Display Blindness? Looking Again at the Visibility of Situated Displays using Eye Tracking

Nicholas S. Dalton
Pervasive Interaction Lab,
The Open University,
Milton Keynes, UK
sheep.dalton@open.ac.uk

Emily Collins
UCL Interaction Centre
University College London
London, UK
e.collins@ucl.ac.uk

Paul Marshall
UCL Interaction Centre
University College London
London, UK
paul.marshall@ucl.ac.uk

ABSTRACT

Observational studies of situated displays have suggested that they are rarely looked at, and when they are it is typically only for a short period of time. Using a mobile eye tracker during a realistic shopping task in a shopping center, we show that people look at displays more than would be predicted from these observational studies, but still only short glances and often from quite far away. We characterize the patterns of eye-movements that precede looking at a display and discuss some of the design implications for the design of situated display technologies that are deployed in public space.

Author Keywords

Public displays;eye tracking;display blindness; space

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous

INTRODUCTION

Public and situated display technologies are increasingly common in many urban spaces. These include advertising displays on bus stops, interactive screens providing information to tourists or shoppers, and large screens in transport hubs showing travel information as well as news and advertising content.

Situated display research has also been prominent in HCI, ranging from studies of community displays in cafes and village shops [30] to large interactive games in public spaces [24] and techniques to allow users to interact with different configurations of display and personal technologies.

Despite this significant interest in the potential of situated display technologies in both the commercial and research worlds, observational studies that have assessed the engagement of passers-by with them in real world settings

such as shopping centers or university buildings [12, 23] have suggested that they are actually rarely attended to. Müller et al. [23] characterise this phenomenon as 'display blindness', drawing a parallel with the 'banner blindness' effect seen with online advertising. They suggest that passers-by deliberately don't look at displays because they expect them to show advertising content that is of little interest. Huang et al. [12] suggest, on the basis of extensive observational studies in public settings, that people pay only very brief attention to displays, if at all. They also suggest that displays at eye height are most effective at attracting attention with those placed higher getting significantly fewer glances, that video content tends to be more successful at attracting attention than text, animated text or still images, and counter intuitively, that in some situations smaller displays attract more attention than large ones. Huang et al. also discuss the role of the surrounding context in mediating the attention of passers-by, suggesting that objects in the vicinity sometimes serve to catch people's attention, which then moves to the display. They also observed that even when potential audiences are "captive" – for example, on an escalator moving towards a display – they still pay little attention to it.

Huang et al.'s and Müller et al.'s work has been very influential in public display research, with much subsequent research focusing on interaction techniques or representations that maximize the likelihood of attracting attention [20, 21] or suggesting that displays in public spaces need to blend representations of useful information in with existing advertising content in order to increase people's interest in the technology [2].

The study presented in this paper was motivated by two developments that have occurred since the seminal work of Huang et al. [12] and Müller et al. [23]. Firstly, displays have changed significantly, with much larger displays becoming available in a variety of form factors and the emphasis of advertising on digital displays has changed from the provision of information about brands (e.g. giving information about the price of a holiday) to the provision of aesthetic content designed to evoke positive affective experiences associated with brands (such as showing a video of a tropical beach with the logo of a brand (e.g.[6])). Secondly, mobile eye tracking technologies have become commercially available, making it possible to study

people's looking behaviors in much greater detail than was possible in the earlier observational studies (e.g. [8]).

The goal of the study was to use mobile eye tracking to determine whether, given the changes described above, the display blindness phenomenon still occurs in complex real world environments and what factors are associated with passers-by being most likely to look at displays.

RELATED WORK

Interactive and non-interactive digital displays are becoming a ubiquitous part of many urban environments [2, 6, 12, 20], and have been found to increase customer traffic and create a more welcoming atmosphere in retail contexts such as shopping centres [6]. While the use of displays varies across different situations, the effectiveness of all public displays relies on the assumption that they will be noticed and attended to [23]. However, it has been suggested that this often does not occur in real world contexts such as train stations, department stores and university campuses [12]. Even when they do attract glances, these are usually very brief. This has been termed 'display blindness' [23] (named after the 'banner blindness' effect seen with web page adverts) and may be because participants expect them to feature uninteresting content such as advertisements. In an extensive observational study of a variety of situated displays, Huang and colleagues [12] suggest that glances at public displays are both rare and typically brief (usually less than the 800ms, which would imply that a glance was intentionally directed [19]).

However, certain features of the display itself or the surrounding environment may make 'display blindness' less likely to occur. Previous research has highlighted that animations or videos, bright colours and text (rather than icons) appear to be most successful in catching an individual's attention and encouraging attention to or interaction with a display [12, 16, 21]. Müller et al. [20] summarise work on visual perception, which suggests that bottom-up features of visual stimuli that indicate need for immediate action are most likely to capture attention. These include the abrupt appearance of new objects, luminance contrast changes and stimuli that seem to loom towards the observer. They also cite Itti et al. [13] who propose a model of Bayesian surprise for bottom-up visual attention that also includes expectations of encounters in the world based on prior experience. A different perspective is presented by Rothkopf et al. [28], who criticise these and other findings, which are based on participants viewing stimuli under controlled laboratory conditions and in the absence of a realistic task. They argue that both task and context determine gaze patterns.

