Vision Research 50 (2010) 2577–2587

Contents lists available at ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

Scene and *screen* center bias early eye movements in scene viewing

Markus Bindemann *

Department of Psychology, University of Essex, CO4 3SQ, UK

ARTICLE INFO

Article history:
Received 12 April 2010
Received in revised form 19 July 2010

Keywords:
Center
Fixation
Bias
Scene
Screen
Person detection

ABSTRACT

In laboratory studies of visual perception, images of natural scenes are routinely presented on a computer screen. Under these conditions, observers look at the center of scenes first, which might reflect an advantageous viewing position for extracting visual information. This study examined an alternative possibility, namely that initial eye movements are drawn towards the center of the *screen*. Observers searched visual scenes in a person detection task, while the scenes were aligned with the screen center or offset horizontally (Experiment 1). Two central viewing effects were observed, reflecting early visual biases to the scene *and* the screen center. The scene effect was modified by person content but is not specific to person detection tasks, while the screen bias cannot be explained by the low-level salience of a computer display (Experiment 2). These findings support the notion of a central viewing tendency in scene analysis, but also demonstrate a bias to the screen center that forms a potential artifact in visual perception experiments.

1. Introduction

When an image of a visual scene is presented on a computer screen, observers look at the center of the scene first. This central fixation bias has been observed in numerous perception experiments (e.g., Buswell, 1935; Mannan, Ruddock, & Wooding, 1995, 1996, 1997; Parkhurst, Law, & Niebur, 2002; Parkhurst & Niebur, 2003) and can account for a substantial proportion of human behavior during eye guidance (see, e.g., Tatler, Baddeley, & Gilchrist, 2005; Vincent, Baddeley, Correani, Troscianko, & Leonards, 2009). The prevalence of this behavior suggests that it is a key feature of scene viewing, but the basis of this effect remains poorly understood. The experiments reported here describe a new approach to investigate the underlying cause of this central viewing bias.

While the basis of the central fixation bias remains unresolved, a few recent studies rule out some potential explanations for this effect. One straightforward explanation, for example, could arise from the fact that many previous studies have confounded the center of a scene with the location of a fixation marker which is presented immediately prior to scene onset, and could inherently bias observers to initially view the scene center (see, e.g., Mannan et al., 1995, 1997; Parkhurst & Niebur, 2003; Parkhurst et al., 2002; Tatler et al., 2005; Vincent et al., 2009). The central viewing tendency persists, however, when non-central fixation markers are used, so that observers are not biased in this manner (Bindemann, Scheepers, Ferguson, & Burton, in press; Tatler, 2007). This is found even with highly eccentric fixation markers, which are presented in the periphery of a visual display. This indicates further that this effect does not arise from a motor bias to perform small amplitude saccades, which are then inevitably scattered near the scene center when a central or near-central fixation point is employed (Tatler, 2007).

Another possible account for the central viewing bias is that it reflects a tendency to look straight-ahead, to a location which typically coincides with the scene center in visual perception experiments. Contrary to this notion, however, observers are still drawn to the display center when the screen is shifted left or right of a central viewing position (Vitu, Kapoula, Lancelin, & Lavigne, 2004). This indicates that this effect does not reflect a viewing preference for a straight-ahead position, but reflects a systematic bias towards the center of a visual display. The central fixation bias also appears to be unaffected by the distribution of visual features in a scene. In photographic images, objects of interest often provide a focal point in a central location that could therefore give rise to a central viewing effect (see, e.g., Reinagel & Zador, 1999; Tatler et al., 2005). However, this cannot explain the central fixation bias either, which persists when the distribution of visual features is systematically biased to off-center locations in scenes (Tatler, 2007).

In a similar vein, the effect is also found when observers are searching for people in visual scenes. Under these conditions, the possibility of a person being located with the first fixation is determined by their proximity to the scene center (Bindemann et al., in press). This pattern is observed even when a person in a scene is located closer to the position of a peripheral pre-stimulus fixation marker than the scene center, and if the initial saccade to the scene center involves scanning across the location containing the person.

---

* Fax: +44 (0)1206 873801.
E-mail address: markus@essex.ac.uk

0042-6989/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.visres.2010.08.016

This is surprising considering that people are detected rapidly and draw attention in artificial visual displays (e.g., Bindemann, Burton, Langton, Schweinberger, & Doherty, 2007; Downing, Bray, Rogers, & Childs, 2004; Langton, Law, Burton, & Schweinberger, 2008; Ro, Friggel, & Lavie, 2007). One might therefore expect that people can also compete strongly for the earliest fixations in a scene. The fact that this is not the case with stimuli of such social importance supports the notion that the central fixation bias may be largely impervious to scene content (Tatler, 2007), but still leaves uncertainty regarding the basis of the central viewing effect.

Resolving the basis of the central fixation bias is an important matter for researchers studying visual perception. It is conceivable, for example, that the center of a scene provides an advantageous spatial location for the efficient extraction of visual information (see, e.g., Najemnik & Geisler, 2005; Renninger, Vergheese, & Coughlan, 2007). In this case, the central viewing bias would reflect an important initial processing stage in eye movement control and scene perception that demands further analysis. However, the central fixation bias could also reflect a methodological shortcoming that arises under laboratory conditions, as previous studies have consistently confounded the center of a *scene* with the center of a display *screen* (for a previous discussion of these issues, see Tatler, 2007). This raises the possibility that the central fixation bias is an artifact that arises from the presentation of visual stimuli on a computer monitor.

The aim of this study was to investigate this possibility by aligning visual scenes with the screen center or by offsetting scenes to the left or right side of a display, so that the screen and scene center were misaligned. To ensure that observers were not inherently biased towards the center of the screen under these conditions, the fixation marker preceding the scene presentation was rotated across several peripheral onscreen locations. The purpose of these manipulations was to determine whether initial fixations are drawn to the center of a scene or, alternatively, whether initial saccades are directed at the center of the screen, independent of the onscreen location of the scenes. To introduce a task demand, observers were instructed to detect the presence of a person in the visual scenes in Experiment 1.

2. Experiment 1

2.1. Method

2.1.1. Participants

Twenty-four undergraduate students participated in the experiment. All had normal or corrected-to-normal vision and received a small fee for participation.

2.1.2. Stimuli

The stimuli consisted of 24-bit RGB photographs of 60 scenes, which were taken from inside houses, apartments, office buildings and courtyards. These scenes measured 750 (W) × 563 (H) pixels at a screen resolution of 66 pixels/in., subtending a visual angle (VA) of ~$22 \times 16^\circ$ at a fixed viewing distance of 80 cm. For each scene, two versions existed that were identical in all aspects, except that one version contained a person and the other did not. The people depicted in person-present scenes were twenty unfamiliar models (10 male) who had volunteered to pose for the experiment. People were always shown in a frontal view and, across the scenes, were equally likely to appear in the left, central or right third of a scene. People varied in size across scenes, ranging from 1.5% of the total display area for the smallest person to 12.6% for the largest person (average person area = 5.4%).

To manipulate scene position, all scenes were presented on the center of a white background measuring 1024 (W) × 768 (H) pixels in the scene center condition, or were displaced to the left in the scene left condition, or displaced right in the scene right condition. This horizontal displacement measured 125 pixels (~3.7° of VA) from the center of the screen. This displacement equates to 1/6 of the total scene width for the comparison between centrally presented and horizontally transferred scenes, and to 1/3 of the total scene width when left- and right-placed scenes are compared directly. Applying this transformation to each of the scenes resulted in a total of 180 person-present and 180 person-absent displays. During the experiment, these scenes were rotated around participants, so that each scene was only shown once to each participant in any of the conditions. However, across all participants the presentation of scenes was counterbalanced so that each scene appeared in each condition an equal number of times. Example scenes and the horizontal onscreen displacement are illustrated in Fig. 1.

