Author(s): Lyyra, Pessi; Astikainen, Piia; Hietanen, Jari K.

Title: Look at them and they will notice you : Distractor-independent attentional capture by direct gaze in change blindness

Year: 2018

Version:

Please cite the original version:

Lyyra, P., Astikainen, P., & Hietanen, J. K. (2018). Look at them and they will notice you : Distractor-independent attentional capture by direct gaze in change blindness. Visual Cognition, 26(1), 25-36. https://doi.org/10.1080/13506285.2017.1370052

Routledge
Taylor & Francis Group

Volume 26 – Issue 1 – January 2018
Visual Cognition
Co-Editors: James W. Tanaka & Christian N.L. Olivers

Visual Cognition

ISSN: 1350-6285 (Print) 1464-0716 (Online) Journal homepage: http://www.tandfonline.com/loi/pvis20

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To cite this article: Pessi Lyyra, Piia Astikainen & Jari K. Hietanen (2018) Look at them and they will notice you: Distractor-independent attentional capture by direct gaze in change blindness, Visual Cognition, 26:1, 25-36, DOI: 10.1080/13506285.2017.1370052

To link to this article: https://doi.org/10.1080/13506285.2017.1370052

VISUAL COGNITION, 2018
VOL. 26, NO. 1, 25–36
https://doi.org/10.1080/13506285.2017.1370052

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Look at them and they will notice you: Distractor-independent attentional capture by direct gaze in change blindness

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ABSTRACT
Humans have shown a detection advantage of direct vs. averted gaze stimuli in visual search tasks. However, instead of attentional capture by direct gaze, the detection advantage in visual search may depend on attention-grabbing potential of the distractor stimuli to which the target needs to be compared. We investigated attentional capture by direct gaze using the change blindness paradigm, in which successful detection does not require comparison between the target and the distractor items. Participants detected a masked gaze direction change in one of four simultaneously presented schematic faces. The distractor gaze directions were systematically varied across three experiments. Changes resulting in direct gaze were detected more efficiently than those resulting in averted gaze, independently of distractor gaze directions. This finding suggests that the detection advantage is specifically due to attentional capture by direct gaze, not properties of distractor items.

ARTICLE HISTORY
Received 31 August 2016
Accepted 8 August 2017

KEYWORDS
Gaze perception; change detection; change blindness; stare-in-the-crowd effect

Gaze perception is one of the foundations of nonverbal human communication, along with the perception of facial expressions, body posture, and biological motion. Gaze conveys information specifically about other persons' intentions, immediate interests, and direction of attention. During face-to-face social interaction, humans particularly attend to each other's eye areas (George & Conty, 2008), and they are naturally adept at judging each other's gaze direction (Gale & Monk, 2000; Symons, Lee, Cedrone, & Nishimura, 2004). At the neural level, this is enabled by subcortical and cortical mechanisms dedicated to gaze processing (e.g., Baron-Cohen, 1995; Nummenmaa & Calder, 2009; Perrett, Hietanen, Oram, Benson, & Rolls, 1992).

Within gaze perception, the perception of direct gaze enjoys a particular relevance. Infants prefer direct gaze to averted gaze (Farroni, Csibra, Simion, & Johnson, 2002; Farroni, Menon, & Johnson, 2006). Mutual gaze of the newborns and their immediate caregivers supports the earliest interaction and enables formation of attachment relations (Argyle & Cook, 1976; Reddy, 2003). For adult humans, receiving direct gaze typically marks the beginning of an interaction and the perception of direct gaze automatically initiates a set of preparatory cognitive and physiological processes specific to approach behaviour (e.g., Conty, George, & Hietanen, 2016). These processes also include attentional ones: direct gaze has been shown to attract and grab the perceiver's attention. In the visual search paradigm, detection times are shorter for deviant direct gaze targets among averted gaze distractors than for averted gaze targets among direct gaze distractors, a phenomenon dubbed the "stare-in-the-crowd" effect (Conty, Tijus, Hugueville, Coelho, & George, 2006; Doi, Ueda, & Shinohara, 2009; Senju, Hasegawa, & Tojo, 2005; Shirama, 2012; von Grünau & Anston, 1995). Moreover, even a task-irrelevant direct gaze facilitates visual search for facial expressions (Doi & Shinohara, 2013), and targets presented at the location of a direct gaze are detected faster than those presented at the location of averted gaze (Böckler, van der Wel, & Welsh, 2014; Miyazaki, Ichihara, Wake, & Wake, 2012).

However, the speed of detection of direct gaze targets is shown to depend on the gaze directions of the distractor crowd (Palanica & Itier, 2011). There is

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also recent evidence from studies using the visual search paradigm suggesting that direct gaze is not necessarily prioritized by detection alone, but the findings more likely reflect the attention-grabbing potential of the distractor stimuli across different search conditions (Cooper, Law, & Langton, 2013). For example, when the distractor context was identical—uniform or heterogeneous—the detection of direct and averted gaze deviants were equally efficient. In other words, the context comprising the distractor stimulus array can both disrupt and facilitate target detection. Cooper et al. (2013) found no evidence for the stare-in-the-crowd effect in the visual search paradigm when these contextual confounding factors were controlled for. It is possible that this paradigm is particularly prone to this problem, since it is based on deviance detection, i.e., the target is the sole deviant item in the search array, and deviant detection is based on comparison of that item to all of the distractor items. Consequently, visual search may not be the optimal way to study the attentional capture by direct gaze because of the attention-grabbing potential of the simultaneously presented distractor faces.

