Running head: CHANGE DETECTION AND CUEING IN STEREO DEPTH

Change Detection and Spatial Cueing in Stereoscopic Depth

Sabine Salome Klois

Cognitive Psychology and Ergonomics

Faculty of Behavioral Science, University of Twente, Enschede, The Netherlands

The research for this Master Thesis was conducted at the Leibniz Research Centre for Working Environment and Human Factors (IfADo), Dortmund, Germany

Master of Science Thesis

Tutors:

Prof. Dr. Ing. W. Verwey & Dr. M. Grosjean

August 21, 2009

Abstract

Change detection plays an important role in user interface design. In light of the recent increase for 3D displays, the aim of this study was to investigate benefits of spatial cues for change detection in stereoscopic depth. To do so, a one-shot change detection task was used in which items could appear at a front or back depth plane or were shared across these two depth planes. In Experiment 1 either no cue or a spatial cue appeared, that lay on the same or different depth as the items. The no cue trials were left out in Experiment 2. The results of Experiment 1 show a replication of a study conducted by Becker, Pashler and Anstis (2000). In Experiment 1, as well as in Experiment 2 a 2D cueing effect was found, but no 3D cueing effect. The results show that simple 2D cues can guide visual attention to improve change detection in depth but not the 3D cues, used in this study.

Change Detection and Spatial Cueing in Stereoscopic Depth

Recent developments in the field of interface design − such as stereoscopic head-up displays − have heightened the need for investigations of attentional processing in 3D displays in order to avoid operator mistakes. In such displays, a great deal of rapidly changing information is displayed in depth. Still, it is unclear if such technical systems are of advantage to attentional processing in 3D space. Studies found robust shortcomings in the detection rate of change in 2D displays when the change occurred during, for example, saccades or eye-movements (for review, see Pashler, 1988; Gimmes, 1996; Rensink, 2000; Simons & Levin, 1997). Focused attention is regarded as the main factor crucial for selective perception, which highlights one important role of attention for human-machine interaction. A considerable amount of literature has been published on focused attention with change blindness/detection tasks on 2D or 2.5D displays rather than 3D displays (for reviews, see Mazza, Turatto & Umilta, 2005; Rensink, R. A., ORegan, J. K., & Clark, J., 1997). Pseudo-3D displays, often also called 2.5D displays, use different types of depth and shape information such as stereopsis, occlusion, texture and shading to allow depth perception. Therefore, 2.5D is a simplified 3D surface representation (Christou & Buelthoff, 2000) and results of studies using 2D or 2.5D cannot simply be adopted to 3D displays. It follows that an important question is to determine how change detection acts in 3D space.

Becker et al. (2000) have found that change detection in 2D displays improved with a cue, leading to the suggestion that cueing also enhances change detection in depth. The goal of the current study was to establish whether the benefit of providing spatial cues for change detection using 2D displays, based on the study conducted by Becker et al. (2000), generalizes to 3D displays. To do so, a task in which there was a one-time change during a trial was combined with a spatial cue (see Becker et al., 2000) and extended into stereoscopic depth.

Perceptual experience provides a basis for change detection and derives through the encoding of visual information. It is generally accepted that perception is an active and organized process. One underlying process of perception is known as *focused attention*, defined as actively processing a limited amount of information and has been likened to a form of spotlight within the field of view. It is responsible for the selection of visual representations of the external world (Fernandez-Duque & Thornton, 2000; Rensink, 2000). Furthermore, when humans look at their environment, their visual system builds short-lived visual representations that are abstract, incomplete and often implicit (Rensink, 2000; Mazza et al., 2005; Rensink, 2002; Simons, 2000). Because of the limited perceptual experience of the external world, it often happens that a person fails to detect changes, when he/she is viewing a visual scene. Rensink (2002; Rensink et al., 1997) provides two alternative hypotheses about the role of focused attention for change detection. First, he hypothesizes that the attentional capacity is limited in the amount of information that can be brought into focus. Second, he suggests that attention limits the comparison of complex visual representations. However, he states that the assumption of limited mental resources is no complete explanation, due to a central bottleneck during the comparison of two pictures. Furthermore, change blindness can even appear when participants know a change will occur and hence, when searching for that change.

Recent studies have demonstrated that this robust *change blindness* phenomenon, which is the failure to detect large changes in highly loaded scenes, results from visual disruptions within the field of view or from a limited time to scan a complex scene in detail (Rensink et al., 1997; Rensink, 2000; Landman, Spekreijse, & Lamme, 2003).

An illustrative example comes from a real world study by Levin and Simons (1997) in which they asked people to look a video. The results show that 70% of the naive participants did not recognize that one actor changed into another one because of a visual cut during the video. This illustrates the robustness of change blindness and its real world importance (it is not just an experimental artifact; Simons, 2000). Apparently, the cut (or interval) during the video, as saccades and eye-blinks in real world, caused change blindness.

Therefore, as has been shown by Simons (2000), only attending to a scene does not guarantee a complete representation of all items that are present. According to Simons (2000) attention is necessary, but not sufficient, for detecting changes. What is seen corresponds to how the world is perceived: The task that is carried out, peoples' intentions, and the respective situations they are in (Rensink, 2002). In addition, the position of a changing aspect, its relevance and meaningfulness in a scene influences change detection, as well as task specific properties such as, motion signals, color, shape, and size of items, all enhance change detection if one of the properties captures attention and is part of the change (Rensink et al., 1997; Rensink, 2002). This suggests that change blindness just as change detection is linked to many factors.

There are several controversial ideas about the underlying mechanisms that have been proposed to account for change blindness: First impressions bias what is seen, no visual information is actually stored, everything is stored but not compared, feature combinations or participants are not able to separate between two successive scenes (for review, see Simons, 2000). Another possibility is that participants do not have enough conscious access to the representations in visual short-term memory (vSTM), which leads to "overwriting" by the post-change display, without the change even being noticed (Simons, 2000; Landman et al., 2003). Sperling (1960) introduced the term iconic memory, which is currently referred to as vSTM. vSTM is the pre-attentive representation of a visual image and appears to have an influence on the detection of change. In line with this, Becker et al. (2000) regarded attention and iconic memory as important theoretical components. In particular, they suggest that attention facilitates conscious awareness, which prevents overwriting. Although several studies (e.g., Rensink et al., 1997; Landman et al., 2005) have discussed the role of mental resources during change detection, there are still disagreements about the underlying mechanisms responsible for change blindness.