2.1.3. Procedure

The stimuli were displayed using SR-Research Experiment-Builder software (Version 1.4.2) on a 21 in. color monitor that was connected to an SR-Research Eyelink II head-mounted eye-tracking system running at 500 Hz sampling rate. Viewing was binocular, but only the participants' dominant eye was tracked. To calibrate the tracker, participants fixated a series of nine fixation targets on the display monitor. Calibration was then validated against a second sequence of nine fixation targets and, if the latter indicated a drift correction error of more than 1° of VA, calibration was repeated (standard nine-point EyeLink calibration procedure). This procedure was carried out at the beginning of the experiment and every 20 trials thereafter.

Each trial began with a fixation dot, which participants were asked to fixate so that an automatic drift correction could be performed. Across trials, this fixation dot was rotated around four possible onscreen locations corresponding to the four corners of the screen, at a distance of 462 (W) × 334 (H) pixels from the screen center. The position of the fixation dot was varied in this manner to ensure that observers were not biased towards the same spatial location at the start of every trial (for example, as is the case when a central fixation point is used). Once participants fixated this dot, the experimenter pressed a button to initiate a trial.

A scene stimulus was then displayed until a response was registered. Participants made speeded decisions concerning whether a person was present or not, by using their left and right index fingers to press the corresponding keys on a button box. Each participant was given 60 trials, comprising 30 person-present (10 scene left, 10 scene center, and 10 scene right) and 30 person-absent trials (10 scene left, 10 scene center, 10 scene right).

2.2. Results

2.2.1. Detection times and accuracy

To ensure that participants were complying with the task demands, response times and accuracy were analyzed for the detection task. People were detected on average in 659 ms ($SD = 97$ ms), while correct target-absent responses were made in 719 ms ($SD = 104$ ms), $t(23) = 4.67$, $p < 0.001$. Accuracy was high and did not differ between these conditions (target-present 2.9% errors, target-absent 2.4% errors, $t(23) = 0.72$, *n.s.*).

2.2.2. Eye movement data handling

Eye movements were pre-processed by integrating fixations of less than 80 ms with the immediately preceding or following fixation if that fixation lay within half a degree of visual angle. Otherwise these short fixations were excluded. The rationale for this was that such short fixations usually result from false saccade planning and are unlikely to reflect meaningful information processing (see

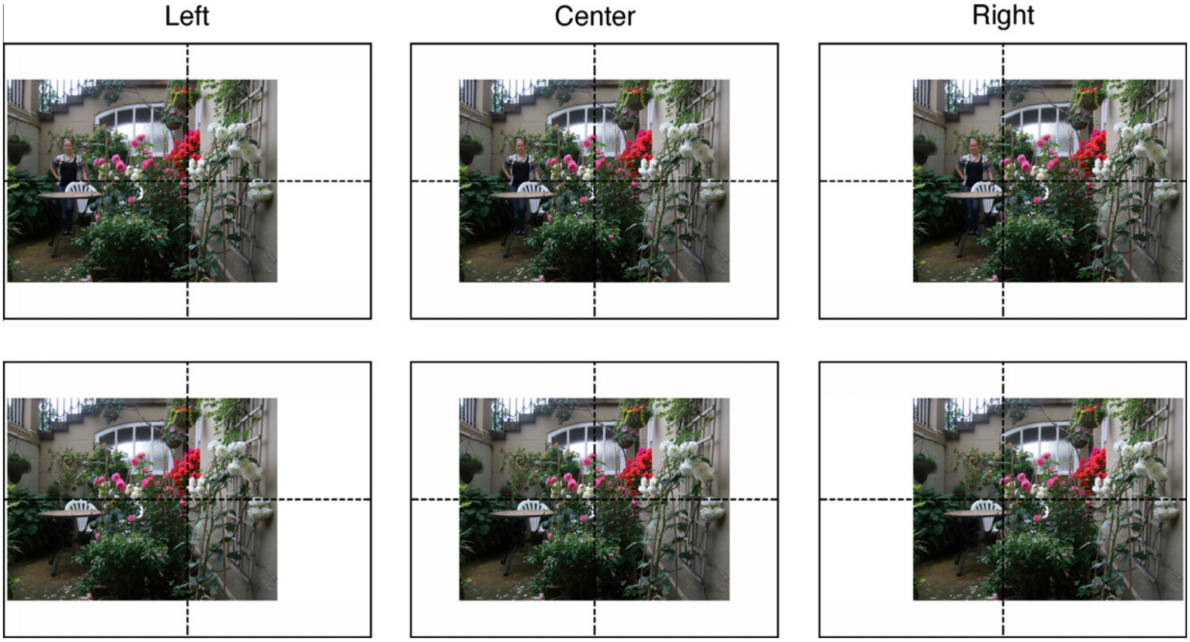

Fig. 1. Examples of scenes presented to the left, right, and in the center of the display screen, and with a person present (top row) or absent (bottom row). Solid black lines indicate the screen boundary. Dotted lines are shown to illustrate the screen center only and were not displayed during the experiment. (For interpretation to colours in this figure, the reader is referred to the web version of this paper.)

Rayner & Pollatsek, 1989). When an eye-blink occurred, its duration was added to the immediately preceding fixation (processing is unlikely to pause during a blink).

2.2.2.1. Distribution of fixations. In a first step of the eye movement analysis, the first three fixations for each trial were fitted with a Gaussian (radius = 3° of VA, chosen as an approximate half-height along the distribution of retinal acuity, see e.g., Lindsay & Norman, 1977) and the onscreen distribution of these fixations was determined for each of the experimental conditions. The resulting distributions were converted to z-scores and are displayed in Figs. 2 and 3 for person-present and person-absent scenes, respectively (for similar analyses, see, e.g., Bindemann et al., in press; Blais, Jack, Scheepers, Fiset, & Caldara, 2008; Tatler, 2007). These figures show that the 1st fixation made after stimulus onset clustered in the center of the display. Subsequent fixations were then directed at other regions as observers were targeting people in scenes directly. During this search process, eye movements clearly shift from the scene center to the side of the display. This is particularly noticeable in 3rd fixations in the scene left and scene right conditions. These fixations are biased to the side of the scene furthest from the screen center, indicating a search process originating centrally that then shifts to more peripheral screen locations.

Figs. 2 and 3 also show difference maps for the 1st fixations, which were calculated by subtracting the distribution of fixations for scene left and scene right displays from the scene center conditions. These difference maps show clearly that, while initial fixations appear to land in the center of the screen, these fixations are also affected by the location of the scenes. These fixations are displaced horizontally in the direction of the scene position (i.e., left in the scene left condition and right in the scene right condition) in comparison to scene center displays.

2.2.2.2. Fixations by screen center. To quantify these observations further, all 1st fixations were compared with two predefined regions of interest (ROI), corresponding to the left and right side of the screen (see Fig. 4). A 2 (person-present vs. person-absent) × 3 (scene left, scene center, scene right) ANOVA of these fixations did not show a main effect of person, $F(1, 23) < 1$, and no interaction between factors, $F(2, 46) < 1$, but a main effect of scene position was found, $F(2, 46) = 87.42$, $p < 0.001$. This effect arises due to a greater proportion of fixations landing to the left of the screen center in the scene left condition, Tukey HSD test, $q = 7.40$, $p < 0.001$, and, similarly, due to a greater number of fixations landing right of screen center in scene right displays, $q = 11.17$, $p < 0.001$, compared to scene center displays. This demonstrates that the initial fixations in a trial were affected by the onscreen location of the scenes and were adjusted accordingly.

2.2.2.3. Fixations by scene center. A further 2 (person-present vs. person-absent) × 3 (scene left, scene center, scene right) ANOVA was conducted to compare the proportion of first fixations directed to the left and right side of the scenes (see Fig. 5). This ANOVA did not reveal a main effect of person, $F(1, 23) = 1.47$, $p = 0.24$, and no interaction between factors, $F(2, 46) = 1.10$, $p = 0.34$, but a main effect of scene position was found, $F(2, 46) = 81.74$, $p < 0.001$. Tukey HSD test shows that first fixations were more likely to fall to the right of the scene center in the scene left condition, $q = 11.46$, $p < 0.001$, and, similarly, were more likely to fall to the left of the scene center in the scene right condition, $q = 17.84$, $p < 0.001$, compared to the scene center condition. This demonstrates that initial fixations to the scenes were also affected by the center of the screen.