In addition to the influence of different kinds of display content on noticability, researchers have also investigated the effects of the spatial and social context of displays. Location in particular, has received substantial attention, as where the display is positioned will influence how it is viewed and, if appropriate, interacted with [1]. One possibility is that longer engagement periods will be associated with areas in which people are likely to be waiting rather than quickly passing through, such as corridors [5, 11]. However, Huang et al. [12] found limited benefits of having such "captive audiences" on looking at screens. They also suggest that smaller displays positioned at eye height encourage more glances than larger displays or those that are positioned higher and that other objects in the vicinity of displays, such as product displays, can attract attention that can then move to the display.

More complex spatial influences, have mostly been investigated with large, interactive installations, such as CityWall [26], or CoCollage [7]. For these kinds of displays, not only does the display itself need to be noticed by passers-by, but they also need to realise it has interactive capabilities and feel comfortable taking part in the interaction (cf. [18]), which is sometimes difficult to achieve [10, 24]. One possibility is to ensure the display is visible to the largest area possible, in particular to those entering the space rather than leaving it [1] Getting a display noticed and encouraging engagement can further influence its visibility through influencing the social dynamics of those around it. Groups of people forming around the display can create a 'honey pot' effect [4], drawing the attention of others.

Despite the high levels of interest in public display technologies, and their ubiquity in many urban environments, there has been a paucity of work that has used eye tracking to understand attention to them. It has long been acknowledged that the location and duration of fixations, as well as more general eye movements can provide a strong indication of how much attention is being paid to particular aspects of an environment or stimulus [19]. Ravnik and Solina [27] who used a display-mounted gaze tracker in a clothes store suggested that 35% of customers who walked past it looked at it for an average period of 0.7s, a significantly higher proportion than might be expected from Huang et al. and Müller et al.'s studies. However, as this system worked by tracking people's faces rather than their eyes, it may have over-estimated the number of looks.

The development of mobile eye tracking technology has greatly expanded the potential for eye-tracking studies in complex real world environments [8]. The few public display studies that have collected mobile eye tracking data have tended to focus on general browsing behaviour in contexts such as museums. However, some have studied eye movements to digital displays on public transport systems [9], reporting a high level of attention being paid to these displays irrespective of content. Although these findings are useful in establishing the utility of such displays on public transport, it is unlikely that the same patterns of engagement would be evident in other contexts; those travelling are likely to be actively searching for an activity to occupy their time or travel information and may be motivated to view the displayed content in a way that

those walking through a shopping centre, for example, may not be. Schrammel et al.[29] conducted a study of participants' eye movements while walking through a shopping street, finding most held a relatively steady gaze in the horizontal middle of the field of view, with a greater orientation to the direction of the shops, which were located to the right of the street. However, research has shown gaze to be highly influenced by the demands of the task (e.g. [8]), making the instruction to simply walk through the street potentially not representative of the motivations of individuals who naturally find themselves in this situation.

The goal of the study presented in this paper was to understand if and when participants in a realistic shopping task in a shopping centre would look at public displays. The organisation of the study is described in the next section.

METHODOLOGY

An ecologically valid in the wild experiment was planned using a mobile eye tracker to record what participants looked at while shopping in a large shopping centre.

Setting

The study was conducted in a large shopping centre (approximately 175,000m^2) in London, UK, which comprises two department stores, a cinema, a supermarket and more than 400 stores and restaurants. It was chosen because it provides an environment with many advertising and information displays (see figure 2), which ensured that participants would pass multiple displays during their shopping task. The centre is spread over three floors. Displays of different sizes are positioned on plinths in the corridors between shops, attached to walls at different heights and are positioned in some shops and shop windows. While many of the displays show advertising content, others are designed to support wayfinding or provide information about the stores, cafes and restaurants within the centre. The study was conducted on weekdays between 10am and 7pm when the shops in the centre were open.

Equipment

A Tobii Glasses mobile eye tracker was used in the study (see figure 1). This comprises a pair of 75g glasses and a 200g recording pack joined by a data cable. These are not significantly heavier than a normal pair of glasses and participants reported that they were unobtrusive. The system recorded a 640x480 pixel movie at 30 frames per second with a recording angle/visual of view of 56° horizontal and 40° vertical. Following calibration, the embedded firmware performs an internal calculation to match the participant's eye movements to the captured video of the scene in front of them. Following recording, Tobii software was used to output video files that superimpose coloured circles onto the video which represent where the eye fixation points (see Figure 2). These were used in the analysis.

Figure 1: Tobii Glasses Mobile Eye Tracking System

Participants

24 participants were recruited for the study, two of whom were excluded from the analysis because they followed a route that didn't go past any displays (straight to a bookshop, where they read books for the duration of the study) leaving 22. Of the 22 participants included in the analysis, 10 were male and 12 female and all right handed. 12 participants reported being unfamiliar with the shopping centre, five somewhat familiar and five very familiar. Ages ranged from 19 to 73. 50% of the participants were British and the rest came from other countries covering 5 continents.

Procedure

The participants were told that the study would investigate what people look at when shopping. No mention was made that displays were the focus of the study.

Participants were paid £10 for participation but were told that there would be a prize draw after the study where one of the participants would receive a gift up to the value of £100. Their task was to find one or more items to spend the money on if they won the draw, which would be paid for by the experimenters. This design was to create an ecologically valid in the wild shopping task, where the participants were focused on shopping for items that were of genuine interest to them.