In spite of that, it is certain that attention is limited but necessary to detect changes in a visual scene. Numerous studies have shown that visual cueing enabled participants to use the attentional barrier optimal (e.g. Posner, Snyder & Davidson, 1980; Becker et al., 2000). They found that a cue enhanced attentional processing at the cued (attended) location and improved change detection. The purpose of the cue is, for example, to cue the participant to salient information and to let him/her screen out irrelevant information, depending on the task. In such experiments, change detection performance increased when the cue appeared at, or pointed to, the location of change. Since the resources of attention are limited, it is hypothesized that the cue helps to allocate attention to the change location, which causes the benefits in performance. Scholl (2000) performed an experiment to show that when attention is exogenously cued to the region of change detection improved.

Only a limited number of studies have examined attention in 3D space. Theeuwes, Atchley and Kramer (1998) investigated cueing of attention in 3D space through binocular disparity. Their results indicate that it is possible to direct attention to a particular depth plane. However, according to Theeuwes et al. (1998), depth should be regarded as simply another feature of an object. Marrara and Moore (2000) agreed that attention can be allocated in depth, but the results of their experiments indicated also that the perceptual organization of the display, for example color and closure, plays an important role. In addition, the participant must have sufficient time to extract the depth information (Marrara & Moore, 2000).

The most important implication of these results with regard to the present study is that focused attention, which is necessary for change detection, can be allocated in 3D space. It is hypothesized that change detection will increase with 2D cues in depth.

Furthermore, benefits of 2D cues can be increased upon with a depth specific 3D cue. If attention was focused always on a particular plane, then the cost for switching attention, should be greater in a display in which the items are distributed over a front-depth plane and a back-depth plane.

Experiment 1

An important issue concerning change detection in space is the nature of the task. Most of the change blindness studies cited thus far, used an inter-stimulus interval (ISI), as a visual disruption, to induce blindness. Furthermore, they combined a one-shot change detection paradigm with this interruption to induce change blindness and to examine the limitations of attention in 2D space (for a reviews, see Rensink et al., 1997). This task involved presenting two displays interrupted by a ISI. One trial, of the one-shot change detection task, consists of a first display presenting the items, often followed by a blank display and a final display that contains the change. Therefore, change is displayed only once during each trial.

The impression of a motion which can occur during the change, is advantageous during change detection, because it triggers attention and is an additional cue for localization. To avoid the impression of a motion during the task, as it is often the case in real world situation because of saccades, a relatively long ISI was used that disrupted the perception of motion (Rensink et al., 1997). A spatial cue was used that highlighted a possible changing rectangle and its position in depth. Furthermore, the participants expected a change so that all available resources were devoted to detecting that change.

Becker et al. (2000) combined the one-shot change detection task with cueing (e.g., Posner et al., 1980). This experiment showed that change detection in 2D space improved with the presentation of a spatial cue that pointed to a potential change location. Experiment 1 is geared to the design used by Becker et al. (2000) and therefore the one-shot change detection task was applied and combined with a spatial cue.

It was predicted that spatial cueing improves change detection, in comparison with trials without a cue. The cues were always 2D valid, which means that they always pointed towards the target item. The position of the cue in depth was either 3D valid or 3D invalid. Valid 3D cues were located at the same depth as the target item. By contrast, invalid 3D cues were located at a different depth than the target item. Items were presented at the same depth in the foreground or in the background, or were shared across these two depth locations (mixed-depth). The front-depth and back-depth display types provide a basis for a replication. Of special interest are the mixed-depth displays. If attention was focused always on a particular plane, then the cost for switching attention, should be the greatest in this display type. It was hypothesized that change detection performance should benefit from 3D valid cues over 3D invalid cues, because switching attention from one depth plane to the other should affect change detection adversely.

Method

Participants. Twenty-four young adults (mean age = 23.3 years; 19 female, 5 male) from the Dortmund community participated in this experiment. All of these participants were paid volunteers or received course credits for their participation. They had normal or corrected to normal vision, and reported that they had no color vision deficiencies and that they did not play computer games. The participants provided their informed written consent to the study and were unfamiliar with the purpose of the experiment. Four additional participants were excluded: Two participants did not meet the criterion in a customized stereovision screening test and two did not follow instructions, as will be discussed below.

Apparatus. The experiment was conducted in dim ambient light (18.5 cd/m^2). Stimuli were presented on an IBM compatible PC with a 21 inch color CRT monitor (refresh rate = 120 Hz) at a spatial resolution of 1024 x 768 pixels. A Quadro FX 3000 graphics card (NVIDIA Inc., Santa Clara, CA) and a CrystalEyes 3 stereo display system (StereoGraphics Inc., San Rafael, CA) were used to present separate left and right eye images through liquid-crystal shutter glasses to simulate depth. This system was synchronized with the monitor at 60 Hz per eye for presentation rate. Custom software written in C/C++ using OpenGL displayed the stimuli on the screen while recording the test data. A chin rest and head rest set the viewing distance of the participants at 52 cm. Responses were given on a custom-made button box.

Task. A one-shot change detection task was employed. This included presenting eight rectangles with different orientations as well as a spatial cue in some trials in order to indicate the target rectangle. The items and the cue were distributed in depth. The participants were asked to provide an unspeeded *yes* or *no* response as to whether a change occurred in the orientation of one rectangle. This answer was given by pressing one of two different keys on a custom-made button box. Furthermore, participants were instructed to pay attention to all rectangles; if a spatial cue was presented, they were to try to use the cue by attending to the target rectangle the cue was pointing at.

Stimuli. As can be seen in Figure 1 (frontal view), the displays consisted of eight dark grey (8.0 cd/m^2) rectangles (height $\times$ width: 1.65° $\times$ 0.61°), which were placed in circular form with an imaginary radius of on an average 4.02° around a central light grey fixation dot (0.22° in diameter; 72.5 cd/m^2) on a dark background (0.2 cd/m^2). Relative to the fixation dot, the rectangles were all presented in the foreground (front-display type), all in the background (back-display type) or were mixed (mixed-display type), distributed in a rotary shape between the foreground and background as depicted in Figure 2.

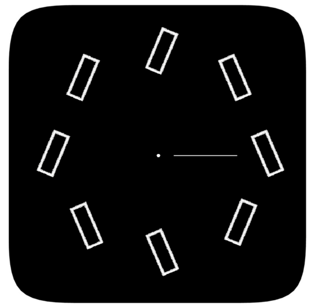

Figure 1. Example of a frontal view with a cue.