Alternatively, the effect that attention has in the breaking of direct gaze stimuli to consciousness can be investigated with the so-called change blindness paradigm. Ordinary change detection in humans is highly efficient: if two versions of an image are successively presented to observers trying to detect changes from one version (S1) to another (S2), changes are immediately detected (Rensink, O'Regan, & Clark, 1997). Consequently, however, this setup cannot be used to study the detection of different change types because of a ceiling effect. In a change blindness paradigm, by contrast, automatic change detection is eliminated by a mask, for example, a blank screen ("flicker") interspersed between S1 and S2 (Rensink et al., 1997). The mask eliminates the change transient that would normally summon attention to its location, and automatically bring the changed stimulus into consciousness. In the change blindness paradigm, it may take up to several seconds for the observer to notice even a large change. The delayed detection rate thus allows for the emergence of detection differences between different stimulus change types, and allows for studying differential detection of direct and averted gaze changes (Yokoyama, Ishibashi, Hongoh, & Kita, 2011).

The change blindness paradigm is typically used to study attentional effects of the stimuli, since successful change detection depends on attention (e.g., Rensink et al., 1997). The inability to perceive the change typically triggers an active search period guided by top-down attention. Only focal attention to the change—and consolidation to the sensory short-term memory—allows for transient perception of change to emerge into consciousness across the unstimulated periods (e.g., Jensen, Yao, Street, & Simons, 2011; Rensink et al., 1997). Evidence has been provided that bottom-up preconscious perception of the changed features can aid the explicit detection of the changes (Smilek, Eastwood, & Merikle, 2000). In particular, socially and biologically relevant contents of the change have been shown to facilitate recovery from change blindness, such as facial vs. non-facial stimuli (Kikuchi, Senju, Tojo, Osanai, & Hasegawa, 2009; Lyyra, Mäkelä, Hietanen, & Astikainen, 2014; Ro, Russell, & Lavie, 2001) and threatening vs. non-threatening facial stimuli (Lyyra, Hietanen, & Astikainen, 2014). The facilitated recovery probably stems from an attentional bias created by the bottom-up signal of the implicitly perceived changes. Thus, it would be expected that direct gaze as a socially and biologically salient stimulus would have a similar bottom-up attentional influence, and, therefore, it should enhance the detection of direct gaze stimuli relative to averted gaze stimuli. This finding would be akin to corresponding findings in interocular suppression, in which a target stimulus is presented to one eye, and conscious perception of the target is delayed by a dynamic high contrast mask presented to the other eye. This delay is found to be shortened for direct gaze, i.e., it breaks to consciousness faster than averted gaze (Akechi et al., 2014; Chen & Yeh, 2012; Stein, Senju, Peelen, & Sterzer, 2011). In interocular suppression, however, it is not clear which cognitive functions contribute to the quickened breakthrough of direct gaze to consciousness, and the role of attention in this phenomenon has not been studied directly (see, e.g., Sterzer, Stein, Ludwig, Rothkirch, & Hesselmann, 2014). Unlike in interocular suppression, enhanced detection of direct gaze stimuli in a change blindness condition could show that attention can contribute to this process, since attention to the changes is necessary for change detection in change blindness: If direct gaze captures attention more efficiently than an averted gaze at the preconscious level, it should lead to an attentional bias to direct gaze stimuli, as found for other socially relevant stimuli.

Importantly, in change blindness, the changed item does not have to differ from the other items in S2, and there is no need to compare the changed item to the other items in the scene. Additionally, the distractor stimuli are not necessarily present in the response phase, potentially decreasing their distractor value. Therefore, attentional capture by target stimuli in a search condition may be investigated more effectively in the change blindness paradigm than in the visual search paradigm. In a previous study using the change blindness paradigm, changes to direct gaze were indeed more efficiently detected than those to averted gaze (Yokoyama et al., 2011). However, the composition of the distractor gaze directions was similar throughout the experiments in that study. Thus, based on that study, it was impossible to show unequivocally that the direct gaze detection advantage in change blindness was not influenced by attention-grabbing by the distractor gaze directions or by a comparison between the distractors and the target, as in visual search.

The purpose of the present study was to systematically investigate the direct gaze advantage and the effects of the background distractor gaze information on this advantage in a change detection condition. To this end, we conducted a series of three change blindness experiments in which we systematically manipulated the gaze distractor background, similarly to Cooper et al.'s (2013) study, which used the stare-in-the-crowd visual search paradigm. In Experiments 1–3, we used a uniform background with distractor faces displaying an opposite gaze direction to the target (direct or laterally averted gaze, Experiment 1), an identical distractor background for both conditions (all distractors displaying an upward or downcast gaze, Experiment 2), and a heterogeneous background (two distractor faces displaying a direct and two displaying a laterally averted gaze, Experiment 3). Changes were either from averted to direct gaze offering the possibility for eye contact (below referred to as a "change to direct gaze"), or from direct (or from upward/downcast) to averted gaze (below referred to as a "change to averted gaze"), as depicted in Figures 1–3. In all experiments, the participants' task was to detect changes across two scenes consisting of an array of four faces with an occasional and randomly located gaze direction change. We assumed that changes to direct gaze are detected more efficiently than changes to averted gaze, independent of gaze directions of the distractor face stimuli, since change detection does not depend on perception of distractor stimuli. As change detection in the change blindness paradigm relies on attention to the changes, enhanced

