The Case of the Missed Icon: Change Blindness on Mobile Devices

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ABSTRACT

Insights into human visual attention have benefited many areas of computing, but perhaps most significantly visualisation and UI design [3]. With the proliferation of mobile devices capable of supporting significantly complex applications on small screens, demands on mobile UI design and the user's visual system are becoming greater. In this paper, we report results from an empirical study of human visual attention, specifically the Change Blindness phenomenon, on handheld mobile devices and its impact on mobile UI design. It is arguable that due to the small size of the screen - unlike a typical computer monitor - a greater visual coverage of the mobile device is possible, and that these phenomena may occur less frequently during the use of the device, or even that they may not occur at all. Our study shows otherwise.

We tested for Change Blindness (CB) and Inattentional Blindness (IB) in a single-modal, mobile context and attempted to establish factors in the application interface design that induce and/or reduce their occurrences. The results show that both CB and IB can and do occur while using mobile devices. The results also suggest that the number of separate attendable items on-screen is directly proportional to rates of CB. Newly inserted objects were correctly identified more often than changes applied to existing on-screen objects. These results suggest that it is important for mobile UI designers to take these aspects of visual attention into account when designing mobile applications that attempt to deliver information through visual changes or notifications.

Author Keywords

Visual attention; change blindness; inattentional blindness; mobile interaction; mobile interface design.

ACM Classification Keywords

H.5.2. [**User Interfaces**]: Screen design.

INTRODUCTION

In recent years computing on mobile devices has become more ubiquitous and comparable with modern desktop computing platform in terms of processing power and visual capability. As a result, complex and demanding applications can now be developed and deployed onto these devices – contributing to the success of online mobile application stores. Devices like the iPhone are able to execute and display similar or identical applications typically found on desktops and laptops with minimal visual output. This down-scaling of the visual display creates the possibility of an information overload and loss of on-screen information during visual search. It is common place to see individuals squinting to read content on mobile devices. Conversely, it is also possible that all on-screen information is equally attendable by the user due to a higher visual coverage of the mobile device, requiring minimal use of peripheral vision. However, there are phenomena that limit the human visual system in its ability to 'see' everything.

One such phenomenon is *Change Blindness (CB)*. CB is the failure to detect a clear and obvious change that is within our field of vision when it occurs during a visual disruption – such as a blink. For instance, a person may not be able to detect a new object entering or appearing within an observed scene if the moment of change itself, is blocked from view. The core principle being that the brain replaces the actual object in the field of vision by a mental representation. This is typically the case if the object is not the focus of attention, and thus changes to objects, whether sudden, obvious or gradual are missed. This is in spite of the fact that human visual attention is naturally drawn towards change. It is attracted to an apparent 'pop' or movement created during the instance of a change, known as a *change transient.* However, when these transients between visual scenes are not attended to, do not exist or are simply obscured; the change itself becomes difficult to detect [1].

Inattentional Blindness (IB) is change blindness in the absence of a visual disruption; a failure to notice a non-disrupted change due to a lack of visual attention placed toward the changing item within a scene [2,12]. IB occurs when visual attention is consumed by the cognitive demands of a primary task. This phenomenon lends itself to the idea of human visual attention being a limited resource. Therefore the cost of attending to specific objects and tasks can be considered high. Given a primary focus or interaction, humans find it difficult to perceive change to the remaining portions of their field of vision [6].

Studies on CB and IB within human-computer-interaction have usually been done in desktop computing environments with relatively large visual outputs [18]. This paper presents a study of visual attention on mobile devices, specifically change and inattentional blindness. The aim of the study was to identify whether traditionally held theories of visual attention are transferable to mobile devices by attempting to induce them in users in a mobile context. We also attempted to quantify the effects of different characteristics of mobile application interfaces on visual attention, by comparing observed CB and IB. The results of which can help provide adequate guidelines for successful UI design and information delivery.

BACKGROUND

Previous research has identified that the noticability of a change to a visual stimulus placed onto a large-screen interface is influenced by several factors, including: salience of the object, the change (type, speed, eccentricity, semantic relevance) and the level of cluttering between objects. Salience is an object's attention-seeking intrusiveness. Consider advertising on web pages. An item of high salience would be a pop-up that requires a user-interaction to bypass, thus diverting attention away from the primary activity. A less intrusive approach would be Google's sidebar advertising that neither attracts nor diverts attention from search result [7].

For HCI considerations, the saliency of different types of change within interfaces has been well investigated within the computer science, HCI and psychology research community. Instant additions/deletions within the user's primary focus has successful rates of change detection, whilst gradual or intermittent changes, both in terms of contrast and colour reduce change detection to levels comparable with that of visual disruption tests [8]. Slow gradual changes can require extra non-visual stimuli such as sound or vibrations to be noticed at all, more so as the speed of change decreases [14]. Investigations into effective visual-searching have also suggested that bright targets surrounded by dim features are more salient than dim targets surrounded by bright features [9].