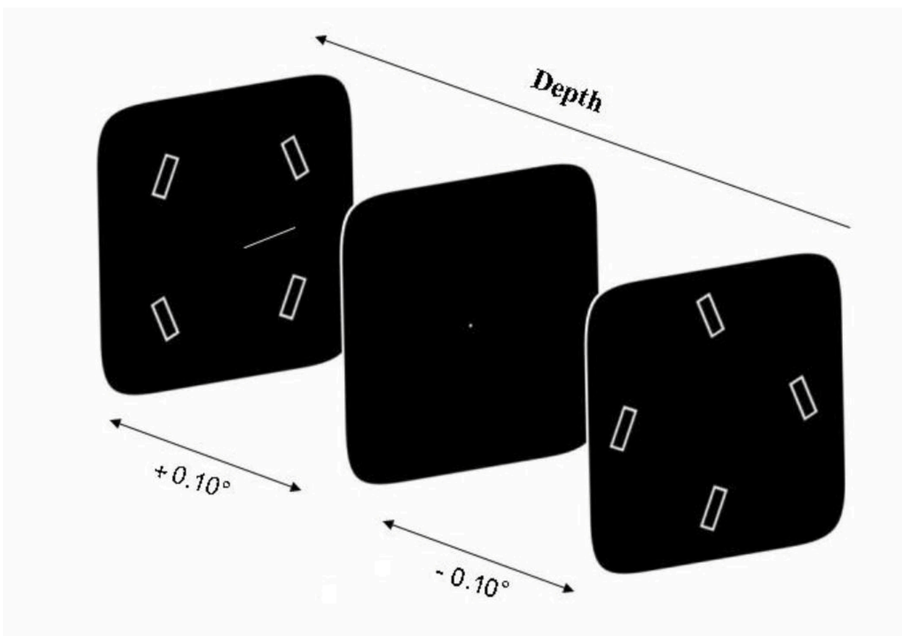

Figure 2. Illustration of a mixed-depth display used both experiments. Objects are shared across the two planes in depth. The 3D invalid cue is presented on the back-depth plane pointing at the 2D location of the relevant rectangle in the front-depth plane.

The cue appeared on the front-depth plane or back-depth plane. Dependent on the position of the cue in depth, it was either 3D valid or 3D invalid, but always 2D valid and hence, pointing at the target rectangle. The 3D validity is the relationship between the location of the cue and the location of the changing rectangle. A 3D valid cue lies at the same depth as the changing rectangle and 3D invalid cue appears on the other depth plane than the change. The same is true for the mixed-display type. Display type, cue validity and presence of a change were mixed within blocks of trials.

Every second item was presented on the front-depth and back-depth plane. The crossed disparity of -0.10° was used for presenting stimuli on the front-depth plane, and the uncrossed disparity of +0.10° was used for the stimuli on the back-depth plane. The stimuli were titled relative to the vertical axis by ±5° and randomly presented in the two different orientations. All rectangles differed only with respect to their orientations and positions in depth. Jittering the distance of each rectangle randomly between 4.41° (max.) and 3.64° (min.) towards or away from the center of the circle avoided figural configuration advantages, such as circular grouping, which can appear on the basis of perceptual grouping principles (Gestalt principles; Spelke, 1990). The cue indicating the relevant rectangle was a dark grey line (8.0 cd/m^2; 1.73° × 0.11°) with a distance of 1.65° from the fixation dot.

Design. Three pilot experiments were conducted to determine the level of the difficulty of the task. A 3 (display type: front-depth, back-depth, mixed-depth) × 3 (cue validity: 3D valid, 3D invalid, no cue) × 2 (change: yes, no) × 2 (change orientation: +5° to -5°, -5° to +5°) within-subjects design was used. The location of change (front vs. back) was also manipulated and balanced in the mixed-depth displays, which resulted in twice as many mixed display types as front-depth and back-depth display types.

Procedure. Each session was split into two phases with the participants first undergoing a screening. Passing this allowed participation in the experiment. The goal of the screening was to deselect participants who did not have sufficient visual acuity and/or were unable to perceive depth through binocular disparity.

In the screening phase, participants were administered a standardized Landolt ring test to determine their visual acuity. The criterion was set for 80% (visual acuity) at a distance of 4 m. After setting up a comfortable posture for the participant in the chin rest and head rest, with the view directed towards the screen, the same test for visual acuity was conducted at 52 cm. Furthermore, participants had to pass the TNO screening test which measures stereoacuity for (para)foveal vision. The participants had to achieve a reference criterion of $\leq$ 120 arc sec, which is a good predictor of normal stereovision (mean stereoacuity = 60 arc sec; see e.g. Walraven & Janzen, 1983). This test determined the ability of the participant to perceive depth on the basis of binocular disparity. Each participant then had to complete and pass a custom stereovision test under the same conditions as in the experiment in order to ensure that the participant has depth perception and to familiarize the participant with the stimuli. The participants received written instructions and the test involved mixed-depth displays. Four rectangles in one depth plane were red. The four rectangles in the other depth plane were green. The coloring of the items, which were distributed in depth, was random. Participants had to verbally report the depth plane at which the green items were presented as accurately as possible and without time pressure. The experimenter coded the participants response on the keyboard. The participants then completed two blocks with 32 trials each. The items were presented for 20 s in the first block and for only 500 ms in the second block in order to minimize eye movements and better approximate the experimental conditions. The first block and the first five trials of the second block were considered practice and not included in the actual analysis. The criterion performance was set at 90% accuracy.

In the experimental phase, the participants who passed the screening procedure received written instructions that were further clarified via oral explanation. The instructor informed the participants about the layout of the displays, about the rectangles in different orientations, but not about the distribution of the items and the cue in depth. The participants' task was to detect whether one of the eight rectangles changed its orientation between the two displays by pressing one of two buttons located on a custom-made response box. They were instructed to give a response with the index finger of their right hand if they detected a change. If there was no change, they were instructed to press the left button with the index finger on their left hand. The instructions emphasized that the participant should concentrate on the orientation of each single rectangle and once a cue appeared, they were to concentrate on the orientation of the cued rectangle. However, it was emphasized that the presence of a cue does not necessarily mean that a change would occur and trials without a cue could also include a rectangle that changed.

Each participant completed 14 blocks, each consisting of 48 trials presented in a pseudo-random order (total = 672 trials). That is, 168 trials for the front display type, 168 trials for the back display type and 336 trials for the mixed-depth display type. The experiment had a total duration of 90 min. The first block served as a practice and the data from this block was not included in the analyses. Fifty percent of all trials were cue trials, and a change occurred on 50% of the trials.

First, the fixation point appeared alone for 1000 ms. Then, the rectangles appeared for 250 ms in the first display (see Figure 3). After the rectangles of the first display disappeared, the fixation point remained in the second display for 250 ms. A spatial cue appeared during this ISI in 50% of the trials. In the third display, the rectangles of the first display were presented with one rectangle that changed in 50% of the trials. If a spatial cue appeared during the ISI, the rectangle that changed in the second display was the one the cue was pointing at. This display remained on the screen until the participant gave a response. If the participant pressed the wrong button, the word “error” was presented; if an anticipation occurred, the word “too early” was presented for 1 s (all messages were in German). The next trial began, regardless of which response was given, after an inter-trial interval of 1 s with the presentation of the fixation point. Each block was split up into two parts; after 24 trials, a rest period of 10 s was given to the participants. Furthermore, after each block, the participants had a break of at least 15 s. The participants performed one practice block (48 trials) to familiarize themselves with the task.