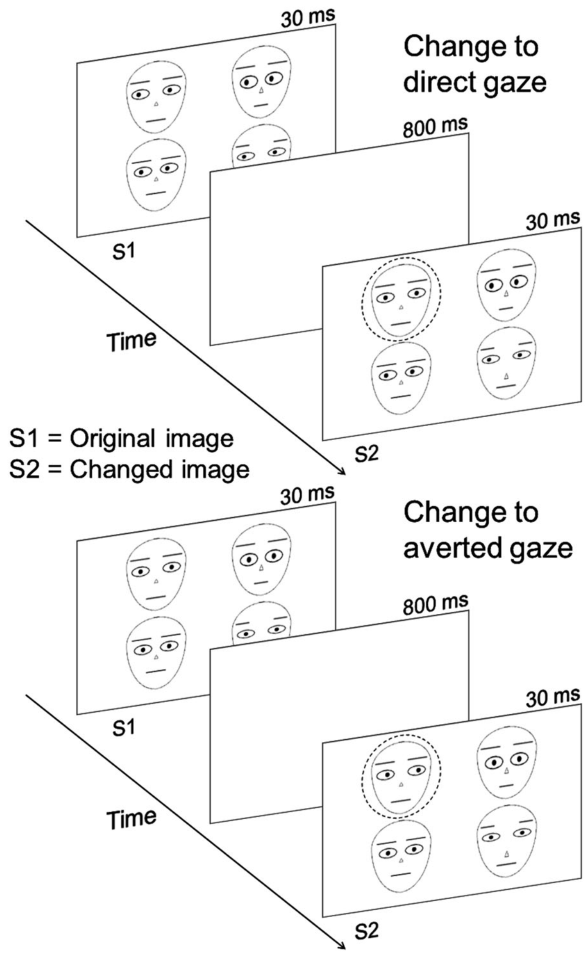

Figure 1. Stimulus setups for the change to direct gaze and change to averted gaze conditions in Experiment 1. Changes in S2s are indicated with dotted circles.

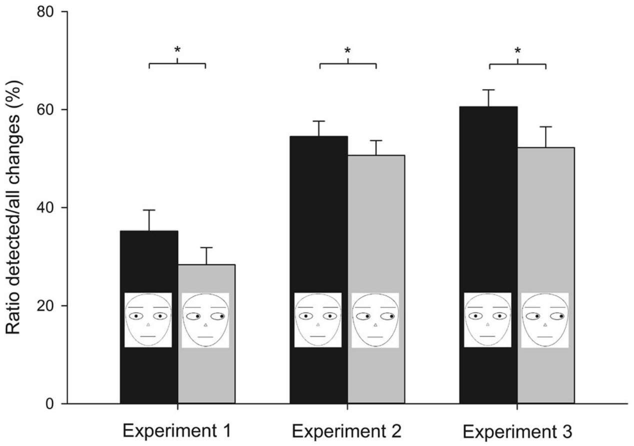

Figure 2. Detection efficacies in changes to direct gaze (black bar) and to averted gaze (grey bar) conditions in Experiments 1–3. Error bars indicate standard errors of the mean. The asterisks indicate significance level of $p < .05$.

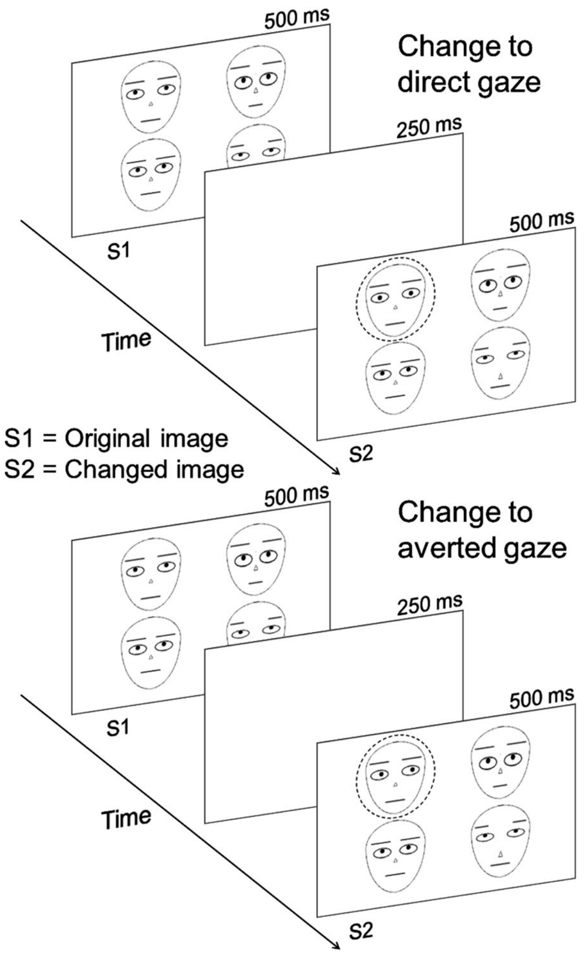

Figure 3. Stimulus setups for the change to direct gaze and change to averted gaze conditions in Experiment 2. Changes in S2s are indicated with dotted circles.

detection of changes to direct gaze would indicate that direct looking faces attract attention more efficiently than averted looking faces. If the change detection advantage remained similar despite manipulation of the distractor gaze composition, it would mean that change detection in a stare-in-the-crowd is relatively immune to the effect of distractor gaze directions. The change blindness paradigm could thus inform us about whether faces displaying direct gaze attract attention more strongly than those displaying averted gaze, and consequently enhance the conscious detection of faces with direct gaze—a question left unaddressed by the visual search and interocular suppression studies.