Participants were met near an entrance to the centre. After reading an information sheet that described the aims of the project they signed a consent form. They were then introduced to the Tobii eye tracking glasses and a calibration procedure was carried out, which typically took less than one minute. The participants were then asked to shop for their gift anywhere in the shopping centre. The shopping task took approximately 15 minutes, after which participants were fully debriefed on the aims of the study, filled in a small demographic questionnaire and were paid.

Analysis

Tobii Studio software was used to convert the eye movements to a fixation point overlaid on the video of the scene – (see the red dots in figure 2). The software can automate much of the process of matching eye fixations to
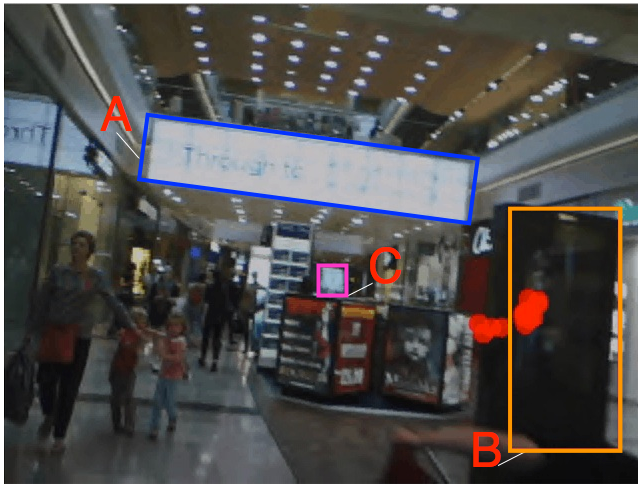
Figure 2: Typical video recording showing eye fixation point in red circle. Potential screens in rectangles

the visual environment. However, automation does not function in the complex spatial environments of a shopping centre. We coded fixations using Anvil software [15] to assist the post-recording analysis process. This was a time consuming process (cf. [14]) taking approximately one day to code each 15 minute video.

We began by focusing on the time that each participant spent wayfinding. Wayfinding [3] was the process of navigating from one location to another in the shopping centre.. During wayfinding, the participants were in motion, engaging in collision avoidance, collecting visual information from the environment, and making decisions about possible destinations. Participants typically only stopped to inspect potential items to purchase. Huang et al. [12] also observed participants when they were 'captured': not in motion, but for example, queuing for a service. During this study none of the participants queued, but some were 'captured' when they stood on moving escalators.

For the duration of the periods of wayfinding, we coded whenever a digital display was available in the video captured by the eye tracker. Each display was given a unique code so that we were able to identify how many times each was fixated on. Figure 2 shows a period when 3 displays (marked as A, B and C) were visible (the red dots denote eye fixations). In the figure, two vertical portrait displays are visible, one in the foreground (B) and one in the background (C). There is also a larger display (A) above eye height, which is also typical of those viewed by our participants. We also coded when participants looked at a display, which we operationalized as two or more consecutive fixations intersecting with the display. If the head moved between fixations (as it often did), then the second fixation would not occur at the same coordinate in the video, but would rather move to compensate for the head movement. We were quite conservative in our coding: for example if the eye followed the edge of a display (as it
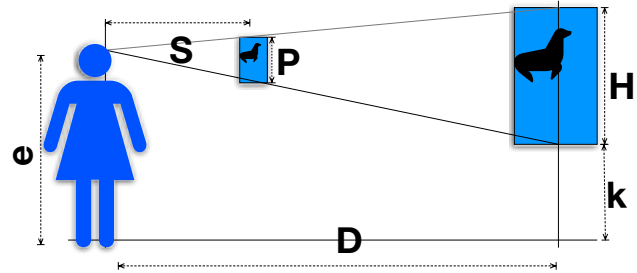

Figure 3: geometry permitting participant's distance to a display to be derived from image measurements

often did), but did not move to the screen, then this was not categorized as looking at a display.

A further code was introduced to record when one of the visible displays noticeably flickered (a large luminance contrast change), which Müller et al. [20] had predicted might attract attention to a display.

The coding was carried out by the first author and seven of the videos were independently coded by a second coder. The inter-rater reliability was calculated through Anvil to give a Cohen's kappa of 0.7.

Distance
We reasoned that if a display was at a fixed height (K in figure 3) above the ground and of a known height (H) in meters, then a measurement of the height of the display in pixels (P) on the video could then be used to estimate the horizontal distance of the participant from the display (D). This was fixed regardless of participant's eye properties (the camera geometry dominated) and would only be weakly influenced by the height of the participant (e). That is if H, S and K are fixed or known, then D is a function of P (see figure 3). In the laboratory we conducted a calibration experiment using the eye tracker. From our calibration experiment we confirmed that the distance from the observer to the screen was a function of the reciprocal of the height in pixels of the screen and our measurements, which gave an R^2 correlation of 0.996 for the relation between screen measurement in pixels and the distance to display. From this we could determine the distance between a display and the participant using only video information.