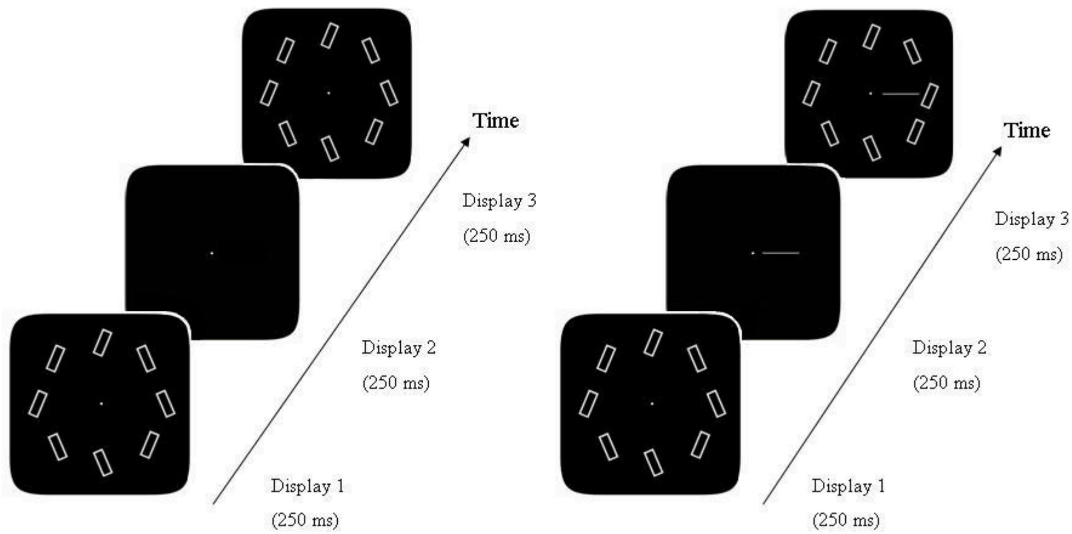

Figure 3. Illustration of the basic trial sequence. The *left* sequence depicts a no-change and no-cue trial used in Experiment 1. The *right* sequence illustrates a change and cue trial used in both experiments.

Half-way through the experiment, the experimenter came in to ask if there were any problems, for example with the shutter eye-glasses. At the end of the experiment, half of the participants filled out a follow-up survey. The aim of this questionnaire was to gather information about the motivation of the participants to perform the task and to determine to what extent they followed the instructions or whether they had developed new strategies during the task. Non-compliance with instructions by using other strategies was an exclusion criterion for the data in a further analysis. In particular, two participants reported that they did not make use of the cue. Despite being informed about the importance of the cue, they stated that they developed a new strategy in which they focused on the whole as one picture and they deliberately ignored the cue.

Data Analysis. A signal detection theoretic analysis, including the sensitivity parameter d' and response bias (c) was applied to assess that differences in performance were due to perceptual processes rather than decision-making processes. Following Macmillan and Creelman (1991), d' was defined as d' = z(hit) - z(false alarm) and response bias as c = -0.5[z(hit) + z(false alarm)]. A d' of 0 indicates the inability to distinguish signals from noise. For the statistical analysis, α was set to .05. For the ANOVAs, violations of the sphericity assumption were corrected for using the Greenhouse-Geisser ϵ.

Results and Discussion

The mean accuracy for the remaining 20 participants was 100% in the custom stereovision test. Figure 4 depicts change detection performance as a function of cue type and display type. The overall change detection performance in cue trials is higher than in no-cue trials. A 3 (cue type: 3D valid, 3D invalid, no cue) $\times$ 3 (display type: front-depth, back-depth, mixed-depth) repeated-measures ANOVA on the d' values was conducted. The ANOVA revealed a significant main effect of cue type, $F(2, 38) = 5.42$, p < .05, $\eta_p^2 =$ 0.22. Neither the effect of display type, $F(2, 38) = 0.23$, $p = .79$, $\eta_p^2 = 0.01$, nor the interaction between cue type and display type, $F(4, 76) = 1.35$, $p = .26$, $\eta_p^2 = 0.07$, were significant. Pairwise comparisons indicated that the significant main effect of cue type reflected significant differences ($p < .05$) between 3D valid cue trials (M = 0.94) and no-cue trials (M = 0.67) as well as between 3D invalid-cue trials (M = 0.87) and no-cue trials. However, d' scores in 3D valid cue trials did not significantly differ from d' scores in 3D invalid cue trials ($p = 1.00$).

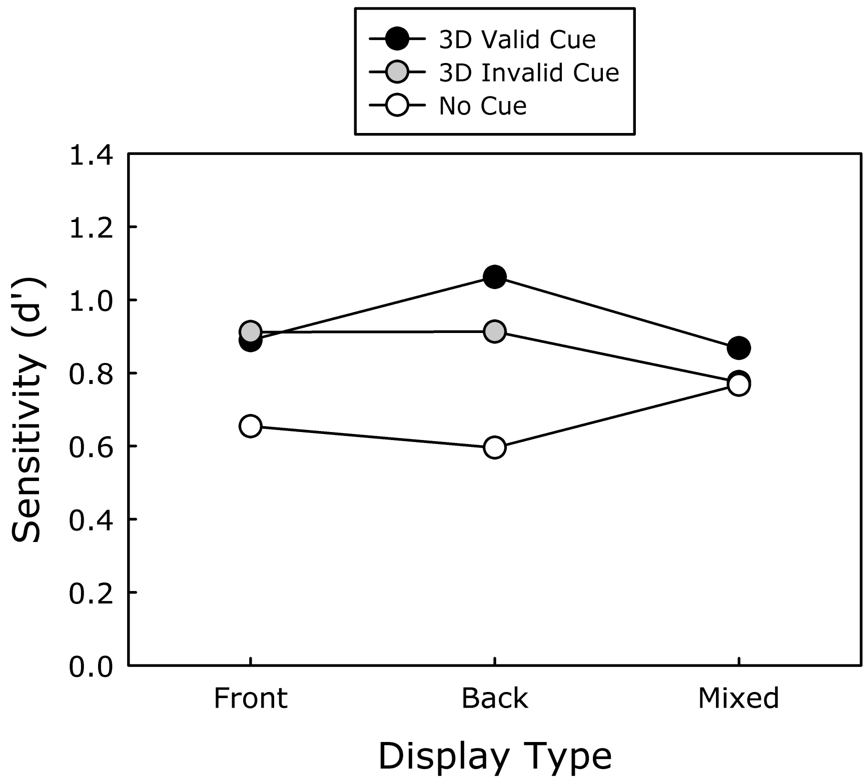

Figure 4. Mean sensitivity (d') shown as a function of display type (front, back, mixed) and cue validity (3D valid cue, 3D invalid cue, no cue) in Experiment 1.