The saliency of a change can be subjectively measured within an interface using criteria such as eccentricity i.e. distance of change from point of visual fixation [10] and the semantic relevance of the change to the primarily attended task or item. Observers detect change when it is pertinent to the task. For example, whilst playing driving simulations games and viewing typical driving scenes changes relating to traffic were detected faster than other stimuli that were less meaningful to the task of driving, such as a change to the object away from the road [11].

Cluttering is the practice of placing lots of items close together in an interface, such as a complex menu or toolbar. The level of cluttering is inversely comparable to levels of change detection [7]. One can envisage this problem increasing in significance as the size of visual outputs decreases and competition for pixels (and ultimately the user's attention) increases, as on mobile devices.

Change Blindness in Mobile HCI

In a mobile context, research into change blindness is limited. One could argue that the display size of a current standard smartphone does not allow for attention towards changing items to be lost. This assumption is based on an expected greater coverage of the smaller device using foveal rather than peripheral vision. Foveal vision is responsible for sharp central vision attending to the main focus at any one time. Peripheral vision is the part of the field vision outside of this central focus.

Pictorial menus have now become standard building blocks for interfaces of the modern-day smartphone. These can be detailed in design, heavily populated with unique icons and cover the entirety of the interface. In terms of icon density, two of the current popular smartphone operating systems, Google Android and Apple's iPhone OS4, display a maximum of 16 and 20 individually animated icons respectively at any one time.

Typical transitions from one view to another in mobile menus and applications, such as blank or loading/updating screens between views, score particularly low in user evaluations in terms of perceived change blindness, visual appearance and usefulness. This coincides with long-held psychological theories, encapsulated by *Rensink's One-Shot Paradigm* [1]. The result may possibly be because of a need of a high cognitive load, due to memorising previous states and commands performed. Direct changes between views are evaluated comparatively poorly by users, suggesting that the visual interruption is not the only cause of visual discomfort on mobile devices [12].

In those mobile menus, certain animations have been shown to increase user ratings of visual appearance of transitions between different views of the menu. Blinking icons can act as a visual cue, alerting the user to pending change. Also, a sliding animation of replacing old icons with new ones proves to be a highly noticeable and visually stimulating transition thanks to the effective re-direction of attention [12]. Here, the difficultly from a design point-of-view is how to draw the user's attention to the transition, without delaying the new view with prolonged animations as such delays are likely to cause annoyance to the user – which may affect the appeal of the overall interface.

Visual Attention in a Mobile Context

The physical environments, in which mobile devices are typically used, have attention diverting stimuli, such as noise or flashing light. But also to consider are tasks that are performed simultaneously - such as walking, evading obstacles and even driving. Constant visual attention toward a mobile device has be reported to decrease to as low as 4 seconds in a field context when compared to a laboratory setting [14], suggesting that additional tasks can add to a cognitive load for the user, rapidly reaching a terminal level. This may also imply that if there is an increase in attention shifts, it is likely to force the user to take their eyes off the interface altogether, leading to *visual-disruption triggered* CB to occur.

EXPERIMENTAL DESIGN

Two separate experiments focusing on CB and then IB were planned. Each required the development and deployment of a custom application on a typical mobile device. The Samsung Galaxy S was chosen for both experiments as it is representative of a typical model within the current smartphone range – with a 4-inch, 480 x 800 pixel touch screen display and running the Android 2.1 operating system. The Samsung device has dimension of 122.4 x 64.2 x 9.9 mm and weighs 119g (Figure 1 Left).

Figure 1. The Samsung Galaxy S (Left), A Typical configuration of the icon-grid menu (Right)

EXPERIMENT 1 (CB) - APPLICATION DESIGN

A mobile application was developed that displayed a grid-style icon menu system, interrupted by various visual disruptions. This set-up allowed one icon in the grid to be changed during the disruption and then to prompt the participant to select the changed icon as quickly as possible.

iPhone Style Menu

The menu style and the icons used were designed to be representative of typical smartphone UI. The 32 icons selected were different from each other in both colour scheme and design (Figure 1 Right).The menu layout provided a familiar feel to the participants in order to reduce the effect of novelty, so that the effects of change blindness can be accurately observed.

Visual Disruptions

Four different visual disruptions were chosen to be included within the application during the icon change. Each represented typical events that commonly occur on modern smartphone interfaces.

1. No Visual Disruption - The change would occur without disruption where an icon is directly replaced by another instantaneously without any visual interference. Rates of detection in this case offer a control result, whereby a comparison can be made with rates from the visually disruptive changes.

2. Flicker - The flicker change event displayed a black blank screen for 0.5s between the pre and post change menus. This is representative of Rensink's Flicker Paradigm within the mobile interface context.

3. Orientation Change - The orientation change rotates the menu from portrait to landscape for 0.5s before rotating back to portrait, displaying the changed menu to the participant. This rotation of the display is typical of many smartphones that can sense a change in the device's orientation and adjust the view automatically at any time.