This distance to screen measure was calculated whenever a screen was first coded as having been looked at. Figure 2 shows a typical participant looking event. A video screenshot image of the first intersection was recorded and the screen dimensions were measured from this (effectively P is the height of the orange box in figure 1). These dimensions could then be used to compute the distance (D) of the participant from the display at the point the display was first noticed. While this could only be done for the eye-height level displays we felt this would give useful objective data for the distribution of 'first view' distances.
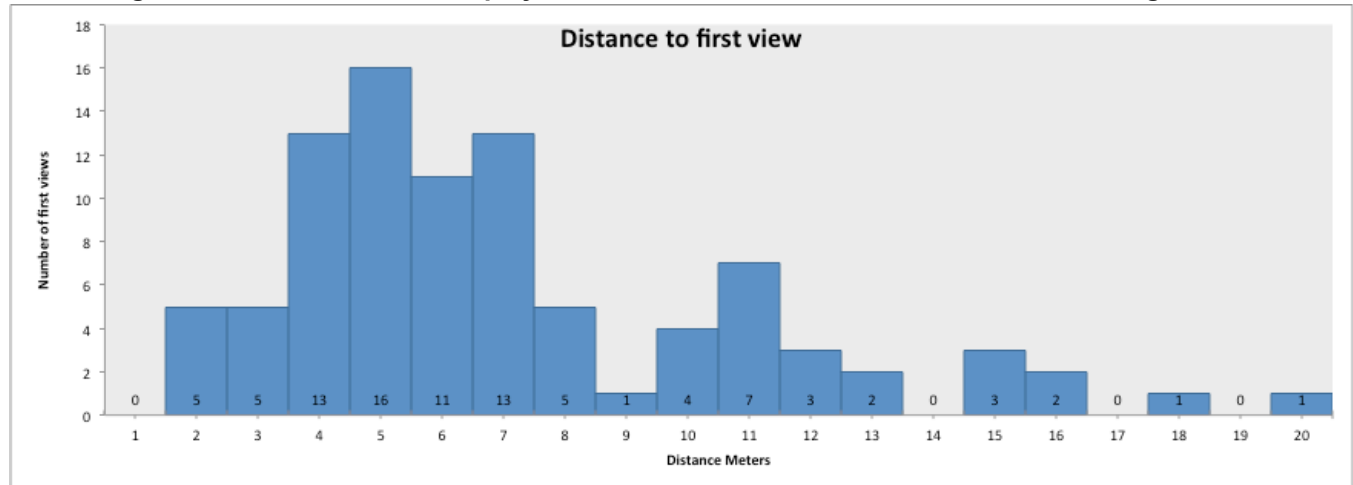
Figure 4: Histogram of frequency of distance to first glance at a display

Due to the nature of the error in pixel measurements, the distance to closer screens could be more accurately measured (+/- 0.2m) than those that were further away, which could be +/- 1.0 m. The histogram of these first view distances is presented in Figure 4.

Comparative viewing data

As well as the above analysis, analysis was conducted of a one minute sample of each video to identify what other environmental features participants attended to whilst wayfinding. A one-minute sub-sample was drawn from the mid-point of the recording, or from the period of wayfinding chronologically closest to the mid-point if the participant was not actively wayfinding at this point. During this one-minute sample **all** of the participant's fixations were exhaustively coded. On average 103 separate fixations were recorded per 1 minute period (min 64, max 124). The fixations were coded as being on: a digital display (looking at a digital display as described), signage (looking at non-digital signage), large text (typically reading the names of shops), architecture (looking at walls, floors, pillars, beams, ceilings or any other architectural feature), people, and products (looking at specific products or into shops). This one-minute sample was used to give some comparative context to the longer wayfinding periods spent collecting only data on digital displays.

RESULTS

Overview

Participants spent a total of 3 hours 43 minutes wayfinding. Each participant engaged in a wayfinding segment for an average of 9 minutes 43 seconds (s.d. 3 minutes 36 seconds). Across all participants, 337 Digital displays were potentially visible for a total of 59 minutes (26% of wayfinding time), giving an average of 2 minutes 36 seconds (s.d. 1 minute 20 seconds) display visibility per participant. Digital displays were potentially noticeable for an average episode of 3.48 seconds (s.d 1.29 seconds) before moving out of the frame (if multiple displays were visible, then this onset of this period was from the first

frame any display was visible and the offset was last frame any display was visible.

Participants each fixated on an average of 16 displays (s.d.= 9, min 3, max 33). The mean period spent fixating on displays during wayfinding was 4.9 seconds (s.d. 2.9 seconds). Each display was fixated on for a mean of 0.318 seconds (s.d. 0.261). While this looks very brief it is informative to compare this with the average time spent looking at other items. From the one-minute mid-wayfinding samples, the mean duration spent looking at different categories of environmental features was also low (see table 1), with the longest non product time being on architectural features. During exhaustive samples participants spent 3.3% of their wayfinding time looking at digital displays.

Category	% of total wayfinding looking time	Average duration of fixation (seconds)
Architecture	38.2%	0.517(∂=0.460)
People	12.7%	0.379(∂=0.247)
Products	39.4%	0.498(∂=0.424)
Signage	1.1%	0.491(∂=0.381)
Large text	5.3%	0.416(∂=0.263)
Digital displays	3.3%	0.340(∂=0.267)

Table 1: Percentages of time looking at all categories of environmental features during 1-minute exhaustive samples

While this is a small proportion of their time it is consistent with the amount of time spent looking at non-digital signage. The longest recorded time looking at a digital display was 2.1 seconds, with most participants looking for maximum of 0.8 seconds. No participant was observed walking up to or attempting to interact with any of the displays, although some were interactive. The duration of

fixation for digital displays in the one-minute sample (0.34 seconds) is consistent with the time found over the entire experiment (0.318 seconds) suggesting that the one-minute samples are reasonably representative of the wayfinding periods.