The overall mean d' scores for the front−depth trials, back-depth trials and mixed-depth trials were separately compared against $d' = 0$. The two-tailed t tests on these values revealed that the d' scores for all conditions significantly differed from 0 (all $t(19)$s > 5.40, all ps $< .01$), which indicates that the perceptual system could distinguish signal from noise in this experiment (see Macmillan & Creelman, 1991).

The results indicated higher change detection rates in cue trials in contrast to no-cue trials. Thus, the results replicated those of Becker et al. (2000), confirming the increased change detection performance by the presentation of a 2D cue, which is also consistent with the usual findings in cueing tasks (Posner et al., 1980). Although the overall pattern indicates that using the 2D information provided by the cue improved performance, the data did not show that the participants selectively shifted attention in depth because no reliable difference in change detection performance between 3D valid and 3D invalid cue trials was found. Therefore, there was no evidence that the position of the items and the cue in depth constrained the detection accuracy of the participant.

The trials containing all items on the same depth plane were used to replicate the study conducted by Becker et al. (2000), but the mixed display type trials were of special interest for the present research. Performance on these trials should indicate whether participants allocated attention to a specific depth plane and then switched their attention because of a 3D invalid cue. The cost of switching should be reflected in lower change detection rates. However, a 3 (cue type: 3D valid, 3D invalid, no cue) $\times$ 2 (change location: front, back) ANOVA on the d' values for mixed-depth trials showed no significant main effect of cue type, change location nor an interaction between these factors (all ps$>$ .05).

Figure 5 illustrates the specific pattern of liberal (yes) responses relating to cue trials. It is suggested that the participants used strategies in which the no-cue trials were preferred because of the perceptual organization of the display, as will be discussed later.

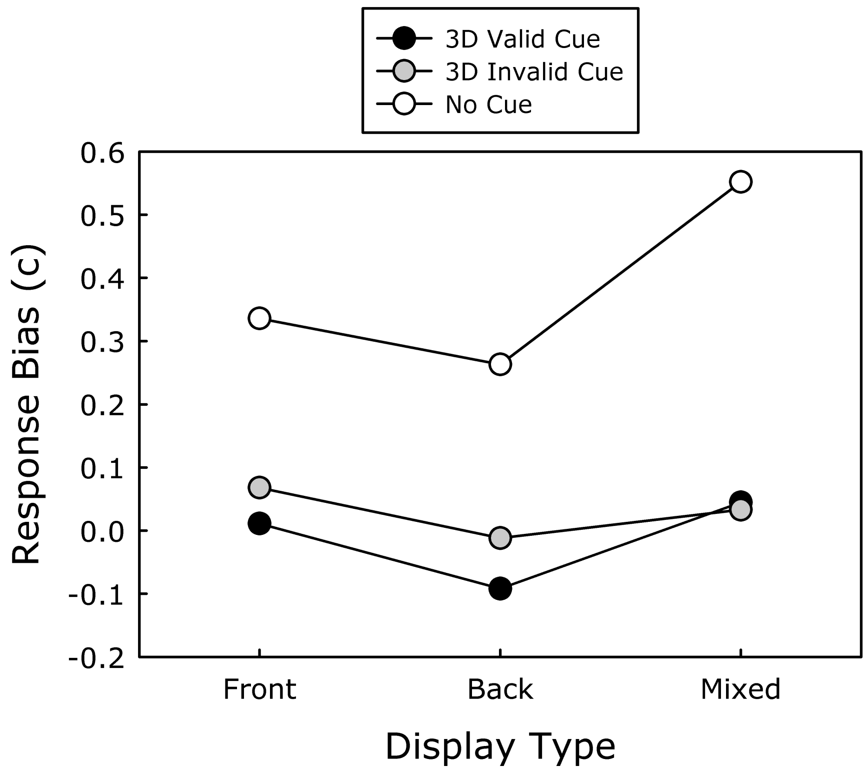

Figure 5. Mean response bias (c) shown as a function of display type (front, back, mixed) and cue type (3D valid cue, 3D invalid cue, no cue) in Experiment 1.

The response bias (c) was analyzed with the same initial ANOVA as the d' values. The results indicated that participants response biases were significantly influenced by cue type, $F(2, 38) = 5.37$, p $<$ .05, $\eta_p^2 = 0.22$, $\epsilon = 0.57$. Participants tended to give a more liberal "yes" response in cue trials than in no-cue trials (3D valid: M = -0.12, 3D invalid: M = 0.30, no cue: M = 0.38). The significant main effect of display type, $F(2, 38) = 6.22$, p $<$ .05, $\eta_p^2 = 0.25$, indicates more conservative responses in mixed trials (M = .21) and more liberal responses in back-depth trials (M = .053). The interaction between cue type and display type, $F(4, 76) = 2.49$, $p = .05$, $\eta_p^2 = 0.12$, was not significant.

The data shows strong evidence of a 2D cueing effect. The detection of change in the one-shot change detection task in depth improved with the presentation of a 2D valid cue. The replication of the task conducted by Becker et al. (2000) was successful.

However, differences in the cueing effect were far less than would have been expected if the participants had allocated their attention to a particular depth and then switched their attention between the depth planes in the 3D invalid cue trials in order to detect a change. Had it been the case that the participants switched attention between depths, then the change detection rate in 3D valid cue trials would have been better than the change detection rate in 3D invalid cue trials. This hypothesis was not confirmed by the analyses. As already discussed, participants had to fill out a questionnaire. Notable are the participants' statements that using the cue led to discomfort and that they felt that the presentation of the cue was distracting and thus might be causing more errors indicated by a more liberal response than in no-cue trials. The more liberal responses in cue trials gives evidence for a strategic assumptions. It seems as if participants regarded the presentation of a cue as a change.

No statistics were gathered for the mean reaction time because the participants were asked to provide an unspeeded response as to whether a change occurred. However, indications for a speed accuracy trade off between cue and no-cue trials would have supported the strategic assumptions.

In summary, spatial cueing improved performance during the one-shot change detection task in depth, but the difference in performance between the 3D valid and 3D invalid cues was far less than would have been expected if the participant was required to switch attention between the depths.