2.2.2.4. Fixations by person location. In a final step, the 1st fixations were also broken down by the location of a person in a scene, as people were equally likely to appear on the left side, right side, or in the center of a scene (see Figs. 6 and 7). The aim of this analysis was to examine whether the first fixations made after scene onset were sensitive to the presence of a person in a visual scene, implying that observers processed at least some scene content at this stage, or whether observers were simply drawn by the abrupt onset of a large visual stimulus (i.e., the scene image).

A 2 (person-present, person-absent) × 3 (person left, person center, person right) × 3 (scene left, scene center, scene right) ANOVA revealed a main effect of person location, $F(2, 46) = 4.87$,

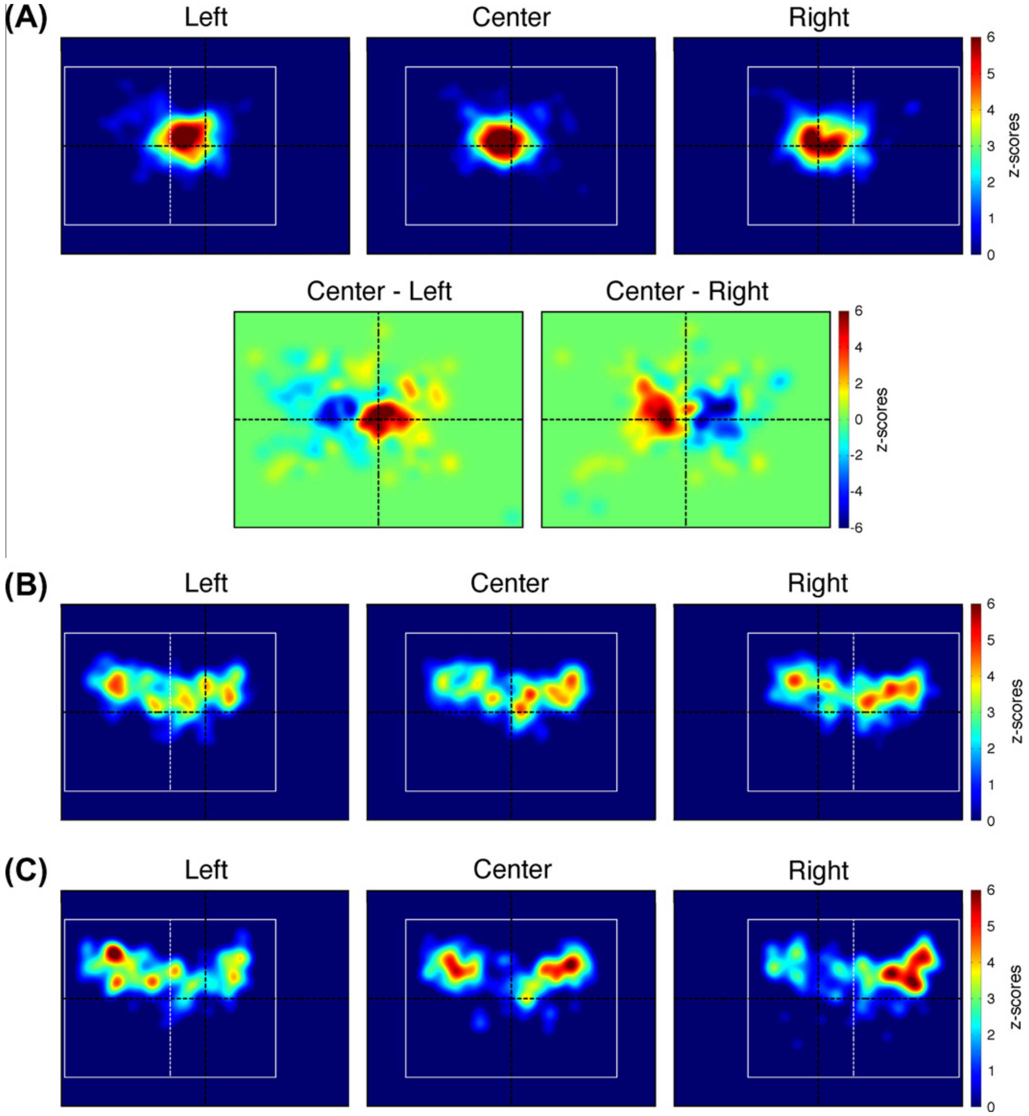

Fig. 2. Gaussian maps of the z-scored distribution of the first (A), second (B), and third (C) fixations to scenes presented left, right, and centrally for person-present trials. In addition, difference maps between the central and horizontally displaced scenes are shown for first fixations. Solid white lines indicate the scene position and dotted white lines illustrate the scene center. (For interpretation to colours in this figure, the reader is referred to the web version of this paper.)

$p < 0.05$, a main effect of scene location, $F(2, 46) = 77.16$, $p < 0.001$, and an interaction of person presence and person location, $F(2, 46) = 8.08$, $p < 0.001$. Analysis of the simple main effects revealed an effect of person location on person-present trials, $F(2, 46) = 16.98$, $p < 0.001$, but not on person-absent trials, $F(2, 46) < 1$. The simple main effect on person-present trials reflects the fact that more fixations landed on the left side of a scene when a person was located on this side and, correspondingly, because more fixations fell on the right side of a scene when the person was located on the right, compared to when the person appeared centrally, $q = 4.12$, $p < 0.05$ and $q = 4.12$, $p < 0.05$, respectively. This indicates that the people depicted in the scenes influenced saccade landing positions. The main effect of person presence and the remaining interactions were not significant, all $Fs < 1.7$.

To explore the effect of person content on initial fixations further, the percentage fixations to the region occupied by the person in a scene were analyzed. These regions received only 26% of 1st fixations but 68% and 75% of 2nd and 3rd fixations on person-present trials. This shows that, while person content affects saccade landing positions, relatively few 1st fixations landed directly on the persons. The same ROIs were also coded on person-absent trials to quantify the extent to which theses regions were fixated in a scene when a person was not shown. Under these conditions, the proportion of fixations landing on these scene regions was low (9% of 1st, 2nd and 3rd fixations).

2.3. Discussion

In this experiment, observers' eye movements revealed a consistent central fixation bias immediately after stimulus onset. This effect was determined in part by the onscreen location of the scenes, so that this viewing bias shifted left when scenes appeared on the left side of the screen and shifted right when the scenes were displaced horizontally in this direction. The eye movement data further suggests that this scene bias does not simply reflect a low-level onset effect (see, e.g., Theeuwes, 1994; Yantis & Jonides, 1984), whereby fixations are driven to the center of any stimulus that appears suddenly within the visual field, regardless of the distribution of visual features within that stimulus. Contrary to this notion, saccade landing positions were modulated by the location of a person within a scene, which suggests that at least some scene content was processed prior to the earliest fixation. Importantly,