Experiment 1

As in Cooper et al. (2013), Experiment 1 was aimed as a repetition of the original stare-in-the-crowd effect (Experiment 1; von Grünau & Anston, 1995) to confirm that our stimulus setup works similarly to previous studies. We used a corresponding composition of gaze direction stimuli as in the experiment by von Grünau and Anston (1995), but adapted to the change blindness paradigm. The crowd in the S1 displays was composed of either faces with exclusively averted gaze or direct gaze. One of the faces in S2 occasionally changed gaze direction, thus appearing like one of the faces had turned its gaze. The change direction was from averted to direct ("change to direct gaze"), or from direct to averted gaze ("change to averted gaze"). The faces were schematic faces as in Öhman, Lundqvist, and Esteves (2001; cf. Yokoyama et al., 2011), but were manipulated to differ slightly in terms of the size of facial elements and their relative distances (see Figure 1) to render the change detection task more challenging. The presentation times of S1 and S2 were kept very short (i.e., 30 ms) for the task performance to reflect change detection, not deviance detection in S2 (Lyyra, Hietanen et al., 2014). The main hypothesis was that changes to direct gaze would be detected more efficiently than changes to averted gaze, corresponding to the stare-in-the-crowd effect in visual search.

Material and methods

Participants

Sixteen healthy individuals (8 males, mean age ± SD = 23.1 ± 3.6), participated in the study, and they were compensated with movie tickets. All participants gave their written informed consent before the experiment. The study conformed to the ethical standards of the American Psychological Association (APA) and The Code of Ethics of the World Medical Association (Declaration of Helsinki). According to Finnish regulations (Act on Medical Research and Decree on Medical Research 1999, amended 2010), specific ethics approval was not necessary for this study. A written informed consent was obtained from all participants.

The sample size was estimated based on previous studies (Lyyra, Hietanen, et al., 2014; Yokoyama et al., 2011). To investigate whether this sample size has sufficient power to reveal the detection difference between changes to averted and to direct gaze, an a priori power analysis for repeated measures ANOVA with one two-level within-subjects factor was conducted using G*Power 3.1 software (Faul, Erdfelder, Lang, & Buchner, 2007), with the parameters of 95% power, expected effect size of at least 0.2–0.3 (η_p^2), an alpha level of .05, the default within-subjects measurement correlation of .5, and non-sphericity correction value (ε) of 1. The expected effect size was estimated based on previous corresponding change blindness studies with reported effect size (e.g., Lyyra, Hietanen, et al., 2014; Yokoyama et al., 2011). The calculation suggested sample sizes of 10–16 participants.

Stimuli and procedure

The stimuli were schematic faces with a direct gaze or an averted gaze (see Figure 1), and were presented in an S1–S2 change blindness paradigm. In S1 (30 ms), four faces were simultaneously presented in an array of 2 × 2 faces (see Figure 1). Each face covered an area of 5° × 5°, and the whole array subtended 17.9° × 13.3° of visual angle horizontally and vertically, respectively. Half of the S1s contained an array of four faces all with direct gaze, and half of S1s four faces all with laterally (randomly left or right) averted gaze. S1s were followed by a blank screen for 800 ms after which S2 (30 ms) was presented. The stimulus setup was designed to result in approximately 50% change detection rate and consequently an equal amount of trials for change detection and change blindness trials.

On one-third of the trials, S2 was identical to S1. On another third of the trials, in those with an S1 of four faces with averted gaze, the gaze of one face changed from averted to direct (change to direct gaze). On the remaining third of the trials, those with an S1 of four faces with direct gaze, the gaze of one face changed from direct to randomly left or right laterally averted (change to averted gaze). The location of the change was randomized in both conditions.

The participants' task was to detect whether a change between S1 and S2 occurred or not. There were no restrictions imposed on eye movements. Participants did not need to recognize the direction of the change, but it sufficed to sense clearly where the change transient occurred. They were discouraged to report having detected the change if they felt unsure about the location of the change. A response window followed S2, in which the participant reported on having detected the change or not by pressing of a left or right button assigned to the given response on a two-button response panel. The assigned buttons for yes/no responses were counterbalanced across participants. Participants completed as many trials as could manage in 40 minutes ($M = 320.84 \pm SD = 78.92$). Detection rates, for both change conditions (change to direct gaze, change to averted gaze) were measured for each participant. The proportion of reports of change despite their absence was very small (1%). The no change trials served as catch trials, and the low false alarm rate indicated that the participants were not guessing but following the task instructions correctly. To investigate that the results were not due to a response bias, as the general performance level was eventually below chance (31.82%, see Figure 2), the discriminability index *d*′ was calculated for each participant. The *d*′, according to Signal Detection Theory (e.g., Green & Swets, 1988), shows, in terms of standard deviations, the distance between the distributions of successful detection and false alarms. The *d*′s were high, $M = 2.06$, $SD = 0.12$, 95% CI [1.83, 2.30], showing that the participants were following the task instructions correctly and detecting changes successfully.

Apparatus

Stimulus presentation and data acquisition were controlled by E-Prime software (Psychology Software Tools). The stimuli were presented on a 23″ CRT monitor (screen resolution: 1280 × 1024 pixels; refresh rate: 75 Hz) at a distance of 100 cm from the participant.