The majority of displays looked at were 55" plasma screens arranged as portrait plinths. These were typically arranged facing, but just to the side of the main walking paths of the shoppers (see item B in figure 2). These displays were typically located at eye-height, except for some occasions when they were on the floor above or below the participants and visible via an atrium space. Contrary to Huang et al.'s [12] finding that few displays above eye height were attended to, of the 285 distinct observations 72 (25%) of the displays observed were above eye height and 13 (5%) below eye-height. The screens above eye height were large multi-display screens in portrait orientation (see A in figure 1).

Proportion of looks at different displays
Our participants began from the same starting location. As they began walking they had a choice of turning either left or right. In both directions, displays were present on both upper and lower levels of the shopping centre. We decided to take the opportunity to count the number of times a display was looked at against the number of times the participant was in the view field of the display. We picked the 12 displays that were most commonly walked past in the early part of the participant's journey. As the participants continued they would encounter further displays but less frequently.

Table 2 represents the numbers of times that these 12 displays were walked past and as well as actual views as a percentage of possible views. The percentage of times that many of these displays were fixated on was very high given if 'display blindness' is assumed to be a similar phenomenon to banner blindness, although not all displays were viewed as often, and one not at all. For example, display B is a large above-eye display (see A in figure 1), which was fixated on by the majority of participants who walked past it (60%). Display E, which was fixated on by many of the participants who walked past it was an approximately 2m high display on a shop front that was edge-on to the primary flow of most participants. Plinth F, which was fixated on by nearly half of those who walked past it was directly in front of an escalator. It should be noted that displays H-L were all located on a less used route leading to the anchor store, in the centre and were walked past proportionally less than the other displays.

Distance
We captured video pixel measurements for each eye-height display of a known size at the point when a display was first fixated on by a participant. We excluded images in which the display was partly occluded, above or below eye-height or if the display was of an unknown dimension. This produced 92 measurements for all participants.

Display	Looked at	Passed	% looked at
A (Plinth)	7	16	44%
B (Above)	9	15	60%
C (Plinth)	3	13	23%
D (Plinth)	4	15	27%
E (Shop front)	7	15	47%
F (Escalator)	7	15	47%
G (Plinth)	2	5	40%
H (Plinth behind Escalator)	0	5	0%
I (Upper Right)	0	2	0%
J (Plinth)	2	3	40%
K(Plinth)	1	1	100%
L (Plinth)	1	4	25%

Table 2: proportion of participants who noticed a display

From this analysis we discovered that participants first viewed the 55-inch plinth screens (see figure 4) at an average distance of 8.03 meters (28ft) (s.d. 8.99m). The maximum distance we observed a participant looking at the screen was beyond 42 m.

We make two main observations from the distance data. Firstly if an observer was standing near to the display it would be unlikely that they could accurately notice a user observing the screen at a range of eight meters. This may account for the disparity between our findings and those of Huang et al. [12] and Müller et al. [23]. Secondly, 50% of the participants looked at the display for the first time from quite far away, at a distance greater than 8m. We noticed that participants viewed large text (typically reading the name of the shop) at quite large distances as well. It is likely that that shop name signage has already evolved to be readable at the kinds of distances from which people make shopping route-choice decisions.

Qualitative analysis
To further understand how the gaze patterns were influenced by the environment we performed a qualitative analysis of the events leading up to each time a display was fixated on to give a more qualitative understanding of what led to it being looked at. This produced 11 different categories of precursors to looks at a display (see table 3), with only six examples classed as "uncategorised". These uncategorisable examples were principally due to lack of saccade and fixation information prior to the look (e.g. blinking).

Overall, 360 precursors to looking events were coded, the largest category being that of 'looking back' (27%). That is,

Look back (look again)	98	27.2%
Architecture	86	23.9%
Scan and hit	66	18.3%
People (honeypot)	44	12.2%
Bright display	19	5.3%
Dark display	15	4.2%
Screen flickered	9	2.5%
Eye lead from products	7	1.9%
Revelation	6	1.7%
Path block	4	1.1%
Uncategorised	6	1.7%

Table 3: events preceding noticing a display

quickly looking back at the display once it has already been glanced at. This seemed to be the eye tracking equivalent of Müller's et al.'s 'landing effect' [22], where people first walk past an *interactive* display, before walking back to use it. This might be due to users needing time to comprehend the information displayed or possibly that they were re-looking at the display as a way of triangulating their position in space.

The second most common precursor to a look at a screen was where the saccade pattern followed some feature of the building's architecture or interior design (vertical pillar, floor, or most commonly ceiling) before moving to a display. For the smaller vertical plinth displays, following lines of perspective would frequently lead to these displays being looked at from quite far. Due to their position, the larger landscape displays, were often looked at after the saccade pattern following the edge of the ceiling lead the eye to the display.

18% of gazes on a display followed a large rapid eye movement, including turning the head and ending with the gaze fixating on one of the displays. We have called these 'scan and hit'. These events had the largest saccade distances prior to the display discovery.

Another theme that links to one established prior to observation is the 'honeypot effect' [4]. We generalized this to any event where the eye was drawn to the display by the proximity of another person or group of people near that display. We noticed no occasion where the other person was overtly looking at or interacting with the display themselves, thus this is a more subtle example of the honeypot effect that has previously been described. In our study this preceded 12% of all fixations on displays.