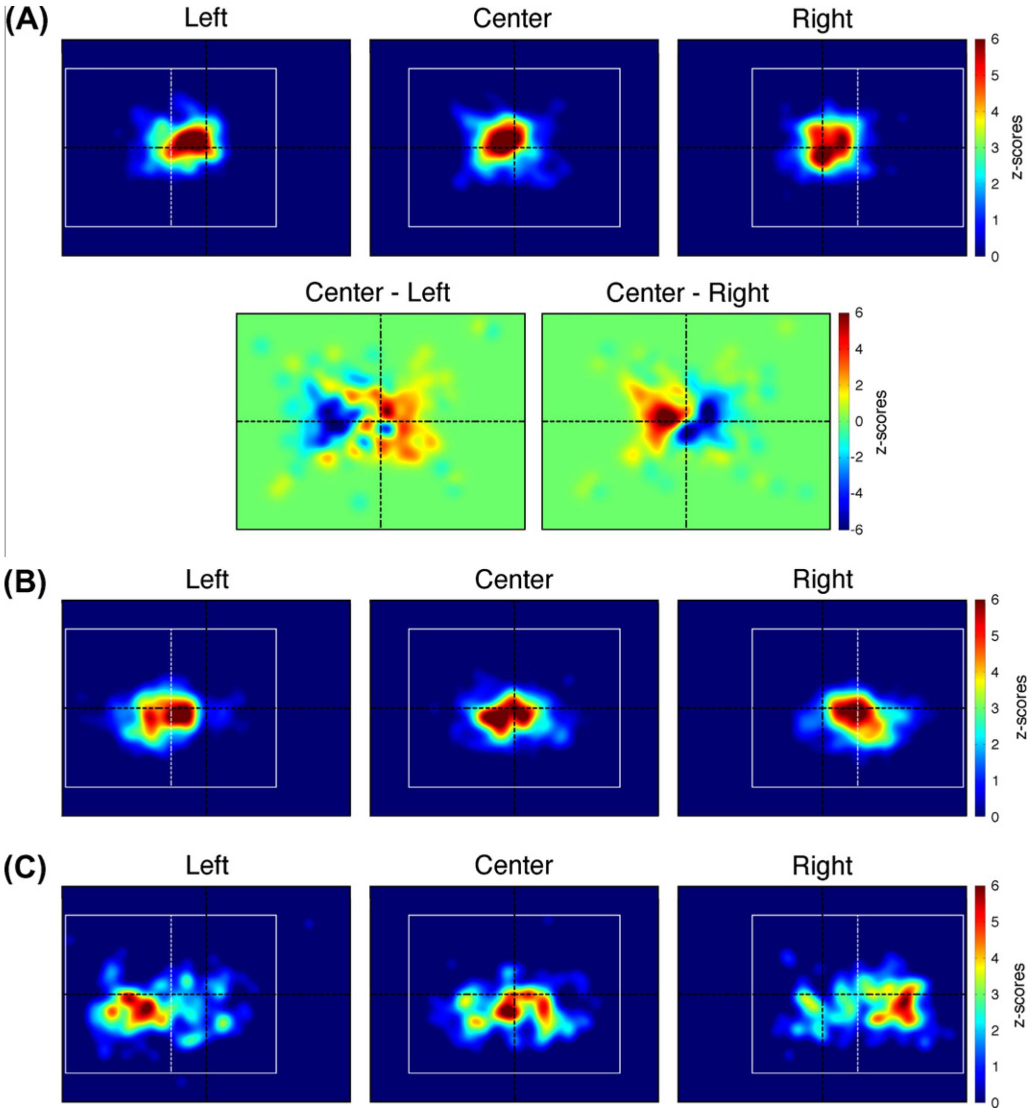

Fig. 3. Gaussian maps of the z-scored distribution of the first (A), second (B), and third (C) fixations to scenes presented left, right, and centrally for person-absent trials. In addition, difference maps between the central and horizontally displaced scenes are shown for first fixations. Solid white lines indicate the scene position and dotted white lines illustrate the scene center.

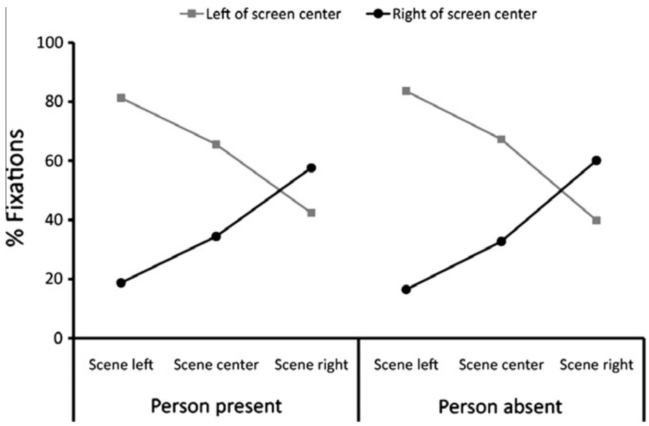

Fig. 4. Mean percentage of first fixations located left and right of the screen center for left, right, and centrally presented scenes.

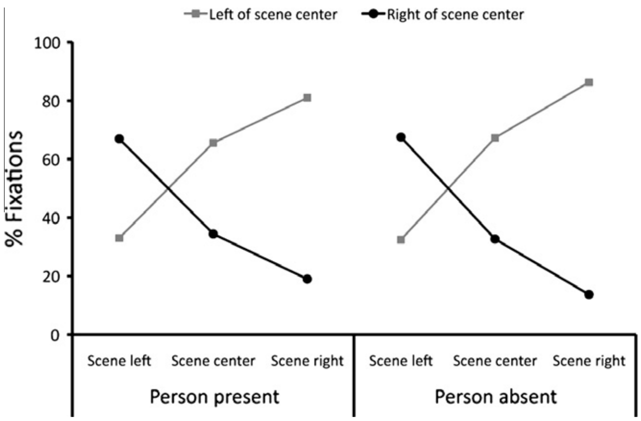

Fig. 5. Mean percentage of first fixations to the left and right of the scene center for left, right, and centrally presented scenes.

however, while initial fixations were clearly drawn in the direction of the displaced scenes, the magnitude of these saccades was insufficient to reach the center of these images. This reveals a parallel effect in this experiment, whereby initial fixation positions are not only determined by the location of a *scene* but also by the center of the *screen*.

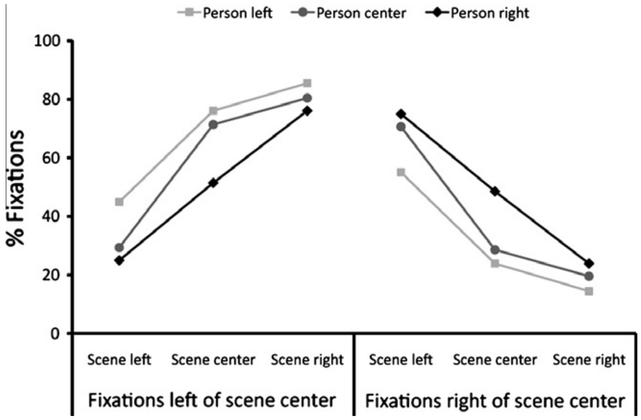

Fig. 6. Mean percentage of first fixations to the left and right of the scene center as a function of person location for left, right, and centrally presented scenes on person-present trials.

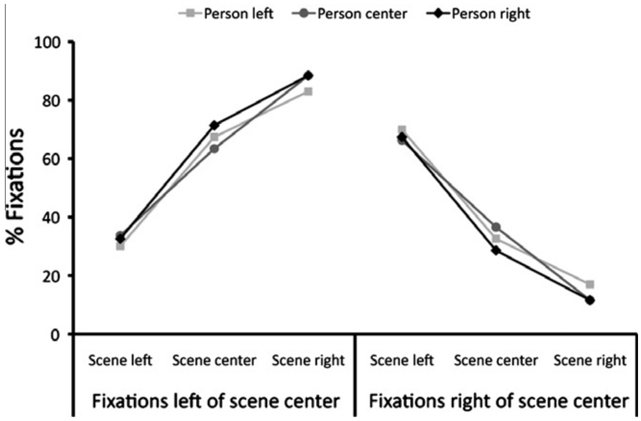

Fig. 7. Mean percentage of first fixations to the left and right of the scene center as a function of person location for left, right, and centrally presented scenes on person-absent trials.

