in the flicker condition, the center-of-interest effect remained intact. This difference, however, may be related to the highly specific conditions

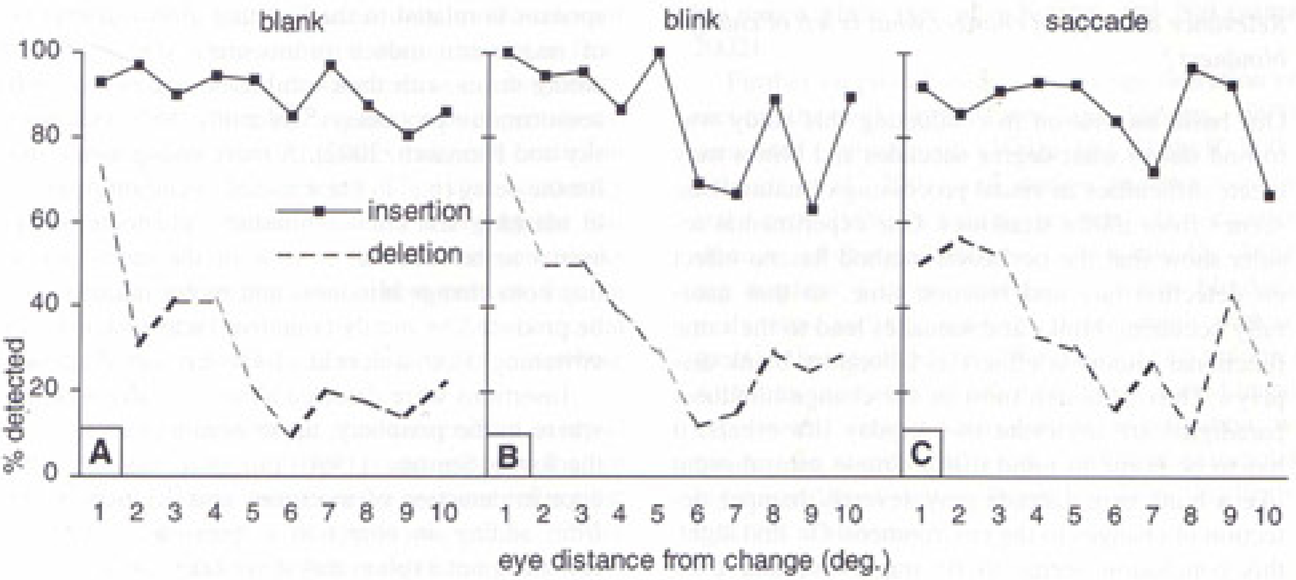

Fig. 6. Mean percent detected as a function of foveal distance and change type over all subjects and all images: (A) blank condition; (B) blink condition; (C) saccade condition.

of the flicker paradigm. We will discuss similarly deviating results obtained in dynamic presentation conditions at the end of the chapter. As Rensink (2002) points out, it is also of importance to distinguish between change and difference: a change refers to a transformation or modification of a single structure over time, whereas a difference refers to a lack of similarity in the properties of two structures. Thus detecting a difference in the simultaneous inspection study and detecting a change in the flicker study represent two different kinds of activities. In our study a single transition instead of a flicker paradigm was used and there appears to be no significant difference, neither in change detection rate nor in change detection latency, between changes occurring during endogenously induced occlusions and exogenous screen disruptions imposed on the subject. Furthermore, the difference between relevant and irrelevant changes remained the same in all occlusion settings.

Similar to O'Regan et al. (2000), we found that overall occluded changes were detected well when they took place within the foveal range. We furthermore found this to be true for blanks, blinks as well as for saccades. Beyond the foveal range — in all occlusion conditions — there was a decrease in performance for irrelevant changes. Relevant changes were almost equally likely to be detected anywhere in the visual field.

Relevance and type of change: what is left of change blindness?

Our basic motivation in conducting this study was to find out to what degree saccades and blinks may create difficulties in visual processing of naturalistic scenes from traffic situations. Our experimental results show that the occlusion method has no effect on detection rate and reaction time, so that naturally occurring blinks and saccades lead to the same functional blindness effects as laboratory blank displays. Thus, although most of the change-blindness paradigms are irrelevant to everyday life events, it has to be borne in mind that a simple natural event like a blink or a saccade may severely hamper detection of changes to the environment. On first sight, this conclusion seems to be impressive and even frightening with respect to driving, because the overall change detection rate is as low as 55%.

In line with a recent proposal "to cure change blindness" (Henderson and Hollingworth, 2002), we would prefer a more differential analysis here. First of all, the detection of relevant changes is considerably better than that of irrelevant changes, though subjects continue to miss about 20% of the changes and even when the changes are detected, reaction times are still almost 220 ms slower than when the change occurs during a fixation. Due to our traffic-related definition of relevance we want to stress that these differences may not be comparable to those found by Rensink et al. (1997) and others. The next step in the dismantling of change blindness is to consider the detection difference due to the types of change. Insertions are likely to be detected almost always. Obviously, the sudden insertion (not disappearance) of relevant objects is of particular importance in real world situations.