Data analysis

Change detection was measured as the ratio (percentage) of detected/all changes (Yokoyama et al., 2011). Mean detection rates of each participant were subjected to a repeated measures ANOVA with Gaze Direction (change to direct gaze, change to averted gaze) as a within-subject factor.

An alpha level of .05 was used in all the analyses. Partial eta squared (η_p^2) represents effect size estimates for ANOVA.

Results and discussion

Change detection performance

Expectedly, a detection advantage for changes to direct gaze relative to changes to averted gaze emerged ($M_{\text{change to direct gaze}} = 35.38\%$, $SD = 17.02$; $M_{\text{change to averted gaze}} = 28.25\%$, $SD = 14.21$, see Figure 2), $F(1, 15) = 7.35$, $p = .016$, $\eta_p^2 = .329$.

Changes from averted to a direct gaze were detected more efficiently than changes from direct to an averted gaze. Direct gaze, thus, seems to break into consciousness faster than averted gaze also when considering change detection. These results repeat the original stare-in-the-crowd effect observed for visual search (e.g., Cooper et al., 2013; von Grünau & Anston, 1995) for change blindness.

As in the original version of the visual search paradigm, in which the stare-in-the-crowd phenomenon was first recognized, the present setup had averted gaze distractors for changes to direct gaze and direct gaze distractors for changes to averted gaze. This kind of a stimulus setup has recently been criticized as the effect of the distractor context, or the "crowd", can confound this result: the enhanced detection rates of faces with direct gaze compared to those with averted gaze may be due to the distraction effect of the crowd being comprised of attention-grabbing direct looking faces (Cooper et al., 2013; see Frischen, Eastwood, & Smilek, 2008 for a similar problem concerning detection advantage for threatening faces). Therefore, it is possible that the more efficient detection of changes to direct than to averted gaze is due to a distracting, attention engaging effect of the direct looking distractor faces in the stimulus array of the change to averted gaze condition. To eliminate the possible confounding effect of distractor context in change conditions, another experiment was conducted using the same context for both the change to averted gaze and the change to direct gaze conditions.

Experiment 2

The same motivation formed the foundation for Experiment 2 and it was devised in the same fashion as Experiment 3 in the visual search study by Cooper et al. (2013): to control for the effect of distractor context. The context was unitary and it was held similar for both gaze direction change conditions. Because of this, no differences in attention-grabbing distractor context were possible between the change conditions. We expected, again, that detection efficacy would be greater for changes to direct gaze relative to changes to (laterally) averted gaze. Such a result would confirm that the differences between the conditions result from the nature of the changes themselves—for changes to direct gaze presumably from their particular relevance for attention.

The setup for Experiment 2, including the instructions to participants for the experimental task, was kept as similar as possible to that of Experiment 1. Only the discrepant methodological details are described in the following section.

Material and methods

Participants

Eighteen healthy individuals (9 males, mean age of all participants ± SD = 23.56 ± 2.22), participated in the study after having given written informed consent, and were compensated with movie tickets. The sample size for Experiment 2 was increased slightly because of smaller change magnitude relative to Experiment 1 (see Figures 1 and 3). None of the participants had participated in Experiment 1. The study conformed to the ethical standards of the American Psychological Association (APA) and The Code of Ethics of the World Medical Association (Declaration of Helsinki). According to Finnish regulations (Act on Medical Research and Decree on Medical Research 1999, amended 2010), specific ethics approval was not necessary for this study.

Stimuli and procedure

The stimuli in S1 were four schematic faces either all with an upward or all with a downcast gaze (see Figure 3). In S2, the gaze of one face shifted to a completely direct or to a slightly averted gaze. The magnitude of the displacement of the pupil from upward/downward gaze to laterally (left or right) averted gaze and to direct gaze was held as similar as possible (about three millimetres on the computer screen for both change conditions, see Figure 3). A couple of amendments to the stimulus procedure were made relative to Experiment 1. As in Experiment 1, we aimed for presentation times during which all faces could not be searched through in S2, and for the detection levels for changed scenes to be as close to 50% as possible. The duration of S1 and S2 was set to 500 ms, and that of the blank screen to 250 ms. The task was also made shorter and less wearisome for the participants than in Experiment 1, and the participants completed as many trials as they managed in 20 minutes ($M = 254.00 \pm SD = 40.43$). As in Experiment 1, the false alarm rate was low (1%), and the d'-values were high, $M = 3.19$, SD = .21, 95% CI [2.80, 3.60], indicating that the participants were performing the task as requested.

Data analysis

The data were analysed as in Experiment 1 by conducting a repeated measures ANOVA with gaze direction (change to direct gaze, change to averted gaze) as a within-subject factor. To investigate the effect of background on change detection more closely, an additional factor of gaze prior to change (downcast gaze, upward gaze) was included.

An alpha level of .05 was used in all the analyses. Partial eta squared (η_p^2) represents the effect size estimates for ANOVA.

Results and discussion

Change detection performance

The changes to direct gaze were detected more often than changes to averted gaze ($M_{\text{change to direct gaze}} =$ 54.50%, SD = 13.35; $M_{\text{change to averted gaze}} =$ 50.72%, SD = 12.86, see Figure 2), $F(1, 17) = 4.53$, $p = .048$, $\eta_p^2 = .21$. Change detection was not influenced by gaze prior to change, $F(1, 17) = 4.53$, $p = .048$, $\eta_p^2 = .21$. The interaction between the main effects was not significant.