These observations suggest complementary effects of both scene and screen center on initial eye movements in a person detection task. This is an important finding that highlights the *onscreen* presentation of visual images as a potential artifact in laboratory experiments. Indeed, it is conceivable that the current task underestimates the screen-based central bias, as the detection task might encourage observers particularly to look at the center of the scenes. This derives from the fact that people were equally likely to appear in the left, central or right third of a scene. The "center of mass" of the person regions across the full set of scenes therefore coincides with the center of the scene images. As a consequence, the visual search component of the person detection task might induce a *strategic* central scene viewing bias, as centering the eyes on the stimulus might provide an optimal location from which to search the scenes for people. To eliminate this possibility, the next experiment used only person-absent scenes and employed a free-viewing task. This task measured observers' spontaneous eye movements, rather than confining viewing patterns through specific task demands (see, e.g., Bindemann, Scheepers, & Burton, 2009; Birmingham, Bischof, & Kingstone, 2008). If the central scene viewing bias observed in Experiment 1 is driven by the distribution of people in scenes and the demands of the person detection task, the initial scene center bias should therefore be eliminated in Experiment 2, as there is no strategic benefit to attending this location. In return, the central screen bias should be less affected, and therefore be enhanced, by the location of the visual scenes.

One further change was made in Experiment 2, arising from the observation that the central viewing biases in Experiment 1 might also be restricted by the relative salience of the screen boundary. If this boundary is highly salient, one might predict a stronger tendency to use the screen as a spatial reference frame for guiding eye movements. A less salient screen boundary, on the other hand, might reduce the influence of the screen as a spatial reference and further shift observers' viewing biases towards the scene center. To address this issue, Experiment 2 compared viewing behavior under ambient lighting conditions, designed to reduce the saliency of the screen boundary, with conditions in which external light sources are eliminated and the screen is relatively more salient.

3. Experiment 2

3.1. Method

3.1.1. Participants

Twenty-four new undergraduate students participated in the experiment. All had normal or corrected-to-normal vision and received a small fee for participation.

3.1.2. Stimuli

The stimuli consisted of the 60 person-absent scenes from Experiment 1. As in Experiment 1, scene position was manipulated by presenting all scenes on the center of a white screen background or by displacing the scenes horizontally in a left or right direction by 125 pixels (~3.7° of VA) from the center of the screen. Applying this transformation to each of the scenes resulted in a total of 180 stimulus displays.

To manipulate screen saliency in this experiment, these scenes were either presented onscreen in a windowless room lit by four high-frequency luminaires (each providing 34 W at 84 Hz) in the *low screen salience* condition, or in the same room without any ancillary lighting in the *high screen salience condition*. To quantify these lighting conditions, viewing conditions were assessed with an Eye-One Display Colorimeter, which gave average illuminance readings of 240 Lux (*SD* = 51) and 0 Lux (*SD* = 0) for the experiment laboratory under light and dark viewing conditions, respectively, $t(46) = 23.17$, $p < 0.001$ (luminance of the white screen background = 232 Lux, *SD* = 31). During the experiment, the 180 scenes were rotated around the low and high salience conditions, so that each scene was only shown once to each participant in any of the conditions. However, across all participants the presentation of scenes was counterbalanced so that each scene appeared equally often in the scene left, scene center and scene right condition and in the low and high salience conditions.

3.1.3. Procedure

The procedure was identical to Experiment 1, except that the study investigated eye movements with a free-viewing task. Therefore, participants were encouraged to direct their eye movements spontaneously onscreen as they wished. As in Experiment 1, each trial began with a peripheral fixation point in one of the four screen corners, which participants were asked to fixate so that an automatic drift correction could be performed. Each scene stimulus was then displayed for 2500 ms. Each participant was given a block of 30 trials in the low screen salience condition and a block of 30 trials in the high salience condition, with each block comprising 10 scene left, 10 scene center, and 10 scene right displays. Trials were randomized within blocks and block order was counterbalanced across participants.

3.2. Results

3.2.1. Distribution of fixations

Eye movements were pre-processed as in Experiment 1, but only the data of most interest, the 1st fixations, were now analyzed. In a first step of this analysis, the onscreen distribution of these fixations was plotted for each of the experimental conditions (see Fig. 8). Consistent with Experiment 1, Fig. 8 shows that these fixations clustered around the center of the screen but were also drawn by the location of the scenes. This is particularly evident from the difference maps, which show that fixations were displaced in the scene left and scene right conditions, in comparison to scene center displays.

3.2.2. Fixations by screen center

These fixations were then compared for two regions of interest (ROI), corresponding to the left and right side of the screen (see Fig. 9). A 2 (low vs. high screen salience) × 3 (scene left, scene center, scene right) ANOVA of these fixations did not show a main effect of screen salience, $F(1,23) < 1$, but a main effect of scene position was found, $F(2,46) = 140.13$, $p < 0.001$. This effect arises from a greater proportion of fixations landing left of the screen center in the scene left condition, Tukey HSD test, $q = 8.55$, $p < 0.001$, and right of screen center in scene right displays, $q = 14.85$, $p < 0.001$, compared to scene center displays. This corroborates the results found in Experiment 1 and demonstrates that initial fixations were affected by the onscreen location of the scenes and adjusted accordingly.

In addition, an interaction of screen salience and scene location was found, $F(2,46) = 3.79$, $p < 0.05$. Simple main effect analyses of this interaction showed an effect of scene position under low screen salience, $F(2,46) = 57.53$, $p < 0.001$, reflecting more fixations left of screen center in the scene left condition, $q = 3.93$, $p < 0.05$, and right of screen center in scene right displays, $q = 10.73$, $p < 0.001$. Similarly, a simple main effect of scene position was found in the high screen salience conditions, $F(2,46) = 85.29$, $p < 0.001$, also reflecting more fixations to the left in scene left displays, $q = 8.16$, $p < 0.001$, and to the right in scene right displays, $q = 10.27$, $p < 0.001$. However, despite the interaction between these factors, no differences between the low and high salience conditions were found for scene center, $F(2,46) = 1.03$, $p = 0.32$, scene left, $F(2,46) = 2.46$, $p = 0.13$, and scene right displays, $F(2,46) < 1$.