What is left of the change-blindness effects, however, is the exceptionally long reaction time. Despite the nearly perfect detection rate, relevant insertions were reported with a delay of approximately 180 ms in comparison to the fixation condition (Velichkovsky et al., 2002). This delay cannot be dismissed on practical reasons, i.e. with respect to road-traffic safety. Perhaps it is also of theoretical significance as the label 'ceiling effect' says nothing about underlying processing. We suspect that the contrast of a high detection rate and still rather slow motor responses is related to the fact that global disruptions of image can induce rudimentary startle and orienting states with their inhibitory consequences for sensorimotor processes (Schlenoff, 1985; Velichkovsky and Pannasch, 2002). A more endogenous cause for the delay (e.g. in the sense of re-entrant processes in masking and change-blindness phenomena) also seems to be feasible in view of the recent reports that both change blindness and motor inhibition can be produced by purely cognitive factors such as task switching (Pannasch et al., 2001; Enns et al., 2002).

Insertions were detected almost equally well anywhere in the periphery, up to distances of 10° from the fovea. Simons' (1996) proposal, that the difference in detection of insertions and deletions results from adding an object to a 'previously empty array' does not explain this if we take the 'previously empty array' literally, since in the present experiment there were hardly any previously empty arrays —

rather, objects were superimposed on an articulated background. In a more figurative sense, however, a deletion may be considered as the removal of visual information from the environment resulting in the inability to relate any stored knowledge to it, and hence as a physical implementation of inattentional amnesia as implied by Wolfe (1999b): if an object is removed from the physical environment while it is not currently attended, there is no way of retrieving any information about it from visual memory. Contrary, if an object is inserted that has neither been encoded nor discarded, then it is likely that the insertion advantage lies in its novelty, rather than in memory for features of the superimposed region. We are inclined to consider the data on insertions in the framework of current studies of expertise (in particular, Reingold et al., 2001) rather than as a manifestation of low-level ambient vision (Trevarthen, 1968) because the detection performance strongly interacts with semantic relevance of the changes across the visual field.

Change detection in dynamically changing displays

Due to the fact that we worked with static scenes the ecological validity of our results remains somewhat unclear. To provide further evidence about the extent of change blindness in road traffic, we conducted a follow-up driving simulator study (Velichkovsky et al., 2002). This time we used only traffic-relevant inserted changes that occurred during blanks or fixations. As in the present experiment, a one-shot detection paradigm was used. Against our expectations, we found systematic differences between occlusion modes. If considered in terms of a speed-accuracy trade-off, the results can be summarized by the following conclusion: as the modes of occlusion, blinks and blanks are related to the best performance in change detection, saccades to the worst, the detection in the control fixation condition is lying somewhere in-between.

What is the reason for this astonishing reversal of 'change blindness'? One could suppose that in the dynamic setting blanks serve as a cue telling the subject if not *where* then at least *when* to search for change. There is compelling evidence against such explanation, however. Firstly, false alarm rate was extremely low in blanks. Secondly and more important, the cuing hypothesis cannot explain a perfect change detection with blinks. We prefer another approach by stressing one similarity of otherwise so different blanks and blinks in one parameter: the duration of occlusion. This parameter also differentiates blinks and blanks as a whole from saccades. With their duration of about 40 ms, saccadic occlusions lead to a relatively low rate of change detection as well as slow reaction times. The question is then, what may happen on the continuum of occlusion durations from 40 to 150 ms that interact with dynamics of the situation and overturn the 'change blindness' effect? A preliminary answer can be found in research on visual motion and causality perception (Michotte, 1946/1963) that demonstrates that occlusions of about 100 ms and more disrupt the perceptual continuity of visual events, transforming them to a short static snapshot. In a static environment, global occlusions obscure the local transient caused by a change and thereby prevent attention from being attracted to it. A dynamic situation is changing constantly. In contrast to static scenes, the multitude of distracting transients (in motion fields but perhaps also in the flicker condition) makes it likely that attention is equally driven to all potential regions of change. Hence, any interruption that is sufficiently long can counteract the attentional load imposed by the flow of moving gradients and contours and thus enables subjects to see that a change has taken place (see also Kourtzi and Nakayama, 2002).

Further empirical studies on change detection errors in the real world (Levin and Simons, 1997), simulated environments (Wallis and Bülthoff, 2000; Shinoda et al., 2001) and motion pictures (Simons and Levin, 1998) can surely provide a better understanding of change blindness in dynamically changing displays. Current studies on change blindness in dynamic settings, however, differ largely with respect to their methods (e.g. Saiki, 2002, this volume). Although the nature of the effects discovered in our experiments clearly needs further investigation, we meanwhile recommend great caution in extrapolating results from static 'change blindness' studies to dynamic situations.

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