The main hypothesis of Experiment 2, that changes to direct gaze are detected more efficiently than changes to averted gaze, was supported by the results of Experiment 2, thus repeating the results of Experiment 1, even though the stimulus context was identical for both change type conditions. This finding seems to confirm that the detection advantage for direct gaze observed in Experiment 1 was probably not due to contextual effects. More likely, the particular relevance of direct gaze for attention underlay the detection advantage for changes to direct gaze in both experiments.

It is also possible that the detection of direct gaze in this paradigm resembles that of the visual search paradigm, as the changed face is the sole deviant in the S2 displays. Even though the observers could not have been browsing through all the stimuli in the array of S2 because of short presentation times, some kind of deviance detection at the implicit level may have contributed to explicit change detection. To counteract even a theoretical possibility of this, the changed face should not be the sole deviant face in the S2. This way the detection would be based solely on change and not on deviance detection. To assess this, a third experiment was devised.

The results from Experiments 1 and 2 also do not completely exclude the possibility that the distractor context could exert some effect on gaze direction change detection rates. In both experiments, the context was unitary, and all of the faces present in a single view had equal attention-grabbing potential. An experiment with a non-unitary context is required to settle whether context can also exert some influence on change detection efficacy. For example, if the crowd consisted of both direct and averted gaze distractors, attention could be grabbed more efficiently by faces with direct gaze than by faces with averted gaze, thus facilitating change detection in direct gaze faces (i.e., changes to averted gaze).

Experiment 3

In Experiment 3, the distractor crowd consisted of faces with both direct and averted gaze. As in Experiment 2, the context (S1) in Experiment 3 was held similar for both change conditions. However, the context was not unitary as in Experiment 2, but consisted of two faces with direct gaze and two with laterally averted gaze. Change conditions were similar to those in the previous two experiments, averted gaze changing to a direct gaze (i.e., change to direct gaze) or direct gaze changing to averted gaze (i.e., change to averted gaze, see Figure 4). This kind of a setup can only reflect change detection and not deviance detection as in the visual search paradigm. In S2, the changed face is similar to two other faces while the sole deviant face in the scene remains unchanged relative to S1. With this setup, we expected that the direct gaze advantage would still hold. It was also ensured that the participants were not able to browse through all the faces during the presentation of S2. We designed the stimulus setup so that only two or three faces could be searched through in S2, but the detection levels for changed scenes would be close to 50%. Beyond this the setup for Experiment 3, including the instructions for the experimental task, was kept as similar as possible to those in Experiments 1 and 2.

Material and methods

Participants

Sixteen healthy individuals (8 males, mean age of all participants ± SD = 27.81 ± 6.25), participated in the study and were compensated with movie tickets. This sample was independent of those in Experiments

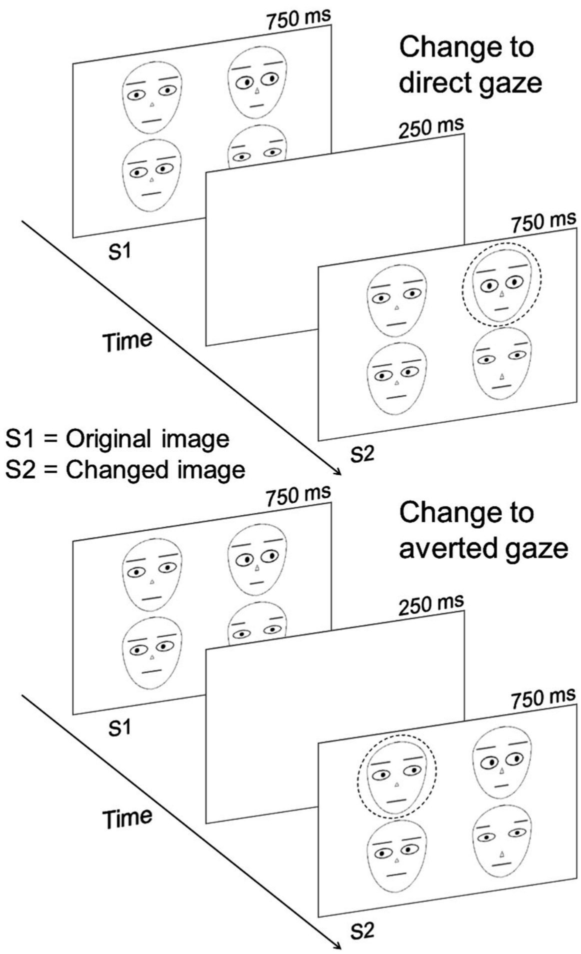

Figure 4. Stimulus setups for the change to direct gaze and change to averted gaze conditions in Experiment 3. Changes in S2s are indicated with dotted circles.

1 and 2. The study conformed to the ethical standards of the American Psychological Association (APA) and The Code of Ethics of the World Medical Association (Declaration of Helsinki). According to Finnish regulations (Act on Medical Research and Decree on Medical Research 1999, amended 2010), specific ethics approval was not necessary for this study.

Stimuli and procedure

The stimulus paradigm was similar to those in Experiments 1 and 2. As in Experiment 2, the backgrounds of the change were kept identical between the change conditions. S1 consisted of four schematic faces, two with direct gaze and two with laterally averted gaze (left or right). The locations of the four faces were randomly assigned to the four locations in the stimulus matrix (see Figure 4). In S2, the gaze of one face with a direct gaze shifted to right or left, or one with laterally averted gaze shifted to direct gaze. The duration of S1 and S2 was 750 ms and that of the blank screen was 250 ms. Participants completed as many trials as could manage in 20 minutes ($M = 223.32 \pm SD = 43.38$). The false alarm rate remained very low also for this experiment (below 2%). Accordingly, the *d*′-values were high, $M = 2.37$, $SD = .24$, 95% CI [2.27, 3.17], showing that the participants were performing the task successfully and as instructed also in Experiment 3.