4. Push Notification - In this change event, a push notification (like a pop-up) was displayed to the user during the icon change for 0.5s. Only part of the menu was covered by this disruption.

Methodology

The experiment required participants to complete a 60 separate 'rounds'. Each round would use one of the visual disruptions and each had a strict timeline (Figure 2). The participant began each round by clicking a start button, placed in the center of the screen. The participant then had the opportunity to view the initial menu view for 3 seconds before one of the change events would occur. Once the change had been made, a further 5 seconds was given to select what the participant thought was the changed icon using the device's touch screen. Once a selection was made or if no response was received within those 5s, an option to start the next round appeared. Out of the 60 rounds, 20 rounds were designed to have *no changes* and were randomly distributed. This encouraged the participants to make an active decision.

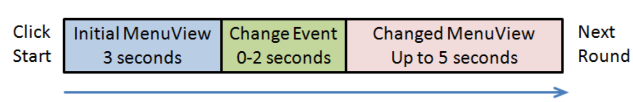

Figure 2. Round timeline

Application Settings

The application automatically randomised the icon graphics so that; the initial icon grid, the position of change and the changed icon were different from one round to the other. It was also ensured that more than 1 instance of an icon could not appear simultaneously as this would affect normal rates of change detection. After a change event, the new icon was always different from the one it replaced. The icon buttons were disabled until the change occurred, in order to prevent early responses being recorded. In order to reduce any effect of anticipation or expectation on levels of change detection, participants were not told about the type of change events they would observe during the experiment.

Each round in the application corresponded to a different combination of the change event and the number of icons. For each participant, the number of icons began at 4, and increased in multiples of 4, up to a maximum of 20 onscreen. Each combination was displayed to each participant with the order randomised across participants. In addition, each visual disturbance was spread equally across each set of icons. To maintain participant's attention towards the task of change detection, it was possible to delay each round to allow for a period of rest/recovery if needed.

EXPERIMENT 2 (IB) - APPLICATION DESIGN

A mobile application based around a simple 2-dimensional driving game was designed and developed (Figure 3). The 'driving' element of the game was designed to consume the participant's visual attention, whilst secondary on-screen changes were made in the form of speed limit notifications.

Figure 3. The 2-D driving game

Primary Task

The main aim for the participant was to control the direction and speed of the red car while avoiding collision with oncoming traffic and collecting stars to gain points. The car was controlled using on-screen touch buttons represented by green right and left arrows.

Secondary Task

The participant had to maintain the car's speed within limits indicated through visual notification on the 'dashboard'. The faster they drove, the more points they could collect – but there were penalties for going over the speed limit and crashing into obstacles. A prize was on offer for the participant who had the best overall score. The speed of the car – also displayed on the dashboard- was controlled using on-screen control buttons.

Notification Systems

In order to analyze the effect of different interface designs on change blindness, four styles of notification system were used throughout the experiment. Each consisted of a slight change in the position and type of visual change displayed.

- *Direct Insertion* - A new icon appeared and was displayed for 3 seconds before disappearing
- *Gradual Change* - A change was introduced within a displayed icon. For e.g., the value of the speed within a speed limit icon could change
- *Top of Screen* - The icon appeared on the top right corner of the screen
- *Bottom of Screen* - The icon appeared on the dashboard

Methodology

These notification styles gave 4 experimental groups, each completing the tasks with one of the following combinations: *Insert/Top, Insert/Bottom, Gradual/Bottom, Gradual/Top.*

Each participant was told about both the primary and secondary task, their motivation for achieving a good score and the controls of the application; using a mock-up of the interface and a clear set of instructions. The participants were not told about the purpose of the experiment until after completion of the task. This prevented participants from solely focussing on detecting the change and ensured that the experiment produced natural detection results during realistic consumption of visual attention. The speed limit notification was chosen as it was relevant to the primary task.

A participant would begin the task by pressing a start button located in the centre of the screen. The car could then be controlled for 60 seconds - points were awarded for collecting stars and deducted for crashes or for travelling at speeds greater than the speed limit at any point. Speed limit changes were displayed using one of the 4 notification systems. When detected the participant selected the correct speed and the speed of the car was changed accordingly. The application recorded the time taken for the correct speed to be selected, measured from when the notification was displayed. If nothing was selected before the next notification appeared, it was recorded as a miss.

Application Settings

For each notification system, steps were taken to ensure that the visual changes to the display (changing, appearing and disappearing icons) happened instantly without any phased change or delay that could influence its noticeability. The notification systems used the same speed limit notification images. It was ensured that the timer could not be stopped by incorrect speed changes and only stopped when the next notification was displayed.

PARTICIPANTS

29 participants (17 male and 12 female) were recruited through advertising on notice boards and mailing lists. The participants were aged between 18 and 24. Sessions with each participant lasted between 20-30 minutes. All participants were asked to bring any corrective eyewear so that poor vision did not affect their visual search ability and therefore change detection levels.