For 'bright display' events there was high contrast between the luminosity of the display and that of the surroundings. This made the display stand out against the darker background (e.g., when a display was shaded by having an escalator above it). These comprised approximately 5% of

the display looks. On occasion the displays could also be very dark with very bright surroundings, we found that 4% of displays discovery events happened when this occurred. Collectively these contrast events occurred 9% of the time.

It might be expected that large changes in the visual field, such as high luminance changes on a screen might be attention grabbing (cf. [20]). However, of the 52 observed examples of a large change, only 9 led the participant to look at the screen and a look following a flicker only comprised 2.5% of the overall looking events, This seems to contradict the intuition that moving and changing displays should 'catch the eye'.

Among the smallest saccades distances away in a display was discovered after looking at a product (2%). These precursors to a fixation were typically with displays within the shop rather than in the larger way-finding area; given the visual separation between product and displays this is not surprising. Related to this were a number of what we term 'revelation' events. These were where the eye was drawn to a display following the screen suddenly becoming visible following one or more people standing or walking in front of it and then moving away to reveal it. These accounted for 1.7% of screen fixation events.

A similar low-frequency event (1.1%) was when the display blocked the path of a participant's movement. At this point the display was normally very large and in front of the participant and it would be difficult for them to ignore it.

LIMITATIONS

Before discussing the implications of these findings it is necessary to highlight some of the limitations of eye tracking systems. Huang et al. [12], cite Müller et al. [19] in suggesting that any dwell time under 800ms is not under conscious control. Our data suggest that nearly all (96%) of participants' gazes in the environment were under this 800ms threshold but this does not mean that they were not processing any perceptual information or that they were not conscious of features in the environment, only that they were not typically consciously choosing to look at the displays (e.g., reading the text of an advert).

A further limitation is that the algorithmically generated 'fixation' produced by the Tobii software, which is a cluster of small saccades, is not designed to work with mobile eye tracking data, where head movements, etc. make the algorithmic calculation of a fixation point very challenging. Our approach in coding the data was to go through frame-by-frame, and to only count a gaze behaviour if two or more consecutive fixations were on the same object. This meant that the fixation had to be on the object itself, and if the head moved between fixations (as it often did), then the second fixation would not occur at the same coordinate in the video, but would rather move to compensate for the head movement.

The Tobii glasses also have a visual error of 1°, which means that the accuracy of a fixation decreases as object distance increases. At the distances where most displays

were viewed, this translates into an error of 9-13cm, but there is a potential error of 73cm at the upper range. Because of this potential error, we were quite conservative in our coding: for example if the eye followed the edge of a display (as it often did), but did not move to the screen itself, then this was not categorized as looking at a display.

The use of mobile eye tracking in public also raises questions about the validity of participants being overly self-conscious during the experiment and changing their behaviour. Our participants did informally report that after wearing the glasses for a short time, they ceased to be overly self-conscious. This would seem to be supported by examples in our data of what can only be described as "checking out" other shoppers. However, it is probably intrinsic to any eye tracking study that some kind of increased self-consciousness is inevitable. Participants were still unaware of the focus of our study and therefore we believe that our findings are still of value to researchers interested in public displays.

DISCUSSION

This study builds on the initial work of Huang et al. [12] and Müller et al. [23] using the new approach of mobile eye tracking to test, augment and challenge the phenomenon of 'display blindness'. Here we discuss each of our main findings, introducing some implications for design and future work on public displays.

Participants were not 'blind' to the displays

Previous studies that took an observational approach to study whether passers-by look at situated displays in real world environments have suggested that people rarely look at them and when they do it is for only a short period, a phenomenon that has been described as 'display blindness' [23]. Our findings suggest that this term may exaggerate people's lack of engagement with situated displays, as all but one of the displays were looked at by a sizeable proportion of the participants.

Reasons for this disparity would seem likely to be related to the challenges of observing when a passer-by is and is not looking at something. It is probable that the previous observational studies were only able to identify a subset of glances at the displays. A second possibility is that changes in the size, design, placement or content of displays (cf. [6]) since initial studies of situated displays were carried out mean that they are more effective in attracting attention.

However, confirming Huang et al.'s [12] observations, participants rarely looked at displays for long: typically around a third of a second. This suggests that most glances at displays were reflexive and simply an aspect of navigating through the busy shopping centre, rather than intentional [19]. However, they were still of a timescale that would enable participants to perceive and cognize information from the display (e.g. [8]). The phenomenon of looking and then looking back at the displays would seem to suggest that something on the display attracted the attention of the participant, who then looked back at it to pick up more information.

This has implications for the design of situated display technologies, as if designers want to grab people's attention, and particularly encourage them to engage with *interactive* displays, then they might need to do so in a way that uses a very simple representation that is easy to perceive and understand in a short space of time. Similarly, if the goal is to convey some information to the passer-by, then it needs to be represented in a format that can be apprehended and understood very quickly. Many of the displays that we saw in the shopping center seemed to be designed to create more of an aesthetic experience than to convey information [6], in which respect they may have been more successful in adding to the generally pleasant and visually interesting design of the centre.