Data analysis

The data were analysed as in Experiments 1 and 2 by conducting a repeated measures ANOVA with gaze direction (change to direct gaze, change to averted gaze) as a within-subject factor.

An alpha level of .05 was maintained in all analyses. Partial eta squared (η_p^2) represents effect size estimates for ANOVA.

Results and discussion

Again, changes from averted to direct gaze were detected more efficiently compared to those from direct to averted gaze ($M_{\text{change to direct gaze}} = 60.42\%$, $SD = 13.79$; $M_{\text{change to averted gaze}} = 52.26\%$, $SD = 17.06$, see Figure 2), $F(1, 15) = 9.13$, $p = .008$, $\eta_p^2 = .381$.

The results showed a similar detection advantage for changes to direct gaze relative to changes to averted gaze as those in the previous two experiments. The direct gaze detection advantage observed here indicates that the change blindness paradigm reflects change detection and not deviance detection in S2. In terms of effect size, the detection difference between the gaze directions remained at the same level throughout all experiments despite distractor context differences (Experiment 1: $\eta_p^2 = .33$; Experiment 2: $\eta_p^2 = .21$; Experiment 3: $\eta_p^2 = .38$). This seems to suggest that the distractor context does not interfere with change detection, or with the attentional bias created by the socially relevant changes to direct gaze.

An additional ANOVA with a between-subjects factor of experiment (Experiment 1, Experiment 2, Experiment 3) and a within subjects factor of gaze direction (direct, averted) showed a main effect of gaze direction ($M_{\text{change to direct gaze}} = 50.28\%$, $SD = .18$, $M_{\text{change to averted gaze}} = 44.02\%$, $SD = .18$), $F(1, 47) = 20.98$, $p < .001$, $\eta_p^2 = .309$.

The main effect of experiment was significant, $F(2, 47) = 14.61$, $p < .001$, $\eta_p^2 = .383$, indicating that the detection performance in Experiment 1 was lower relative to Experiments 2 and 3 (E1: $M = 31.81\%$, $SD = .15$, E2: $M = 52.61\%$, $SD = .12$, E3: $M = 56.34\%$, $SD = .15$). However, the difference in change detection between gaze directions did not differ between the experiments, as indicated by the non-significant gaze direction × experiment interaction, $F(2, 47) = 0.94$, $p = .396$, $\eta_p^2 = .039$.

Similar to Experiments 1 and 2, changes to direct gaze were detected more efficiently than changes to averted gaze. As the changed item was not the deviant item in S2, this result also seems to confirm that the direct gaze advantage in change detection studies is not based on deviance detection. The results showed that, overall, direct gaze also breaks through into consciousness more efficiently than averted gaze in a change detection condition. The results confirm that this effect was similar in all studies despite contextual differences in distractor gaze directions. Compared to previous studies applying the visual search paradigm, the change blindness paradigm seems to be less sensitive to attention-grabbing by distractor stimuli, and thus offers a useful alternative for the investigation of attentional capture by and break to consciousness of implicitly presented stimuli.

General discussion

The present series of experiments explored the potential of implicitly presented gaze direction changes to capture attention and their emergence into consciousness using the change blindness paradigm. The results from all experiments indicated that changes resulting in a direct gaze were detected more efficiently than changes resulting in an averted gaze, thus repeating the previous results by Yokoyama et al. (2011). We also explored the effect of distractor context on the detection advantage of direct gaze. Manipulation of the distractor context had no discernible effect on direct gaze advantage in change detection, suggesting that, unlike in visual search (Cooper et al., 2013), contextual differences do not affect the direct gaze advantage in change detection. These consistent findings imply that—particularly in change blindness—the target stimulus content can have a facilitatory bottom-up attentional effect on conscious change detection. Our findings indicate that direct gaze can have a similar detection advantage as threat-related stimuli for change detection (e.g., Lyyra, Hietanen, et al., 2014). Direct gaze probably implies social attention or interest to interact or approach, thereby increasing the relevance of a face displaying direct gaze to the observer. The enhanced social relevance of direct gaze probably contributes to its privileged status in implicit processing (Rothkirch, Madipakkama, Rehna, & Sterzera, 2015) and related attentional bias required for enhanced explicit change detection.