EXPERIMENT CONDITIONS

Each trial was performed in the same indoor location under artificial light and each participant was asked to sit in the same seat. The participant was allowed to choose any sitting position (e.g. leaning back, leaning forward) that felt comfortable to them (Figure 4) for a naturalistic setting.

Figure 4. The conditions used for both experiments and a participant completing the mobile tasks

For both experiments, each participant was told to keep the entire mobile screen in view, and as much as possible not to cover any part with their hands when they held the mobile device. This ensured that all parts of the screen could be seen equally across participants and that there would be minimal effect on the results observed. An experimenter was present in the room as the task was performed but did not interfere with the participant or the completion of the task in any way.

RESULTS - EXPERIMENT 1 (CB)

Effect of Visual Disruption

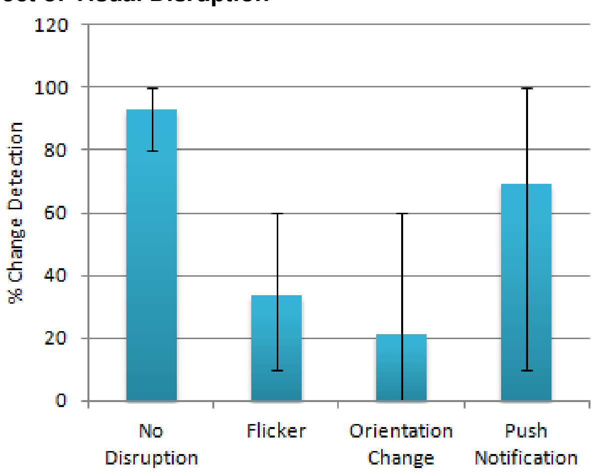

Figure 5. Effect of visual disruptions on % change detection

Rates of accurate change detection showed a significant *(F(3,112)=174.99, p<0.001)* decrease when any of the three visual disruptions were added (Figure 5). Individual pairwise comparisons between the groups concurred with this results in all cases. The control percentage coming from the *No Disruption* rounds was 93% and decreased to a peak low of 21% when the orientation change masked the changing icons. The result supports the hypothesis about the link between brief visual disruptions during change and change detection.

Effect of Cluttering

In succession, groups of 4, 8, 12, 16 and 20 icons were presented 8 times each to participants and equally across each visual disruption.

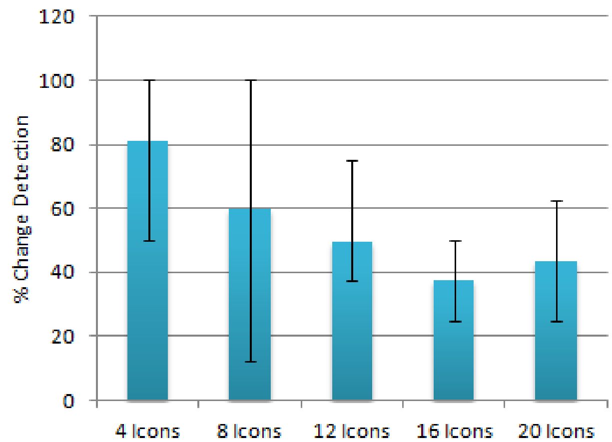

Figure 6. Effect of increasing number of onscreen entities on % change detection

Overall, the mean change detection rates were significantly higher when fewer numbers of icons were visible onscreen. In all cases but one, rates were found to significantly decrease *(F(4,140)=51.84, p<0.001)* each time 4 more icons were added to the screen (Figure 6). Individual pairwise comparisons between the groups concurred with this results in all but one non-significant case: *16-20 icons*. Despite the slight increase for detection within a menu of 20 icons when compared to a menu of 16 icons, there is strong evidence that the number of visual entities displayed has a negative effect on successful change detection. *Pearson's Correlation Coefficient(ρ)* was calculated at -0.679 - a strong negative correlation - supporting the relationship between change blindness and the number of items displayed on a mobile device.

Effect of Position

Through analysis of the data for the full 20 icons screen (5 rows with 4 icons per row), we were able to investigate any effect that the position of change within the menu grid may have on detection levels. This was done by comparing detection rates of changes appearing within each row. As the push notification only covered the inner section of the menu grid, it was excluded to avoid bias. The mean rate of change detection was slightly higher for rows 4 and 5 compared to the first three rows. However, the different rate between any two lines was found not to be statistically significant *(F(4,97)=0.82, ns)*.

Effect of Eccentricity

A secondary test to analyse any effect of the position of change was done by splitting the menu grid into two distinct and independent groups. These are outer (change in the outer edge of the grid) and inner (change in the centre of the grid surrounded by other icons) positions in the menu grid (Figure 7).

