

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD-MM-YYYY) March 2007		2. REPORT TYPE Final Report		3. DATES COVERED (From – To) 31 August 2006 - 08-Jan-09	
4. TITLE AND SUBTITLE Looking but not Seeing: Does Perceptual Depth Reduce Change Blindness?				5a. CONTRACT NUMBER FA8655-06-1-3081	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Professor B.L. William Wong				5d. PROJECT NUMBER	
				5d. TASK NUMBER	
				5e. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Middlesex University Ravensfield House, The Burroughs London NW4 4BT United Kingdom				8. PERFORMING ORGANIZATION REPORT NUMBER N/A	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) EOARD Unit 4515 BOX 14 APO AE 09421				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S) Grant 06-3081	
12. DISTRIBUTION/AVAILABILITY STATEMENT: Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT: Recent studies have shown frequent failures in the visual detection of changes, even if changes are large and anticipated. Failures in the detection of changing information have implications for human-computer interface design. Operators monitoring computer displays in safety-critical environments such as air traffic control centres, nuclear plants or hospital emergency rooms, need to monitor and keep track of a large volume of information. The state of the processes can change rapidly, and need to be kept within given safety or operational limits. In those cases, missing changing information could have an immense human and economic cost. In this report, we review research documenting several types of perception-“blindness” known as change blindness, inattention blindness, comparison blindness and repetition blindness. Understanding the perceptual and attentional factors that produce these ‘blindness’ might inform the theory and practice of computer interface design in order to create visualizations that will enhance change detection in monitoring tasks. Based on an Emergent Themes Analysis approach, we identified 5 effects, or properties, common across the different forms of change blindness, and hence the likely effects that designers need to consider when designing visual interfaces to reduce it. These five effects are (i) the effect of rate of change, (ii) the effect of eccentricity, (iii) the effect of proximity, (iv) the effect of significance, and (v) the effect of task relevance. Several highlighting techniques used to enhance visual search and stress important information in visual displays such as changes in colour, intensity, blinking; and boxing have not been fully successful. We propose using a new technology known as the Multi-Layered Display (MLD) to investigate perceptual depth as a cue to enhance change detection. Until now, perceptual depth as a cue for change detection tasks has not yet been investigated. We believe that the additional information provided by MLD will improve the management of attentional resources, and thus lead to an improvement in change detection. Further research will comprise the completion of three experiments investigating the use of perceptual depth in the detection of changes in monitoring tasks taking into account the influence that the 5 effects have on change detection.					
15. SUBJECT TERMS EOARD, Human Factors, Display Devices					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UL	18. NUMBER OF PAGES 68	19a. NAME OF RESPONSIBLE PERSON TAMMY SAVOIE, Lt Col, USAF
a. REPORT UNCLAS	b. ABSTRACT UNCLAS	c. THIS PAGE UNCLAS			19b. TELEPHONE NUMBER (Include area code) +44 (0)1895 616459

IDC Technical Report 2007-3-001

Looking but not Seeing: Does Perceptual Depth Reduce Change Blindness?

Gabriela Mancero
William Wong
Paola Amaldi-Trillo

Interaction Design Center,
Middlesex University

March 2007

Prepared for:

European Organization of Aerospace Research and Development (EOARD)