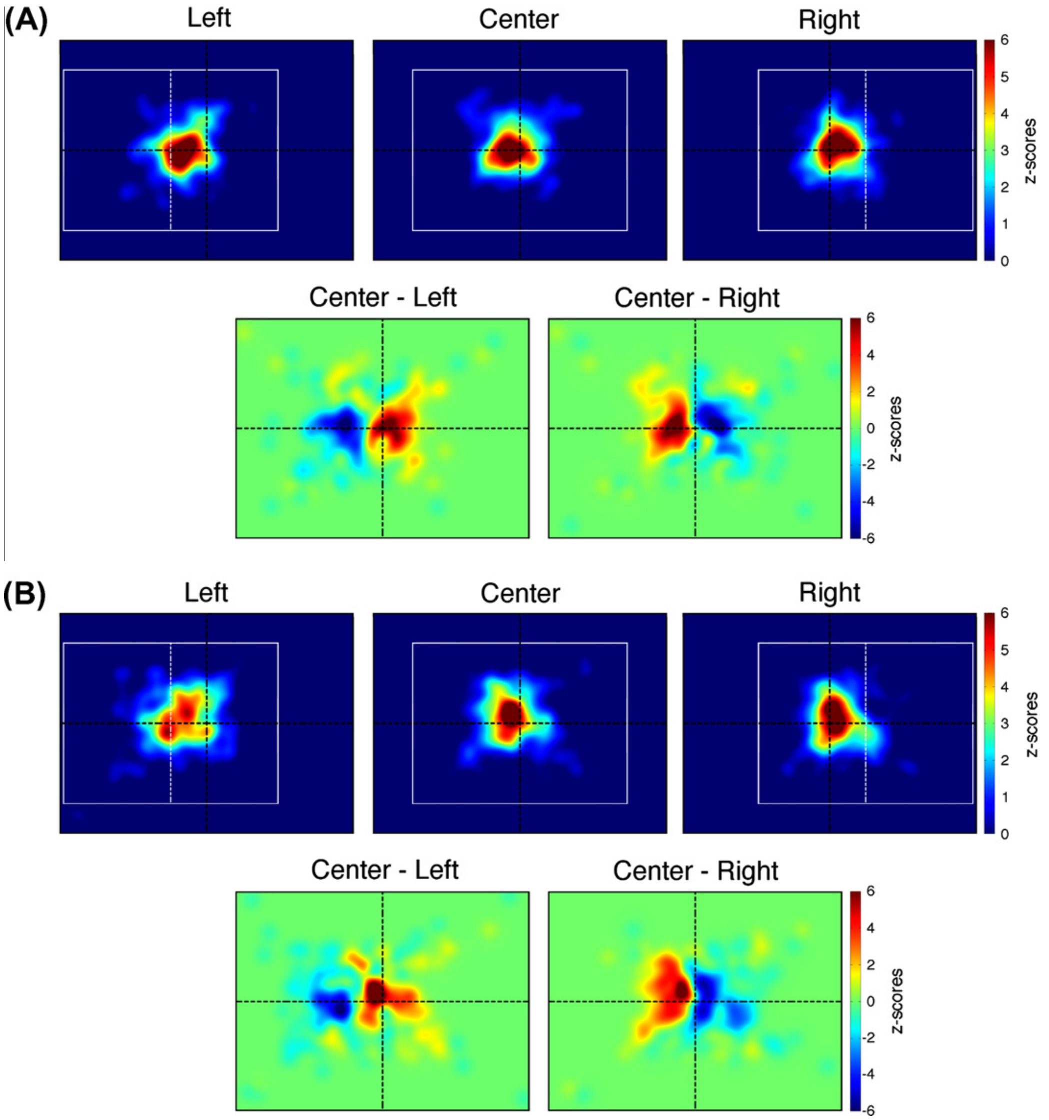

Fig. 8. Gaussian maps of the z-scored distribution of 1st fixations under high (A) and low screen salience (B) for scenes presented left, right, and centrally. In addition, difference maps between the centrally presented and the horizontally displaced scenes are shown. Solid white lines indicate the scene position and dotted white lines illustrate the scene center.

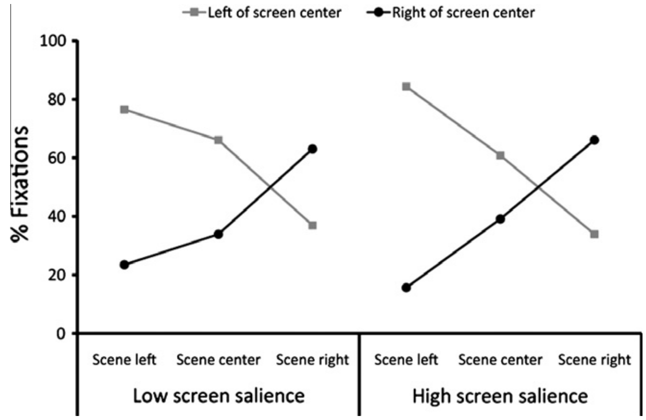

Fig. 9. Mean percentage of first fixations located left and right of the screen center for left, right, and centrally presented scenes for the low and high screen salience conditions.

3.2.3. Fixations by scene center

A further 2 (low vs. high screen salience) × 3 (scene left, scene center, scene right) ANOVA was conducted to compare the proportion of first fixations directed to the left and right side of the scenes (see Fig. 10). This ANOVA did not reveal a main effect of screen salience, $F(1,23) < 1$, but a main effect of scene position, $F(2,46) = 90.60$, $p < 0.001$.

Tukey HSD tests showed that observers were more likely to look right of the scene center in the scene left condition, $q = 11.19$, $p < 0.001$, and, similarly, to the left of the scene center in the scene right condition, $q = 7.74$, $p < 0.001$, compared to the scene center condition. This shows that initial fixations to the scenes were also affected by the center of the screen. In addition, the interaction of screen salience and scene position approached significance, $F(2,46) = 2.77$, $p = 0.07$. Again, however, no differences were found between the low and high screen salience condition for scene center, $F(2,46) < 1$, scene left, $F(2,46) = 1.34$, $p = 0.26$, and scene right displays, $F(2,46) < 1$, suggesting these fixation locations were also unaffected by the relative salience of the screen display.

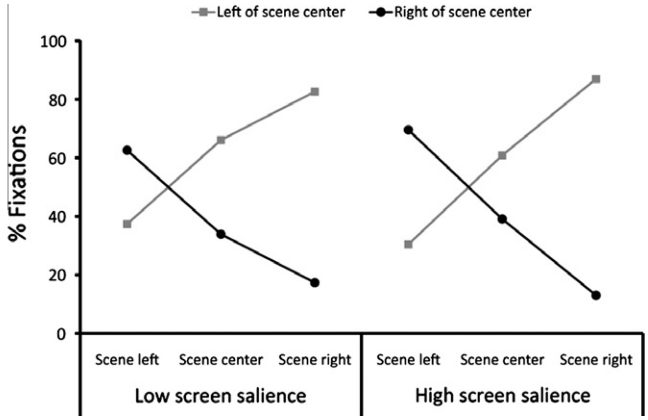

Fig. 10. Mean percentage of first fixations to the left and right of the scene center for left, right, and centrally presented scenes for the low and high screen salience conditions.

3.2.4. The location of the pre-stimulus fixation markers

In a final step, the 1st fixation data was also broken down by the location of the pre-stimulus fixation point that observers focused on immediately prior to scene onset. Recall that these fixation markers were presented in the four corners of the screen and were therefore closer to the scene location on some trials (e.g., a fixation marker on the left side of the screen preceding a scene on the left) than on others (e.g., a left-sided fixation marker preceding a scene on the right). The aim of this analysis was to determine the extent to which these fixation markers influenced initial eye movements. For this analysis, the data was collapsed across the high and low screen salience conditions and the trials on which the fixation markers were presented on the same side of the screen (i.e., top and bottom corner) were pooled into *left* and *right fixation marker* conditions. The differences between the fixation distributions for these conditions were then calculated for scene left, scene center and scene right displays. These distributions are displayed in Fig. 11.

Fig. 11 shows that the location of the fixation points influenced initial eye movements to the scene displays. In all conditions, the distribution of fixations was anchored in the direction of these pre-stimulus markers, so that a fixation following a left-sided marker fell further left compared to fixations made following a right-sided marker. Visual inspection of these distributions suggests further that the influence of the fixation markers might underlie the separable tendencies to fixate the scene and the screen center. Thus, when a scene is presented close to the pre-stimulus fixation marker, the initial fixations to that scene fall closer to its center. And when a scene appears further from the fixation marker, initial eye saccades land closer to the screen center.

To analyze these differences further, the average onscreen location of the 1st fixations was calculated for the three scene conditions (left, center, and right). The horizontal distance between these fixation locations (specifically, between the average fixation locations to scene left and scene center displays, and between scene center and scene right displays) was then calculated for the left and right fixation marker conditions (see Fig. 12). This data shows that this inter-fixation distance was similar between scenes closest to the pre-stimulus fixation marker and scenes in the center *and* between centrally presented scenes and scenes farthest from the fixation marker.

These observations were confirmed by a 2 × 2 ANOVA with factors fixation marker (left vs. right) and fixation displacement (the

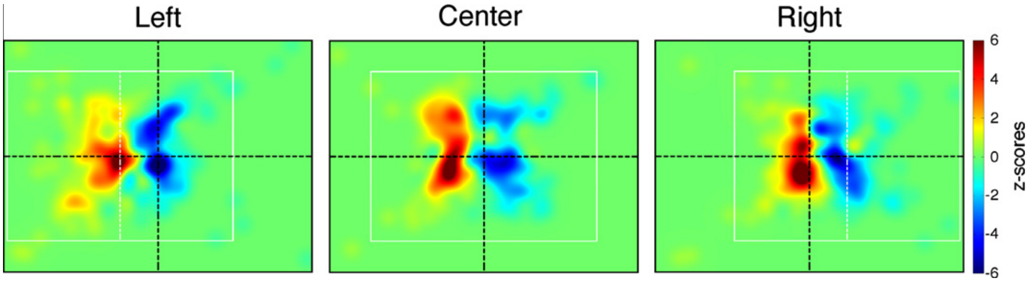

Fig. 11. The distribution of first fixations for scenes presented left, right, and in the center of the screen display as a function of the location of the pre-stimulus fixation marker. These figures represent the difference maps between scenes preceded by a fixation marker located on the left and on the right (left minus right).