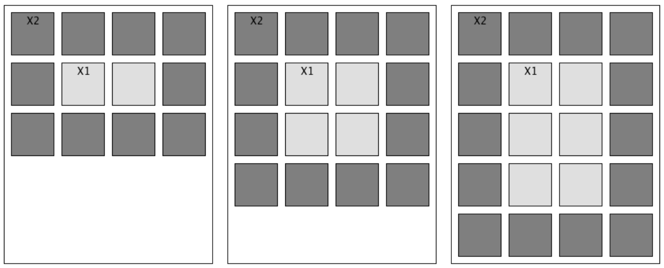

Figure 7. The icon positions included within the inner and outer groups

Once again, to avoid possible bias leaning towards outer changes, results from the push notification disruption were excluded. Results from trials with 4 or 8 icons were also excluded, due to the lack of a distinct differentiation between inner and outer positions within the grid. The mean rate of accurate change detection was not found to be significantly different (*F(1,52)=0.32, ns)* for both inner and outer groups at 37% and 41% respectively. Both sets of results from the positional analysis performed proved insignificant. We therefore cannot infer that onscreen position of change has any impact of levels of change blindness on mobile interfaces.

RESULTS - EXPERIMENT 2 (IB)

Inattentional Blindness

Throughout the experiment, a total of 87 notifications were shown to 29 participants playing the driving game. A total of 30 (34.5%) notifications went completely unnoticed and the average response time for the successfully detected notifications was 3877ms. This shows that the consumption of the user's visual attention through playing the game had a negative effect on their ability to detect on screen changes. The effect of different interface choices is analysed next.

Analysis of Response Times

Response times of the correct detections observed were split into four groups, representing differences in the position on screen (top/bottom) and also the type of change (insert/gradual) applied, so that effect of these independent differences could be seen directly.

First, we compared response times when the notification was positioned on the top and bottom of the screen. There was no significant difference (*F(1,55)=0.19, ns)* between the mean response times for detected notifications which were 3721ms (top) and 4224ms (bottom), showing that the on-screen position of the notification had little direct effect on the speed of detection (Figure 8).

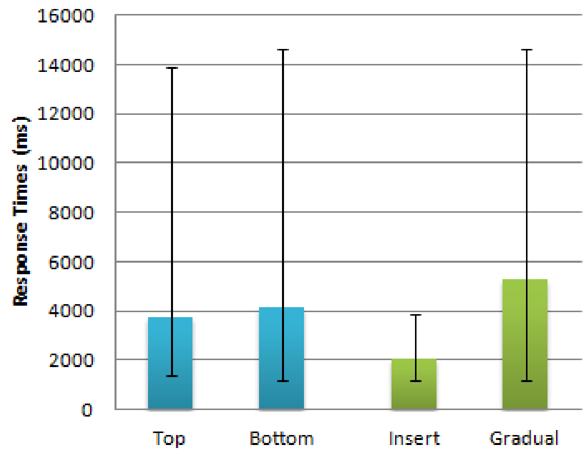

Figure 8. Observed response times for both positional and change type groups

Next, we observed that the mean response times when comparing insertion and gradual changes were 2034ms and 5317ms, respectively. In this case, the difference is significant *(F(1,55)=17.24, p<0.001)*, which means that on average, the participants using the inserted notification detected the notification in less than half the time that those using the gradually changing notification took.

Analysis of Change Detection

A successful detection was the selection of the correct speed (i.e. the detection of the notification) at any point, irrespective of the time taken. Each participant had the opportunity to detect 3 notifications throughout the game. We once again looked at the four groups, representing differences in the position on screen and the type of change applied (**Error! Reference source not found.**).

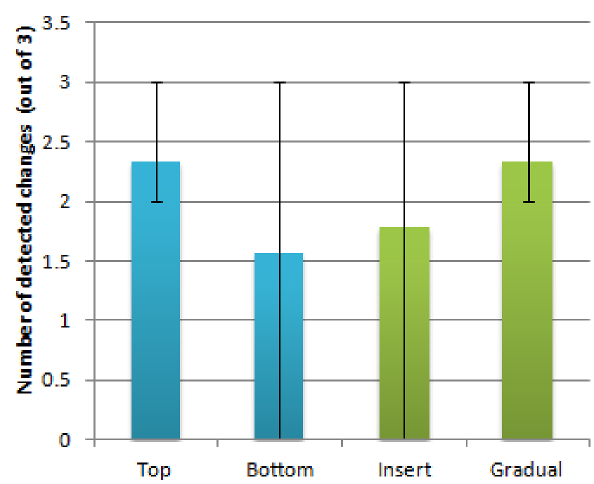

Figure 9. Observed detections for both positional and change type groups

In this case, the position on screen was shown to have a significant effect *(F(1,28)=4.58, p<0.05)* on rates of detection. On average, 2.3 notifications positioned at the top of screen were detected, compared to only 1.5 of those positioned at the bottom of screen. The difference in detection levels for inserted notifications and those gradually changing was not statistically significant *($F(1,28)=0.84$, ns)*. This shows that the type of change was less of a decisive factor in total detection than the notifications position on screen.