Experiment 2

The questionnaire in Experiment 1 was designed to assess the participants' subjective motivation towards using the cue and to determine strategies of the participant that could influence the results. It is possible that the participants learned to regard all the positions of the rectangles as a whole picture, according to the Gestalt principle of closure (e.g., Spelke, 1990). This led to the assumption that the cue trials (in comparison to the no-cue trials) distracted this perception the participants and therefore, participants were hesitant to respond. As mentioned, it seems as if the no-cue trials made it easier for the participants to regard the eight rectangles as a Gestalt and that this perception was destroyed in cue trials. Based on the results of the questionnaire, it can be assumed that the participants were less inclined to use the cue, because they thought ignoring the cue would make it easier to compare the two displays. If participants mixed strategies in which they used and did not use the cue because of perceptual advantages when masking the cue, then the data is noisy and the effect of the different cues cannot rightly be observed. It cannot be ruled out that the participants did not use the cue as frequently as possible.

Experiment 2 consisted of just cue trials to exclude the possibility that the participants learn to regard the displays as Gestalts because of the perceptual organization of the items. Therefore, excluding the no-cue trials should enhance the usage of the cue and help prevent participants from engaging in using other strategies. The results of Experiment 1 show that the participants were able to use the 2D information of the cues, which was indicated by an increased performance in cue trials. If the participants learn to use the cue more efficiently and consistent, a significant difference between the 3D valid cue and 3D invalid cue conditions is expected because of disadvantages in the attentional shifts. On the other hand, if no attentional shift is required in order to solve the task, again no effect of cue validity will be found.

Method

The method was the same as in Experiment 1, except for the following differences. Thirteen young adults (mean age = 23.8 years; 9 female, 4 male) participated in this experiment and were volunteers from the Dortmund community. Two additional participants were excluded as will be discussed later. The design was basically the same as that in Experiment 1, except that the no-cue trials were removed. A 3 (display type: front-depth, back-depth, mixed-depth) $\times$ 2 (cue validity: 3D valid, 3D invalid) $\times$ 2 (change: yes, no) $\times$ 2 (change orientation) within-subjects design was used. Each block consisted of 32 trials and the participants completed 14 blocks (total = 448 trials). In total, 112 trials with front-depth as display type, 112 trials with back-depth display and 224 trials with no-change displays. The experiment lasted a total of 60 min. The participants had a mean stereoacuity of 60 arc sec.

Results and Discussion

The mean accuracy for the eleven participants was 100% in the custom stereovision test. One additional observer did not meet the criterion in this test. The data from another additional participant was excluded from further analysis because the overall mean d' of 0.1 indicated that the participant was not able to discriminate change trials from non-change trials in this task.

As shown in Figure 6, it seems that change detection performance did not vary with the validity of the cue. A 2 (cue type: 3D valid cue, 3D invalid cue) $\times$ 3 (display type: front-depth, back-depth, mixed-depth) repeated-measures ANOVA on the d' values was conducted. The ANOVA revealed no significant main effects of cue type, $F(1, 10) = 0.87$, $p = .37$, $\eta_p^2 = 0.08$, $\epsilon = 1.00$, or display type, $F(2, 20) = 0.32$, $p = .73$, $\eta_p^2 = 0.03$. The interaction between cue type and display type was not significant either, $F(2, 20) = 0.51$, $p = .61$, $\eta_p^2 = 0.05$.

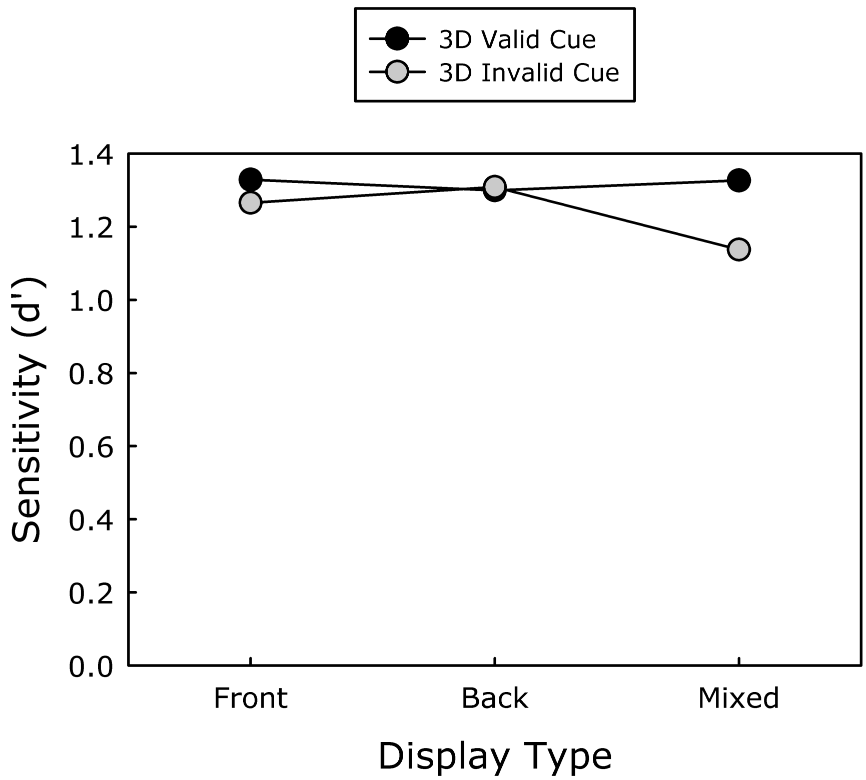

Figure 6. Mean sensitivity (d') shown as a function of display type (front, back, mixed) and cue validity (3D valid cue, 3D invalid cue) in Experiment 2.

The overall mean d' scores for the front-depth trials, back-depth trials and mixed-depth trials were separately compared against $d' = 0$ with separate t tests to control for above chance responses. The results showed that the d' scores for all conditions were significantly greater than 0 (all $t(10)$s > 7.31, all ps $< .01$). Therefore, the perceptual system distinguished signals from noise in this task (see Macmillan & Creelman, 1991).

A separate 2 (cue type: 3D valid, 3D invalid) $\times$ 2 (change location: front, back) ANOVA on the d' values of the mixed-depth trials did not indicate any significant main effect of the independent variables cue type and display type, nor an interaction between cue type and change location (all ps $> .05$).

Figure 7 depicts the response bias (c) results. Response bias was analyzed with a 2 (cue type: 3D valid cue, 3D invalid cue) × 3 (display type: front-depth, back-depth, mixed-depth) repeated-measures ANOVA. Results indicated that participants' response bias did not significantly differ between 3D valid and 3D invalid cue trials, $F(1, 10) = 0.07$, $p = .80$, $\eta_p^2 = 0.01$. No significant main effect of display type, $F(2, 20) = 1.55$, $p = .24$, $\eta_p^2 = .13$, nor an interaction between the cue and display types, $F(2, 20) = 0.22$, $p = .81$, $\eta_p^2 = 0.02$, were found. The participants were biased towards liberal responses (overall mean $c = 0.15$) in Experiment 2.