Prominent change blindness theories argue that changes are detected by a random serial search supported by top-down focal attention (Rensink et al., 1997). The transient feeling of change in successful detection can only grow when supported by the extended memory span of focal attention. Top-down attention is also needed to bind together the elements of complex stimuli. However, facial stimuli (Kikuchi et al., 2009; Lyyra, Mäkelä, et al., 2014; Ro et al., 2001) and their emotional expressions (Lyyra, Hietanen, et al., 2014) seem to form an exception, and our results suggest that gaze direction may also be implicitly represented in a manner that can exert a similar bottom-up influence speeding up recovery from change blindness. This is also in line with studies using interocular suppression (Akechi et al., 2014; Chen & Yeh, 2012; Stein et al., 2011) and studies using visual search (Conty et al., 2006; Doi et al., 2009; Senju et al., 2005; Shirama, 2012; Von Grünau & Anston, 1995). In visual search, however, the search advantage for direct gaze has been contested as being confounded by the attention-grabbing effect of the gaze directions of the distractor faces. Our results conclusively show that in a search condition, direct gaze is indeed prioritized independently of the attention-grabbing potential of the distractor faces. Unlike interocular suppression, change detection involves a prolonged search period and a shift of focal attention to the change for it to become conscious. The change blindness paradigm may thus better reveal the implicit attentional shift to direct gaze and the ensuing detection enhancement than either the interocular suppression or the visual search paradigms. Focal attention to change is not, however, sufficient for conscious detection of change: attention can be directed to changes, i.e., they can be stared at "blankly" without perceiving the change (e.g., Caplovitz, Fendrich, & Hughes, 2008). A further consolidation process supported by working memory seems to be required for conscious detection (Jensen et al., 2011). The attentional bias related to direct gaze may aid the consolidation process and thus conscious detection of changes. Future studies are needed to ascertain at which stage of visual information processing the social relevance of change starts to facilitate conscious change detection.

In visual search, when the distractor context is controlled for, the detection advantage of direct gaze over averted gaze has been suggested to disappear (Cooper et al., 2013). In change blindness, the detection advantage survived even after elimination of possible distractor context influences. It is not clear—and cannot be fully determined on the basis of the present results—why visual search and change detection yield differential results. One major difference is that visual search involves comparison of all the items with each other to determine the sole deviant item. In change blindness, however, the detection is based on the difference between two consecutive stimuli. In successful detection, with the aid of appropriate allocation of attention, the change creates a visual transient across the two stimuli. Change detection in the change blindness paradigm is about focal attention tracking the elongated change signal spanning through the unstimulated period between the original and modified scenes. This only requires comparison of the sequential versions of the changed item, not comparison of all the items in the scene to each other as in visual search. Therefore, the effects of attentional capture may be more easily observable in change blindness than in visual search. For the first two experiments, it is possible that participants reported the change after noticing one face differing from the others only based on the S2 displays, which would make detection similar to that in the visual search paradigm. However, this is not a possible explanation for the results of the third experiment, in which the sole deviant face in S2 was not the changed one across S1 and S2. The results of this third experiment were very similar to those of the other two experiments. The presentation times were extremely short, especially in the first experiment, so that the distractor faces had long disappeared in the response phase, and the task was only to locate the changes. For these reasons, it is highly improbable that deviance detection could have accounted for the results of any of the experiments, especially as they differed from the results of the studies based on deviance detection in the visual search paradigm (Cooper et al., 2013). We thus believe that our results specifically reflect the cognitive processes related to change detection.

In visual search, the search phase and response phase can be differentiated on the basis of eye movements. The latency of the first fixation landing on the deviant stimulus marks the length of the search phase and the remaining time until response marks the response phase, both of which are reflected in the detection latencies. Using gaze tracking, it has been shown that shorter detection times to direct gaze than to averted gaze in visual search can result from both a shorter search phase and a shorter response phase (Hu, Zhao, Liu, & Li, 2012; Palanica & Itier, 2011). In the S1–S2 change blindness paradigm, the efficiency of the search phase is directly reflected by the change detection performance, and the response phase can be measured separately. This can be seen as another advantage for the change blindness paradigm relative to the visual search paradigm. In the present results, direct gaze was detected more efficiently than averted gaze, reflecting the efficiency of the search phase, and this was unaffected by the distractor composition.

We used extremely simplistic schematic frontal view faces as stimuli. The gaze directions in these kinds of stimuli are determined by their distinct low-level physical properties, namely the location of the pupil inside the eye-white area. Consequently, the eyes of the direct-looking face are both vertically and horizontally symmetrical, whereas the averted looking eyes are only horizontally symmetrical. Although the stimuli are otherwise perfectly symmetrical, it is possible that local symmetry explains the results of all the studies using frontal view direct gaze stimuli. Even if symmetry perception plays an elemental role in face and gaze perception (e.g., Chen, Kao, & Tyler, 2007; Rhodes, Peters, Lee, Morrone, & Burr, 2005), we consider it unlikely that the present results could have been based only on internal stimulus symmetry. Yokoyama et al. (2011) already observed a similar direct gaze advantage for change detection using both schematic faces with frontal-views and with rotated head-views, the latter with non-symmetrical direct gaze stimuli in the change blindness paradigm. Similarly, in interocular suppression, the facilitated awareness of direct gaze relative to averted gaze is observed for face stimuli with both frontal/symmetrical (Chen & Yeh, 2012) and rotated/asymmetrical head orientation (Stein et al., 2011). Nevertheless, eye contact perception in laterally rotated head stimuli would not completely correspond to the present findings. This is because they require a different, more holistic eye contact perception mechanism compared to low-level feature-based frontal view eye contact stimuli for which horizontal symmetry is the only visual cue about the presence of a direct gaze (Senju, Kikuchi, Hasegawa, Tojo, & Osanai, 2008). In any case, the role of symmetry in eye contact perception requires further elucidation in future studies.

In sum, our results showed that changes consisting of a gaze shift to a direct gaze were detected more effectively than gaze shifts ending with an averted gaze. The results highlight the importance of direct gaze for human perception. Complex stimuli such as faces with different gaze directions can be represented at the implicit level and yet have the potential to influence explicit behavioural detection of changes depending on their social or biological relevance.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Academy of Finland under grant #266187 to JKH; Kulttuurin ja Yhteiskunnan Tutkimuksen Toimikunta.

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