Using the observed correct response times, we found no interaction between the Top/Bottom and Insert/Gradual variables (Figure 10).

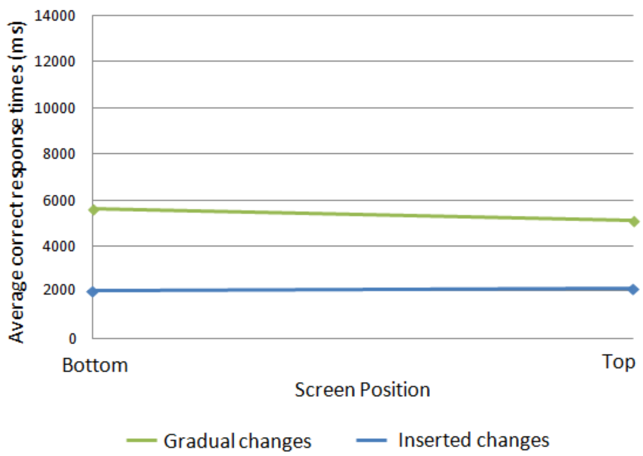

Figure 10. No Interaction effect between Top/Bottom and Insert/Gradual variables

Analysis of Subjective Data

Participants were asked to rate out of 5 the effect to which the notification distracted them from the primary task of driving the car. High scores indicating that the participant's vision was diverted away from the car by a significant amount. It appears that notifications placed towards the top of the screen (2.93) were perceived as more distracting than those at the bottom (1.28), but there was no real difference in opinions regarding inserted (2.28) and gradual changes (2). Next, participants were asked to rate out of 5, whether both the top and bottom of screen was their main focus of their attention. The average scores were: Bottom: 3.83, Top: 3.65 *($F(1,56)=0.31$, ns)*. This shows that they could not pinpoint one area on the mobile screen to which they mostly focussed.

By formulating the perceived distance of the focus of vision from the notification, we were able to view possible correlations between this distance and the average response time/number of notifications detected overall. A participant *Vision Distance Score* was calculated as follows:

$$\text{Vision Distance Score} = c + (x1 + x2)$$

where c is the Positive offset (in this case 5), $x1$ is the Near position rating: (top/bottom) where the notification appeared and $x2$ is the Far position rating: (top/bottom) where the notification did not appear

The *Pearson's Correlation Coefficient(ρ)* of the vision distance against notifications detected was 0.238. The confidence interval (0.95) was 0.556 indicating that no statistical correlation could be confirmed. The correlation coefficient of this distance with the average response times was -0.122. The confidence interval (0.95) of -0.486 confirmed no statistical correlation. This lack of correlation shows that the proximity of the participant's visual focus from the notification had no bearing on whether, or how fast it was detected.

DISCUSSION AND CONCLUSIONS

Users may over-predict their ability to see and comprehend visual changes on small screens of mobile devices due to an expected greater use of foveal rather than peripheral vision. The results seen from these experiments performed show that this is largely not the case, and that CB and IB are still important factors to consider in the design of graphical mobile interface.

Change Blindness on Mobile Devices

The fact that rates of change detection were significantly lower with each of the three visual disruptions, compared to when there was no disruption, suggests that change blindness does occur on mobile devices. As with previous research using larger non-mobile visual displays, the visual disruption has removed the change transient, which was clearly visible when no disruption occurred. The results from the no disruption rounds (93% detection) show that the change was to a major extent obvious and noticeable in the absence of the visual disruption. This means that change blindness is the cause of the reduced detection rates when disruptions were introduced. This also confirms that it is not the changed visual entity itself that is noticed after a change, but the change transient. The transient in this case, was the apparent visual 'pop' of one icon directly changing to another, to which the viewer's visual attention was naturally drawn.

Flicker

The low detection results from the flicker disruption (33%) employed in this study coincide with traditional one-shot paradigm style studies in pictorial and visual display environments. This also helps to model the negative effect of attention shifts [4], something which is highly prevalent in a mobile context.

Orientation Change

The results from the orientation change disruption (21% detection) were the worst of all the visual disruptions in terms of change detection. This shows that change blindness occurred to a great extent even when the icons remained on screens at all times. This was not a 'blocking' visual disruption, but the movement of the icons during the change masked the change transient and clearly this was not visually attended to by the participants.

Push Notification

The results from the push notification disruption shows a decreased rate of detection (69%), but to a lesser extent compared to the other two visual disruptions (21% and 33%). This may show that the viewer's visual attention has been diverted away from the change transients that were visible. However, the high-level of detection compared to the other disruptions may imply that the changes to the icons behind the notification were not noticed, and those visible were. These mixed results do not confirm a 'mud-splashes' effect [5] but may rather bolster the conclusions based on the observed impact of the blocking visual disruptions.