Displays were often looked at from far away

Using simple geometric calculations we were able to estimate the distance at which some of the displays were first glanced at. This proved to be from further away than might have been expected: looking at the graph in figure 4, there is a peak of first glances at around 11 meters and then a larger peak at around 5 meters. This goes some way to explaining the previous underestimation of the proportion of looks at displays in observational work [12, 23], as it would be very difficult to determine from this distance what passers-by are looking at without access to a mobile eye tracker. Again, this finding has implications for the design of situated displays in the wild. If the first glance at a display is from 5 or 11 meters away, then any information on the display will need to be able to be perceived from this distance, which will significantly limit the font size of any text used or the complexity of any graphical representation.

Context matters in attracting glances to a display

Huang and colleagues [12] described how objects such as products in the vicinity of displays could attract the attention of passers-by, which would then move to the displays themselves. Our eye-tracking study supports and adds detail to this finding. In particular, our participants were seen to look at displays following looks at architectural features, with fixation patterns often following lines such as ceilings or wall edges to the displays. Participant's attention also seemed to be attracted to the displays by the proximity of other people: this is like the 'honey pot' effect described by Brignull and Rogers [4], but nearby people did not need to be particularly engaged with the display. Architects and interior designers might be able to use these findings in considering where the optimal location might be to position a display, for example at the end of a long piece of furniture or at the end of a line projected from some architectural feature. Researchers and interaction designers may also be able to use the proximity of people to a display, not only to attract their attention, but to attract the attention of others in the environment who might be further away. Again to design elegant interaction

techniques that work robustly in a busy environment such as a shopping center will present many challenges.

Higher and bigger displays seem to attract at least as much attention as smaller displays at eye height

Huang et al. [12] suggested that displays positioned at eye height received more looks than displays that were positioned higher and that larger displays seemed not to attract more glances than small ones. Neither of these findings held in our study. Although, we do not have enough data for inferential statistics, the large displays in the shopping center that were positioned high above people's heads seemed if anything to attract more looks than the smaller eye height plinth displays. Two possible explanations for this disparity are that Huang et al.'s observational approach may have underestimated the number of glances at larger displays from further away. A second explanation is that the displays in the shopping center showed different kinds of content to the displays observed by Huang and colleagues. Many of the images of displays visible in their paper seem to be relatively heavy on text, which might be difficult to read from below. As described by Dennis and colleagues [6], there is now more of an emphasis in retail contexts on "atmospherics": using displays and other features of the environment to create a pleasing and interesting atmosphere to generate positive associations with brands rather than to provide information. Where the displays were used to provide information, messages were typically short, and used very large fonts.

Static luminance differences seem more important than luminance changes

We had anticipated that the kinds of visual changes that might be expected to require immediate action [2, 20], such as large variations in luminance, or that would be characterized by a model of Bayesian surprise [13] might attract attention. However, we found limited evidence for this, with most significant changes in the luminance of displays being ignored. A possible explanation for this comes from alternative models of human gaze deployment that suggest a much stronger role for both task and context in determining where people look [8, 29]. The environment of the shopping center was visually very busy, and the participants were engaged in a realistic shopping task, so bottom-up visual salience might have had less of an effect than it would have done in a calmer visual environment, or one where participants were engaged in some other task.

Where luminance did seem to have an effect was where the brightness of displays seemed to grab participants' attention when they scanned around the space with large head movements. We characterized these as "scan and hit", and suggest that it was the relative brightness of the displays that led to the gaze settling on them. A similar phenomenon, but without large head movements was observed whereby bright displays against relatively dark backgrounds and dark displays against relatively bright backgrounds seemed to 'pop out' and attract more looks than other displays. This is, however, quite speculative and

further work would be required to validate this finding. If it is found to generalize, then designers might think more explicitly about the relationship between a representation on a display and the visual context around it.

CONCLUSION

There is a significant amount of work in HCI research on the design of different display technologies, particularly interactive displays to be used in public spaces. It is premised on the idea that people will actually notice these displays, pick up information from them and choose to interact. The 'display blindness' effect seemed to suggest that this premise may be questionable [12, 23]. By using mobile eye tracking, we have been able to uncover more detail about exactly when people do look at interactive displays and have presented a more nuanced perspective than 'display blindness', which should aid designers and researchers in developing new mechanisms to attract and hold their attention (cf. [1, 2, 10, 17, 20, 21, 25]) and to encourage them to interact with these devices.

However, this study has only investigated the engagement of people engaged in a shopping task with situated displays in a single retail context. Significantly more work needs to be carried out to understand the relative contribution of task and context on patterns of looking at displays and other kinds of situated technologies in a variety of real world environments (cf. [29]).

Observational studies in real world environments have questioned the extent to which people look at situated displays. In this study, we have used mobile eye tracking to demonstrate that people in a shopping center do look at displays more than had initially been thought, but only for short period of time, and often from quite far away. A qualitative analysis of what precedes looking at a display has allowed us to categorize different patterns of behavior that may be of use to researchers and designers who seek to develop situated technologies for public spaces.

ACKNOWLEDGEMENTS

REFERENCES

1. Akpan, I., Marshall, P., Bird, J., and Harrison, D. Exploring the effects of space and place on engagement with an interactive installation. In *Proc. CHI 2013,*, ACM Press (2013), 2213–2222.

2. Alt, F., Schneegaß, S., Schmidt, A., Müller, J., and Memarovic, N. How to Evaluate Public Displays. In *Proc. PerDis 2012*, ACM Press (2012), 17:1–17:6.