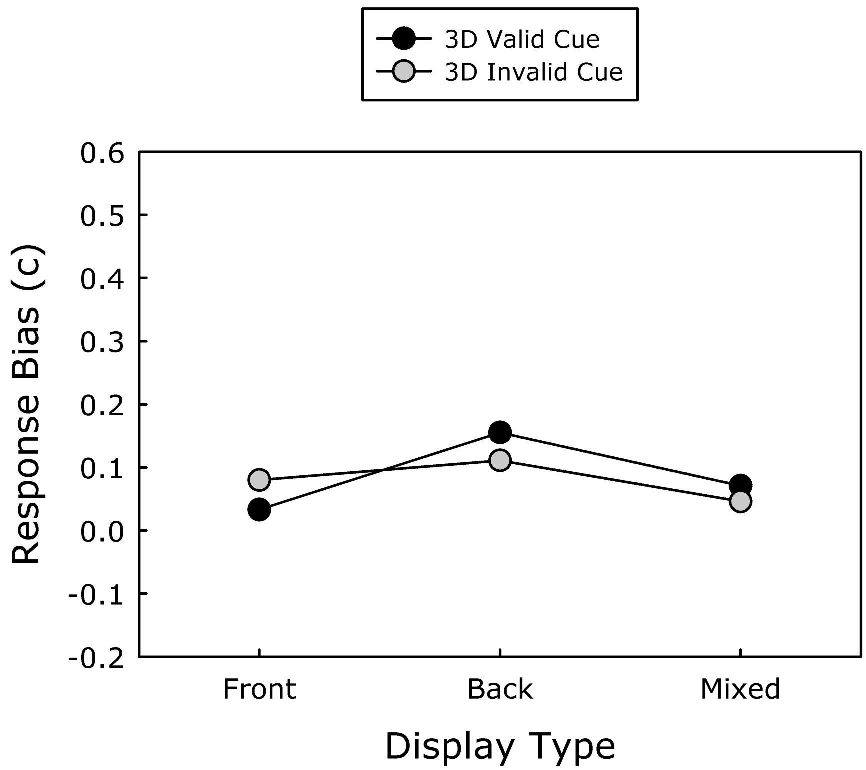

Figure 7. Mean response bias (c) as a function of display type (front, back, mixed) and cue type (3D valid, 3D invalid) in Experiment 2.

Figure 7 compared with Figure 5 shows a higher change detection performance in Experiment 2. A 2 (cue type: 3D valid cue, 3D invalid cue) × 2 (display type: front-depth, back-depth, mixed-depth) mixed design ANOVA with experiment (Experiment 1, Experiment 2) as a between-subjects factor revealed significant differences between the experiments, $F(1,\ 29) = 7.99$, $p < .05$, $\eta_p^2 = 0.22$. The sensitivity d' in Experiment 2 (M = 1.28) was higher in comparison with Experiment 1 (M = 0.90). This results are in line with the assumption that participants did not used the cue as effective as in Experiment 2 without no-cue trials. However, caution must be applied when taking the small sample size in Experiment 2 and the individual differences in consideration, because the findings might not be robust.

In contrast to the expectations, the results did not show the expected differences between 3D valid and 3D invalid cue trials despite the absence of no-cue trials in Experiment 2. It was assumed that the design of Experiment 2 would encourage the participants to use the cue more efficiently than in Experiment 1. However, no differences in performance between 3D valid and 3D invalid cues were found. Therefore, it cannot be proven that the participants selectively shifted attention between specific locations in depth. Worth mentioning is the difference between Experiment 1 and Experiment 2. Without no-cue trial the change detection performance increased, which is in line with the strategic assumptions that were produced through the no-cue trials in Experiment 1.

General Discussion

This study has examined change detection and cueing in stereoscopic depth. Prior studies have observed cueing effects in change detection tasks with 2D displays (see, Becker et al., 2000; Landman et al., 2003). This effect is attributed to a specific orientation of attention to an object with the aid of a spatial cue (Posner et al., 1980). To our knowledge, there are no empirical studies investigating attentional shifts in depth during change blindness studies combined with spatial cueing. Therefore, the question of the present study was whether the 3D valid cue, compared with the 3D invalid one, improved change detection performance in stereoscopic depth. All cues were 2D valid, thus always pointing at the relevant item. Cues that were 3D valid were located at the same depth as the changing stimulus, in contrast to 3D invalid cues, which were located at a different depth. A one-shot change detection task in 3D space was combined with 3D valid, 3D invalid and no-cue trials in Experiment 1.

The significant differences between cue trials and no-cue trials in Experiment 1 confirmed that the 2D information of the cues improved the change detection rate of participants when compared with no-cue trials in depth. These results are in line with the general results of cueing tasks (Posner et al., 1980; Becker et al., 2005) and indicate a successful replication of the study performed by Becker et al. (2005).

A remaining hypothesis for Experiment 1 resulted from the results of a study conducted by Han et al. (2005), in which 2.5D displays were used. It was assumed that shifts of spatial attention in 3D invalid cue trials would affect change detection adversely because visual attention is limited and can only be allocated to one location at a time (Posner et al., 1980). Consequently, it was expected that a 3D valid cue would enhance performance compared with 3D invalid cues. Contrary to expectations, the present study did not reveal a significant difference between the 3D valid and 3D invalid cue trials. Thus, there is no evidence that the location of a cue in space relative to a change influences the change detection rate.

Even if the assumption that 3D invalid cues in depth are less distracting than assumed is plausible, there are several alternative explanations for this result. One important consideration concerns the potential distortion of results.

A first possibility is that participants' strategies influenced the change detection rate. Based on the results of the questionnaire and the mean response bias in cue trials compared with no-cue trials, it became apparent that participants used strategies during the first experiment which may have resulted in a distortion of the effects of 3D valid and 3D invalid cues. In order to rule out possible strategies, as the perception of a Gestalt (Spelke, 1990) during the task, Experiment 2 was conducted. It was assumed that excluding the no-cue trials would enhance the usage of the cue and help prevent participants from engaging in using other strategies. Experiment 2 provided evidence against the alternative explanation that strategies were used because even without no-cue trials, no difference between the depth specific cues were found.

Second, it is possible that the context acted as a confounding variable, because location of change was correlated with display type (contextual cueing; Chun & Jiang, 1998). Indeed, in front-depth or back-depth trials the change always appeared at the same depth on the items. Future research with more focus on attentional shifts in depth will need to place more emphasis on the depth position of the cue and the items. To emphasize the importance of depth during the experiment, further experiments could consider using the one-shot change detection paradigm with only change trials and mixed-depth trials and then ask the participants to explicitly state the depth of change, for example, if the changing object was in the front-depth plane or in the back-depth plane.