Cluttering

Increasing the number of icons displayed was shown to directly and significantly affect rates of change detection *(correlation coefficient* ρ*=-0.679).* As the number of icons in the menu increased, the mean rate of detection decreased. This confirms that traditional change blindness theories of cluttering are transferable to mobile devices. Regardless of the visual display, human vision clearly has an upper threshold of attendable entities, much like and possibly related to the limited capacity of short-term memory [16][19].

Position of Change

The position of change was one aspect of change blindness that has been shown to have a minimal effect on levels of change detection in a mobile context. It was also the case that changes located towards the outer edge of the screen were detected equally with those encased within the menu grid. The screen position of the change was entirely random during the experiment, meaning that this result was not due to expectation or anticipation towards any part of the screen and that position was not a great factor in detection. This shows that when no other task is attended to, the entirety of the visual output on a typical mobile device can be equally attended to and changes detected with equal success. The second experiment helped in identifying whether position of change has an effect on CB, when visual attention is consumed by a primary task.

Implications of CB for Mobile Interface Design

The main conclusions discussed demonstrate that the change-transient is important for changes to be detected by users of mobile devices.

Reduction of Simultaneous On-Screen Activity

It would be advisable not to use change-transient-blocking, *loading/updating* style transitions between screens on a mobile device. Completely blocking any change transient that occurs has a negative effect on detection rates. Mobile application developers should instead place greater importance on creating visual changes that maximize the visibility and strength of the transient, rather than solely focusing on the saliency, brightness or visual noticeability of the entities on-screen. One way is to ensure that the changing entity on-screen is static and that no other visual activity occurs during the change. This ideal solution may be difficult to achieve in some applications, so the trade-off to be addressed is between accurate change detection and the level of simultaneous activity on-screen. A reduction of simultaneous on-screen activity will also help to minimise the negative effect of attention shifts that has been found in this experiment to be very disruptive to change detection.

Amplification of Change-Transients and Scene Differentiation

In this study attention shifts were modelled by the flicker disruption, producing 67% detection failures. In a real-life mobile context, where interaction with the device is generally a secondary task, this can be assumed to be even more prevalent [14]. A solution here is to maximise not only the transient, but also the resulting saliency-difference of the changed entity. An example of this is *moticons* which are icons that move and wobble once changed, prolonging the change-transient, forcing the change to occur over a larger area and emphasising the differentiation between the pre and post-change scenes should the initial change-transient be missed [2]. It has been suggested that transitions that increase the size, hue, brightness or shape of the changed entity could produce a similar effect [15].

Reduction of Attendable On-Screen Entities

Whilst the position of change proved to be insignificant, the number of attendable icons present was found to be related to levels of change blindness. This shows that an information overload is possible – even on small screen. As the complexity of the interface increases we expect the relative saliency of a change within an individual location to decrease as that location blends into the 'noise' of the surrounding entities. A possible approach is to use multi-level display systems, whereby each on-screen selection reveals the next level of related selections or data displays, thereby reducing the number of entities visible at any one time. The key from a design perspective is to minimise annoyance and selection time, whilst maximising the chances of on-screen changes being detected, if of course this is the desired effect.

This implication adds the benefit of improving visual perception of change to the common design pattern, known as *One-Window Drill-Down*. The pattern is commonly included in mobile interface design, as seen in Apple's iPod. On top of usability and performance, this pattern is used to reduce the complexity of the visual experience and also the information/cognitive load on the user. In addition, visual attention is more directly focused towards on-screen entities that are relevant to the primary activity or task at that time [17].

Inattentional Blindness on Mobile Devices

With 34.5% of the speed limit notifications going completely unnoticed whilst participants played the simple driving game, we can first conclude that inattentional blindness can occur on the smaller visual output of a mobile device.

Response Time

Accurate response times where hugely in favour of directly inserted notifications (2034ms) rather than changes to an existing onscreen notification symbol (5317ms) $(F(1, 55) = 17.24,\ p < 0.001)$. This does not only show that the increased saliency of the change transient allowed the notification to be spotted sooner, but also that it was successfully understood and acted upon by the user. Therefore, on a mobile user interface, more salient changes such as suddenly appearing graphics are more effective signals of secondary change than other methods such as simply changing the contents or text of an existing graphic.

However, there was no observable difference in response times when viewing notifications at the two different positions onscreen *(F(1, 55) = 0.19, ns)*. This shows that the change transient of the notification had equal effectiveness wherever it was placed on screen. Even when completing a primary visual task, if the entirety of the screen is in view, a user of a mobile device is able to respond equally to similar change transients throughout this display. The smaller visual output on the mobile device has caused increased screen-coverage by foveal vision, rather than the peripheral vision for vast areas of the screen, whereby IB has been shown to drastically increase [15]. While it is possible to attend to changes in both foveal and peripheral vision, changes in peripheral vision require a stronger change signal may be needed. However, despite this foveal coverage of the visual output, we have seen that IB remains a factor in the detection of visual change on mobile devices.