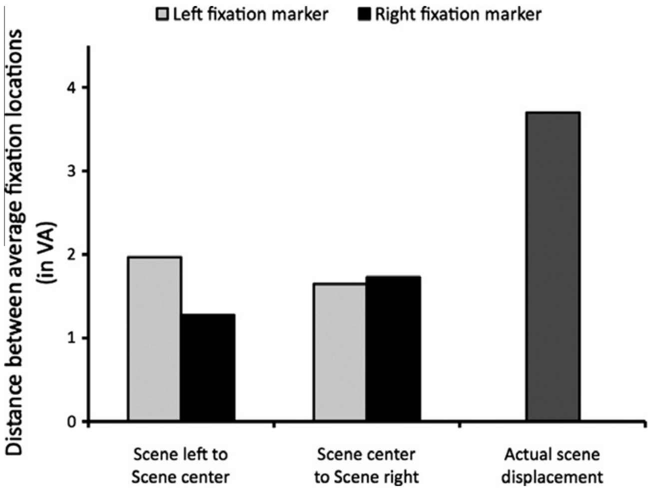

Fig. 12. The horizontal distance (in VA) between the average fixation location in scene left and scene center displays, and between scene center and scene right displays, as a function of the location of the pre-stimulus fixation markers (left vs. right). The actual horizontal displacement between the scenes is also shown (see Section 2.1 of Experiment 1).

horizontal distance between the average fixation locations for: scene left vs. scene center displays, scene center vs. scene right displays). This analysis showed a main effect of fixation marker, $F(1, 23) = 4.72$, $p < 0.05$, reflecting a larger fixation displacement for eye movements originating from the left side of the screen. Importantly, however, no main effect of fixation displacement, $F(1, 23) < 1$, and no interaction between both factors was found, $F(1, 23) = 2.11$, $p = 0.16$. This indicates that the horizontal distance between the average fixation locations in the scenes was unaffected by the scenes' proximity to the initial fixation position. This suggests that observers' eyes are drawn equally by the scenes here, regardless of their spatial proximity to the pre-stimulus fixation markers.

4. Discussion

This experiment set out to explore whether the bias towards the scene center in Experiment 1 was driven by the person content of the scenes and the task demands. To address this issue, Experiment 2 employed a free-viewing task with scenes in which no people were present. In addition, this experiment investigated the role of the relative salience of the screen in the central viewing biases, by manipulating the lighting conditions under which the experiment was conducted. The results replicate the main findings of Experiment 1 by demonstrating complementary viewing biases that appear to be driven by both the center of the scenes and the center of the screen. This demonstrates that these biases do not arise from the person content or viewing strategies that are tied to the person detection task, but also appear under free exploration of visual scenes. Moreover, these central biases also appear impervious to lighting differences in viewing conditions, suggesting that the low-level visual salience of the display screen contributes little to these effects.

Observers' viewing patterns were also analyzed by the location of the pre-stimulus fixation markers. This analysis showed, unsurprisingly, that the distribution of fixations was anchored in the direction of these fixation markers, so that any saccades following a left-sided marker landed at an onscreen location further left, compared to saccades made from a right-sided fixation point. Initial visual inspection of this data hints that the influence of these pre-stimulus markers may underlie the separate tendencies to fixate the scene and the screen center here (see Fig. 11). Thus, when the scene center is closest to the pre-stimulus marker, more fixations fall near the center of a scene, but when the scene center is furthest from the fixation marker, observers look nearer to the screen center.

On closer analysis, however, this data shows that fixations were displaced horizontally by a corresponding margin by scenes that appeared close to the pre-stimulus fixation marker and scenes presented further away (see Fig. 12). This suggests that observers are drawn to the scenes irrespective of their pre-stimulus viewing position and the onscreen location of the scenes. At the same time, it is notable that these effects equate only to approximately half of the horizontal displacement between the three scene conditions. This suggests that the scenes consistently pull the observers' gaze to their onscreen location but do not do so fully. This is therefore in line with a bias to look at the center of the scenes *and* a complementary tendency to also direct eye movements to the center of the screen.

5. General discussion

In visual perception experiments, observers tend to initially fixate the center of a scene that is presented on a computer screen. This study examined whether this central fixation bias is driven by the center of a scene or the center of the screen. To dissociate these possibilities, observers searched visual scenes for a person in Experiment 1, while these scenes were aligned with the screen center or offset horizontally. Eye movements revealed a consistent central fixation bias immediately after scene onset that was driven by both, the onscreen location of visual *scenes* and a complimentary tendency to look at the center of the *screen*. Specifically, the results showed a central viewing bias that shifted left when scenes appeared on the left side of the screen and shifted right when the scenes were displaced horizontally in this direction, but that was influenced by a complementary tendency to anchor eye movements to the screen center.

The current findings go further and rule out a number of factors that might underlie these effects. Firstly, Experiment 1 demonstrates that initial saccade landing positions were modulated by the person content of scenes. This suggests that the central *scene* bias does not reflect a simple onset capture effect (see, e.g., Theeuwes, 1994; Yantis & Jonides, 1984), but involves at least some limited processing of social scene content prior to the 1st fixation. Overall, however, the people in scenes were rarely fixated at this early stage as the central viewing biases predominantly determined eye guidance. Experiment 2 provides further evidence that these central scene viewing tendencies are not related to the person content of the scenes or the demands of the person detection task, but are also found in a free-viewing task and when no people are present in visual scenes.

Experiment 2 also shows that these effects cannot be explained by the proximity of a pre-stimulus fixation marker to the scene center. While eye movements were clearly biased in the direction of these fixation markers, the horizontal distance between the average fixation location was equivalent between the scenes that appeared closest to the location of the fixation marker and scenes in the center of the screen, and between scenes in the center and scenes furthest away (see Fig. 12). This demonstrates that the scenes draw the observers' gaze irrespective of their onscreen location.

However, while initial fixations were clearly drawn in the direction of the displaced scenes, these fixations did not reach the scene center. In fact, the horizontal displacement of eye fixations in the direction of the scenes equated to only half of the scene displacement. This shows that, while the scenes consistently pull the observers' eyes to their onscreen location, they do not manage to do so fully. These findings reveal a parallel effect whereby initial fixation positions are not only determined by the location of the scenes but also by the center of the screen. These complementary effects appear similar in size (e.g., c.f., Figs. 4 and 5) but a direct comparison is not made here; presumably the relative magnitude of these effects is influenced by factors such as screen dimensions, the degree of scene displacement, and the contrast polarity between the scenes and the screen background (see, e.g., Deubel, Wolf, & Hauske, 1984; Findlay, 1982; Findlay & Gilchrist, 1997). While these factors are not examined here, Experiment 2 does also indicate that the central viewing biases are unaffected by external lighting conditions during scene viewing. This suggests that, while the screen clearly forms a spatial reference frame for observers' eye movements here, this is not a low-level effect that is simply driven by the salience of an illuminated monitor in a dark room.