A third possibility is that participants learned to use the 2D information of the cue without paying attention to its position in depth. This connection between the context of the task and performance has important implications for the possibility of strategies. It can be assumed that depth was not as relevant as supposed to detect change in this task and therefore, no significant differences between 3D valid and 3D invalid cues were found. One limitation of this study lies in the fact that participants were not directly instructed to shift attention between depths. The instruction emphasized the 2D validity of all cues, but not the 3D validity and 3D invalidity as an additionally important feature of the cue. Therefore, the participants could tend to ignore the depth information of the items and the cue (Marrara & Moore, 2000). One possible design of a future experiment should force the participant to concentrate directly on the different depths of the items.

Finally, another possible explanation for the absence of a 3D cueing effect becomes apparent from a study conducted by Atchley, Kramer, Andersen and Theeuwes, 1997 (see also, Marrara & Moore, 2000). They have shown that cueing in 3D space works with an exogenous cue, which “touches” the relevant item. Han, Wan and Humphrey (2005) have also studied the importance of the type of cue. They have shown that attention, allocated to a target item by an exogenous cue, operates in 3D space. Object based cues induce this shifts of spatial attention. In the present study, the cue was neither exogenous nor endogenous but resembled a pointer. Further studies, which take this type of cue into account, will need to be undertaken to establish the effect of object based and space based attention in depth. A square could be placed around the target item in depth as an exogenous cue and if this square also touch the target item the cue also would be object-based.

Additional investigations need to be done to determine the effect of different cues, for example, exogenous cues, during change blindness tasks in stereoscopic depth. Another interesting research question related to this experiment is how the effect of cueing differs if items were to change across depths and not just with respect to the orientation (Harris, McKee & Watamaniuk, 1998).

The goal of user interface design and usability engineering is to design displays as simple and efficient as possible (Grabbard, Hix & Swan, 1999). To achieve this, technical functionality must be optimally combined with the design of visual elements. The results have interesting implications for interface design. We interpret the present results as evidence that 3D displays, for example stereoscopic head-up displays, developed by user interface design can make use of simple 2D cues, if depth is not relevant, to enhance the user’s change detection. Considering that the application of simple but well-directed 2D cues in 3D space displays enhances task performance (regarding chance blindness), adapting and changing designs to make them more usable to user needs can be easily applied without compromises in the usability.

References

Atchley, P., Kramer, A. F., Andersen, G. J., & Theeuwes, J. (1997). Spatial cueing in a stereoscopic display: Evidence for a depth-aware attentional focus. *Psychonomic Bulletin and Review*, *4*(4), 524-529.

Becker, M. W., Pashler, H., & Anstis, S. M. (2000). The role of iconic memory in change-detection tasks. *Perception*, *29*, 273-286.

Christou, C., & Buelthoff, H. H. (2000). Perception, representation and recognition: A holistic view of recognition. *Spatial Vision*, *13*(2), 265-275.

Chun, M. M., & Jiang, C. Y. (1998). Contextual cueing: Implicit learning and memory of visual context guides spatial attention. *Cognitive Psychology*, *36*, 28-71.

Fernandez-Duque, D., & Thornton, I. M. (2000). Change detection without awareness: do explicit reports underestimate the representation of change in the visual system? *Visual Cognition*, *7*(1), 323-344.

Gimmes, J. (1996). On the failure to detect changes in scenes across saccades. *Percepion Ed. K Akins (Oxford: Oxford University Press)*, *1*(1), 89-110.

Grabbard, J. L., Hix, D., & Swan, J. E. (1999). User-centered design and evaluation of virtual environments. *IEEE Computer Graphics and Applications*, *19*(6), 51-59.

Han, S., Wan, X., & Humphrey, G. W. (2005). Shifts of spatial attention in perceived 3-d space. *The quarterly journal of expeimental psychology*, *58*(4), 753-764.

Harris, J. M., McKee, S. P., & Watamaniuk, S. N. J. (1998). Visual search for motion-in-depth: stereomotion does not 'pop out' from disparity noise. *Nature Neuroscience*, *1*(2), 165-168.

Landman, R., Spekreijse, H., & Lamme, A. F. (2003). Large capacity storage of integrated objects before change blindness. *Vision Research*, *43*, 149-164.

Levin, D. T., & Simons, D. J. (1997). Failure to detect changes to attended objects in motion pictures. *Psychonomic Bulletin and Review*, *4*, 501-506.

Macmillan, N. A., & Creelman, C. D. (1991). Detection theory: A user's gide.

Marrara, M. T., & Moore, C. M. (2000). Role of perceptual organization while attending in depth. *Perception and Psychophysics*, *62*(4), 786-799.

Mazza, V., Turatto, M., & Umilta, C. (2005). Foreground-background segmentation and attention: A change blindness study. *Psychological Research*, *69*, 201-210.

Pashler, H. (1988). Familiarity and visual change detection. *Perception and Psychophysics*, *44*, 369-378.

Posner, M. I., Snyder, C. R. R., & Davidson, B. J. (1980). Attention and the detection of signals. *Journal of Experimental Psychology: General*, *109*, 160-174.

Rensink, R. A. (2000). Seeing, sensing, and scrutinizing. *Vision Research*, *40*, 1469-1487.

Rensink, R. A. (2002). Change detection. *Annu. Rev. Psychology*, *53*, 245-277.

Rensink, R. A., O'Regan, J. K., & Clark, J. (1997). To see or not to see: the need for attention to perceive changes in scenes. *Psychological Science*, *8*(5), 368-373.

Scholl, B. J. (2000). Attenuated change blindness for exogenoulsy attended items in a flicker paradigm. *Visual Cognition*, *7*, 377-396.

Simons, D. J. (2000). Current approaches to change blindness. *Visual cognition*, *7*(1), 1-15.

Simons, D. J., & Levin, D. T. (1997). Change blindness. *Trends in Cognitive Sciences*, *1*, 261-267.

Spelke, E. S. (1990). Principles of object perception. *Cognitive Science*, *4*, 29-56.

Sperling, G. (1960). The information available in brief visual presentations. *Psychological Monographs: General and Applied*, *74*(11), 1-30.

Theeuwes, J., Atchley, P., & Kramer, A. F. (1998). Attentional control within 3-d space. *Journal of Experimental Psychology: Human Perception and Perfomance*, *24*(5), 1476-1485.

Walraven, J., & Janzen, P. (1983). Tno stereopsis test as an aid to the prevention of amblyopia. *Ophthalmic and Physiological Optics*, *13*(4), 350-356.

ACKNOWLEDGMENTS

I would like to thank Dr. Marc Grosjean from the IfADo - Leibniz Research Centre for Working Environment and Human Factors for his assistance as well as for kindly providing and programming the tasks. Thanks also go to Prof. Willem Verwey for his comments on an earlier rough draft.

"*Nichts erweitert so den Horizont,*
schenkt so viel Selbstvertrauen,
wie Erfahrung!"
(Sylvia Plath)