3. Arthur, P. and Passini, R. *Wayfinding: people, signs, and architecture.* 1992.

4. Brignull, H. and Rogers, Y. Enticing people to interact with large public displays in public spaces. In *Proc. INTERACT*, (2003), 17–24.

5. Churchill, E.F., Nelson, L., and Denoue, L. Multimedia fliers: Information sharing with digital community bulletin boards. In *Proc. C&T 2003,* Springer (2003), 97–117.

6. Dennis, C., Brakus, J.J., Gupta, S., and Alamanos, E. The effect of digital signage on shoppers' behavior: The role of the evoked experience. *Journal of Business Research 67*, 11 (2014), 2250–2257.

7. Farnham, S.D., McCarthy, J.F., Patel, Y., et al. Measuring the impact of third place attachment on the adoption of a place-based community technology. In *Proc CHI 2009*, ACM Press (2009), 2153–2156.

8. Hayhoe, M. and Ballard, D. Eye movements in natural behavior. *Trends in Cognitive Sciences 9*, 4 (2005), 188–194.

9. Höller, N., Schrammel, J., Tscheligi, M., and Paletta, L. The Perception of Information and Advertisement Screens Mounted in Public Transportation Vehicles-Results from a Mobile Eye-tracking Study. In *Proc. 2nd Workshop on Pervasive Advertising*, (2009).

10. Houben, S. and Weichel, C. Overcoming interaction blindness through curiosity objects. In *Proc. CHI'13 Extended Abstracts*, ACM Press (2013), 1539–1544.

11. Houde, S., Bellamy, R., and Leahy, L. In search of design principles for tools and practices to support communication within a learning community. *ACM SIGCHI Bulletin 30*, 2 (1998), 113–118.

12. Huang, E.M., Koster, A., and Borchers, J. Overcoming assumptions and uncovering practices: When does the public really look at public displays? In *Proc. Pervasive Computing*. Springer, 2008, 228–243.

13. Itti, L. and Baldi, P.F. Bayesian surprise attracts human attention. *Advances in Neural Information Processing Systems*, (2005), 547–554.

14. Jacob, R.J. and Karn, K.S. Eye tracking in human-computer interaction and usability research: Ready to deliver the promises. *Mind 2*, 3 (2003), 4.

15. Kipp, M. and others. Spatiotemporal Coding in ANVIL. *LREC*, (2008).

16. Kukka, H., Oja, H., Kostakos, V., Goncalves, J., and Ojala, T. What makes you click: exploring visual signals to entice interaction on public displays. In *Proc. CHI 2013*, ACM Press (2013), 1699–1708.

17. Marquardt, N., Ballendat, T., Boring, S., Greenberg, S., and Hinckley, K. Gradual engagement: facilitating information exchange between digital devices as a function of proximity. In *Proc. ITS 2012*, ACM Press (2012), 31–40.

18. Michelis, D. and Müller, J. The audience funnel: Observations of gesture based interaction with multiple large displays in a city center. *Intl. Journal of Human–Computer Interaction 27*, 6 (2011), 562–579.

19. Müller, H.J. and Rabbitt, P.M. Reflexive and voluntary orienting of visual attention: time course of activation and resistance to interruption. *Journal of Experimental Psychology: Human Perception and Performance 15*, 2 (1989), 315.

20. Müller, J., Alt, F., Michelis, D., and Schmidt, A. Requirements and Design Space for Interactive Public Displays. In *Proc. MM 2010.*, ACM Press (2010), 1285–1294.

21. Müller, J. and Krüger, A. *MobiDiC: context adaptive digital signage with coupons.* Springer, 2009.

22. Müller, J., Walter, R., Bailly, G., Nischt, M. and Alt, F. Looking glass: a field study on noticing interactivity of a shop window. In *Proc. CHI 2012,* ACM Press (2012), 297-306.

23. Müller, J., Wilmsmann, D., Exeler, J., et al. Display blindness: The effect of expectations on attention towards digital signage. In *Proc. Pervasive Computing*. Springer (2009), 1–8.

24. O'Hara, K., Glancey, M. and Robertshaw, S. Collective play in an urban screen game. In *Proc. CSCW '08*, ACM Press (2008), 67-75.

25. Ojala, T., Kostakos, V., Kukka, H., et al. Multipurpose interactive public displays in the wild: Three years later. *Computer 45*, 5 (2012), 42–49.

26. Peltonen, P., Kurvinen, E., Salovaara, A., et al. It's Mine, Don'T Touch!: Interactions at a Large Multi-touch Display in a City Centre. In *Proc. CHI 2008*, ACM Press (2008), 1285–1294.

27. Ravnik, R. and Solina, F. Audience measurement of digital signage: Quantitative study in real-world environment using computer vision. *Interacting with Computers 25*, 3 (2013), 218–228.

28. Rothkopf, C.A., Ballard, D.H., and Hayhoe, M.M. Task and context determine where you look. *Journal of Vision 7*, 14 (2007), 16.

29. Schrammel, J., Mattheiss, E., Döbelt, S., Paletta, L., Almer, A., and Tscheligi, M. Attentional behavior of users on the move towards pervasive advertising media. In *Pervasive Advertising*. Springer, 2011, 287–307.

30. Taylor, N., Cheverst, K., Fitton, D., Race, N.J., Rouncefield, M., and Graham, C. Probing communities: study of a village photo display. In *Proc. OzCHI*, ACM Press (2007), 17–24.