Change Detection

Full detection was statistically equal for both inserted and existing notifications, but with a slightly higher detection rate for changes to existing notifications *(F(1, 27) = 0.84, ns)*. This was expected, due to the notification remaining on screen for the full selection period despite the decreased observable transient, and shows that the user was able to some extent, and possibly intermittently, attend notifications away from the primary activity, even if the initial transient was missed.

There was, a slightly significant difference in full detection between the two onscreen positions used *(F(1, 27) = 4.58, p < 0.05)*. More notifications were completely missed when positioned on the dashboard at the bottom of the screen *(1.57 out of 3 notifications detected)* than when positioned at the top of the screen *(2.33 out of 3 notifications detected*). This contradicts all of the position data seen so far from both experiments. A possible explanation is that the notification at the top of the screen was located in an active part of the screen. Meaning that the notification was covering the traffic and stars within the game, therefore it was more disruptive and also more likely to be attended to than the notification placed on the dashboard.

Subjective Data

The user ratings of the ability of the notification to distract visual attention were fairly low with the highest score for any category being 2.93 out of a possible 5. This shows that the users could to some extent perceive the difficulty they had in viewing the secondary visual notifications whilst performing the primary task – indicating that IB can directly affect the perceived quality of a user interaction and therefore the user experience of a mobile application usage. Surprisingly, the perceived detection scores of the inserted and gradually changing notifications were fairly similar. This differs from the numerical data analysis. It shows that it is difficult for the user to gauge the effect of CB and IB on the mobile device. It provides evidence that onscreen changes can go totally undetected without the user realising anything at all, rather than not comprehending the information within changes that were visually attended to. The distraction ratings show a preference towards the notifications placed at the top of the screen, meaning that these were perceived to be more salient purely because of their position on screen. More notifications were missed when located at the bottom of screen.

As previously discussed, the participants on average, could not pinpoint one onscreen area to which their field of vision was mostly focused (p = 0:579). This emphasises the difficulty in separating the screen of a mobile device into areas of foveal and peripheral vision, and suggests that the whole screen was easily and equally attendable using foveal vision. Also, there was no correlation found between the perceived distance of the focus of vision from the notification and detection levels. These results are subjective evidence that the onscreen position of change has no effect on its noticeability. The contradiction of the effect of position seen here supports the idea that passive areas of screen, those 'irrelevant' to the primary activity - in this case the dashboard - are typically ignored by the user of mobile devices, even though these areas could be equally visually attended to.

Implications of IB for Mobile Interface Design

Amplification of Change-Transients

Results from this study indicate that during the completion of a primary visual task, secondary notifications rely on the strength of the change transient to be noticed. Increasing or amplifying this transient as much as possible such as using newly appearing objects over changing existing objects, improves the speed of detection. If the change transient is missed altogether due to attention shifts on the mobile screen or the lack of attention towards the mobile device itself [2], the extent of differentiation between the pre and post-change scenes becomes more important.

A concatenation of these two principles, supported by the experimental results, is to have a newly appearing notification that then remains onscreen for as long as possible, offering the user the chance to see the high-salient transient, but also allowing them to intermittently scan the changed scene and visually attend the changed object even if the transient is missed. This effect can be further amplified by increasing the differentiation between pre and post-change scenes, such as changing the shape, colour, brightness or movement of the changed item. Other methods of increasing this change signal have been suggested in previous research within traditional computing environments. These include creating changes that are bold, with a large hue or brightness difference from the rest of the interface and increasing the size and screen coverage of the change.

Active and Passive Positioning

The results show that the users were able to differentiate between the active and passive sections of the mobile interface and attend more towards those relevant to the primary task. It is therefore important, when designing a mobile interface that vital changes must impact on the user's view of these active areas, increasing the disruption of the primary task and therefore increasing the saliency of the notification. In the specific case of mobile navigation applications, to which the driving game was directly analogous, it is detrimental towards change detection, for any notification to appear or change whilst placed on a static panel that is not needed to be attended to, in order to complete the primary task. Regardless of the type of change used and it's on-screen position, placing the notification above the active panel, in this case containing the road/position display, improves actual and perceived change detection. This implication means that before the design of an application interface, a trade-off between the importance of the completion of the primary visual task, and the secondary change being successfully delivered, needs to be considered.

Multi-Modal Change Cues

While this study has solely focussed on the visual aspects of change detection on mobile devices we must also consider that these modern devices such as mobile phones, mp3 players or navigation devices are inherently multi-modal. Thus, *attention-grabbing* cues toward occurred change, such as sound or vibration prompts have been suggested to aid the user to attend the change regardless of their current visual focus or activity [15]. More research into these possibilities in a mobile context is needed to fully understand their effect on change blindness, but also their effect on the quality of the user experience and effectiveness in certain operational environments.

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