These results present an important finding. The central viewing bias appears to be an integral feature of visual perception experiments that can account for a substantial proportion of human behavior during eye guidance (see, e.g., Tatler et al., 2005; Vincent et al., 2009). The current findings suggest that this effect reflects a tendency to fixate the center of visual scenes, as observers are drawn to the onscreen location of scenes even when these are offset from the screen center. It is possible that this reflects an advantageous viewing position for extracting information from scenes (see, e.g., Najemnik & Geisler, 2005; Renninger et al., 2007). At the same time, however, the current study also demonstrates that these central viewing tendencies reflect, in part, an experimental artifact that arises from the onscreen presentation of visual scenes. This artifact appears difficult to remove in a laboratory setting. For example, the current study shows that it cannot be eliminated by offsetting scenes from the screen center, by varying the onscreen location of a preceding fixation marker, or by manipulating the relative salience of the screen. In addition, this bias appears to be largely unaffected by the distribution of visual features in a scene (Tatler, 2007). It appears that scene content of high social relevance may form an exception to this rule, as people in scenes can exert a moderate influence on saccade landing positions. However, even under these conditions people are rarely fixated immediately after the onset of a display, which demonstrates that the central viewing tendency predominantly determines initial fixation positions (see also Bindemann et al., in press). Taken together, these findings suggest that the screen-based central fixation bias might be an inescapable feature of scene viewing under laboratory conditions.

In real life, visual information is not constrained by the spatial dimensions of a computer screen. Screen-based artifacts such as a central viewing bias therefore raise questions concerning the extent to which laboratory experiments generalize to the real world. The alternative – eye-tracking observers outside the laboratory – is a technically challenging scenario in which it is difficult to control extraneous variables. However, some recent studies with dynamic visual displays show that this is becoming increasingly feasible. Cristino and Baddeley (2009), for example, recorded eye movements while observers viewed real-life video footage on a computer screen. Modeling of these eye movements also showed that a central location has some predictive power of viewing behavior. However, eye movements were accounted for best by a slightly different reference point in the middle of the visual field, which is linked to the perceived location of the horizon. These fixation patterns to moving video suggest, therefore, that vision in real life may also utilize some sort of central reference frame (see also Vincent et al., 2009). However, this study still presented visual information, albeit in the form of dynamic visual displays, on a computer screen. This leaves in doubt the extent to which these viewing biases are scene- or screen-based effects.

In another recent study, 't Hart et al. (2009) employed a mobile eye-tracking setup to compare eye movements during the free exploration of outdoor scenes with video footage of the same outdoor environment in a laboratory setup. In the latter setting, a central viewing bias was found that was strongest when observers watched a stream of 1-s video clips compared to when a coherent video clip was shown. In contrast, this bias was noticeably weaker in the free exploration condition. This suggests that a central viewing location is used initially when visual information appears *onscreen*, but that this location may be less influential in real world exploration. The current experiments extend these findings by showing that these viewing biases are not directed solely to the center of visual scenes, but are also determined by the center of the screen. These findings therefore confirm studies that have highlighted the central viewing bias as a potential artifact in laboratory settings (e.g., Bindemann et al., in press; Tatler, 2007; 't Hart et al., 2009). This is an important finding that needs to be considered in future studies of visual perception.

References

't Hart, B. M., Vockeroth, J., Schumann, F., Bartl, K., Schneider, E., König, P., et al. (2009). Gaze allocation in natural stimuli: Comparing free exploration to head-fixed viewing conditions. *Visual Cognition, 17*, 1132–1158.

Bindemann, M., Burton, A. M., Langton, S. R. H., Schweinberger, S. R., & Doherty, M. (2007). The control of attention to faces. *Journal of Vision, 7*(10):15, 1–8.

Bindemann, M., Scheepers, C., & Burton, A. M. (2009). Viewpoint and center of gravity affect eye movements to human faces. *Journal of Vision 9*(2):7, 1–16.

Bindemann, M., Scheepers, C., Ferguson, H. J., & Burton, A. M. (in press). Face, body, and center of gravity mediate person detection in natural scenes. *Journal of Experimental Psychology*: *Human Perception and Performance*.

Blais, C., Jack, R. E., Scheepers, C., Fiset, D., & Caldara, R. (2008). Culture shapes how we look at faces. *PLoS ONE, 3*, 1–8.

Birmingham, E., Bischof, W. F., & Kingstone, A. (2008). Gaze selection in complex social scenes. *Visual Cognition, 16*, 341–355.

Buswell, G. T. (1935). *How people look at pictures: A study of the psychology of perception of art*. Chicago: University of Chicago Press.

Cristino, F., & Baddeley, R. (2009). The nature of visual representations involved in eye movements when walking down the street. *Visual Cognition, 17*, 880–903.

Deubel, H., Wolf, W., & Hauske, G. (1984). The evaluation of the oculomotor error signal. In F. W. Johnson & A. G. Gale (Eds.), *Theoretical and applied aspects of eye movement research*. Amsterdam: North-Holland.

Downing, P. E., Bray, D., Rogers, J., & Childs, C. (2004). Bodies capture attention when nothing is expected. *Cognition, 93*, B27–B38.

Findlay, J. M. (1982). Global visual processing for saccadic eye movements. *Vision Research, 22*, 1033–1045.

Findlay, J. M., & Gilchrist, I. D. (1997). Spatial scale and saccade programming. *Perception, 26*, 1159–1167.

Langton, S. R. H., Law, A. S., Burton, A. M., & Schweinberger, S. R. (2008). Attention capture by faces. *Cognition, 107*, 330–342.

Lindsay, P. H., & Norman, D. A. (1977). *Human information processing* (2nd ed.). New York: Academic Press.

Mannan, S., Ruddock, K. H., & Wooding, D. S. (1995). Automatic control of saccadic eye movements made in visual inspection of briefly presented 2-D images. *Spatial Vision, 9*, 363–386.

Mannan, S., Ruddock, K. H., & Wooding, D. S. (1996). The relationship between the locations of spatial features and those of fixations made during visual examination of briefly presented images. *Spatial Vision, 10*, 165–188.

Mannan, S., Ruddock, K. H., & Wooding, D. S. (1997). Fixation sequences made during visual examination of briefly presented 2-D images. *Spatial Vision, 11*, 157–178.

Najemnik, J., & Geisler, W. S. (2005). Optimal eye movement strategies in visual search. *Nature, 434*, 387–391.

Parkhurst, D. J., Law, K., & Niebur, E. (2002). Modeling the role of salience in the allocation of overt visual attention. *Vision Research, 42*, 107–123.

Parkhurst, D. J., & Niebur, E. (2003). Scene content selected by active vision. *Spatial Vision, 16*, 125–154.

Rayner, K., & Pollatsek, A. (1989). *The psychology of reading*. Englewood Cliffs, NJ: Prentice-Hall.

Reinagel, P., & Zador, A. M. (1999). Natural scene statistics at the center of gaze. *Network, 10*, 341–350.

Renninger, L. W., Vergheese, P., & Coughlan, J. (2007). Where to look next? Eye movements reduce local uncertainty. *Journal of Vision 7*(3):6, 1–17.

Ro, T., Friggel, A., & Lavie, N. (2007). Attentional biases for faces and body parts. *Visual Cognition, 15*(3), 322–348.

Tatler, B. W. (2007). The central fixation bias in scene viewing: Selecting an optimal viewing position independently of motor biases and image feature distributions. *Journal of Vision* 7(14):4, 1–17.

Tatler, B. W., Baddeley, R. J., & Gilchrist, I. D. (2005). Visual correlates of fixation selection: Effects of scale and time. *Vision Research, 45*, 643–659.

Theeuwes, J. (1994). Stimulus-driven capture and attentional set: Selective visual search for color and visual abrupt onsets. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 799–806.

Vincent, B. T., Baddeley, R., Correani, A., Troscianko, T., & Leonards, U. (2009). Do we look at lights? Using mixture modeling to distinguish low- and high-level factors in natural image viewing. *Visual Cognition, 17*, 856–879.

Vitu, F., Kapoula, Z., Lancelin, D., & Lavigne, F. (2004). Eye movements in reading isolated words: Evidence for a strong bias towards the center of the screen. *Vision Research, 44*, 321–338.

Yantis, S., & Jonides, J. (1984). Abrupt visual onsets and selective attention: Evidence from visual search. *Journal of Experimental Psychology: Human Perception and Performance, 10*, 601–621.