Award Grant No. FA8655-06-1-3081

EOARD POC Lt. Col. Robert Kang

Table of Contents

Table of Contents	2
Table of Figures.....	4
Abstract	5
Preamble	6
Chapter 1 Are we really blind to changes?	8
<i>Change Blindness.....</i>	<i>8</i>
<i>Inattentional Blindness.....</i>	<i>12</i>
<i>Comparison Blindness</i>	<i>17</i>
<i>Repetition Blindness.....</i>	<i>18</i>
Change Blindness in Operational Environments	19
Chapter 2 Why does change blindness occur?	22
Overwriting Hypothesis	22
Gist/First Impressions	22
Nothing is stored.....	23
Everything is stored.....	23
Combination of features.....	24
Chapter 3 Perceptual Depth as an alternative technique.....	26
The highlighting paradox.....	26
Multi-Layered Display (MLDTM).....	28
Studies conducted on the MLD	30
<i>Visual Search Tasks</i>	<i>30</i>
<i>Legibility.....</i>	<i>30</i>
<i>Information Layering and De-cluttering.....</i>	<i>31</i>
<i>Multiple Object Tracking</i>	<i>32</i>
Chapter 4 Cognitive Processes for the MLD and Change Detection	33
Vision and Attention in the Eyes of Change Blindness	33
How do we perceive in depth?	34

The depth cues.....	35
<i>Stereopsis</i>	35
<i>Motion parallax</i>	36
<i>Texture gradients</i>	36
<i>Overlapping and partial occlusion</i>	36
Deployment of attention in depth	38
 Chapter 5 The 5 Effects of Change Blindness	40
Effect of the Rate of Change	40
Effect of Eccentricity	41
Effect of Proximity	42
Effect of Significance.....	42
Effect of Relevance of the Task.....	44
 Chapter 6 Discussion and Conclusions	46
References.....	49
Appendix 1.....	53

Table of Figures

Figure 1: Flicker Paradigm.....	10
Figure 2: Mud-splash Technique.....	11
Figure 3: Failure to Detect Changes to People in Real-World Interactions	12
Figure 4: Screen shots Inattentional Blindness Experiment.....	13
Figure 5: Most et al. 2000 Experiment.....	15
Figure 6: Gorillas in the Midst (Simons and Chabris 1999)	16
Figure 7: Current Approaches to Change Blindness	24

Abstract

Recent studies have shown frequent failures in the visual detection of changes, even if changes are large and anticipated. Many man-made systems and processes rely heavily on visual displays to convey information, so failures in the detection of changing information have implications for human-computer interface design. Operators monitoring computer displays in safety-critical environments such as air traffic control centres, nuclear plants or hospital emergency rooms, need to monitor and keep track of a large volume of information. The state of the processes can change rapidly, and need to be kept within given safety or operational limits. In those cases, missing changing information could have an immense human and economic cost.

In this report, we review research documenting several types of perception-“blindness” known as change blindness, inattention blindness, comparison blindness and repetition blindness. Understanding the perceptual and attentional factors that produce these ‘blindness’ might inform the theory and practice of computer interface design in order to create visualizations that will enhance change detection in monitoring tasks.

Based on an Emergent Themes Analysis approach, we identified 5 effects, or properties, common across the different forms of change blindness, and hence the likely effects that designers need to consider when designing visual interfaces to reduce it. These five effects are (i) the effect of rate of change, (ii) the effect of eccentricity, (iii) the effect of proximity, (iv) the effect of significance, and (v) the effect of task relevance.

Several highlighting techniques used to enhance visual search and stress important information in visual displays such as changes in colour, intensity, blinking; and boxing have not been fully successful. We propose using a new technology known as the Multi-Layered Display (MLD) to investigate perceptual depth as a cue to enhance change detection. Until now, perceptual depth as a cue for change detection tasks has not yet been investigated. We believe that the additional information provided by MLD will improve the management of attentional resources, and thus lead to an improvement in change detection. Further research will comprise the completion of three experiments investigating the use of perceptual depth in the detection of changes in monitoring tasks taking into account the influence that the 5 effects have on change detection.

Preamble

Studies during the past decades have shown that we are unable to detect changes under certain circumstances. Surprisingly, we are blind to certain changes that happen in our field of view. There are several types of perception-”blindness” known as Change Blindness, Inattentional Blindness, Comparison Blindness and Repetition Blindness. These types of “blindness” present significant problems especially in dynamic operational environments where operators monitoring computer displays have to monitor and keep track of a large volume of information that change rapidly, and which need to be kept within given safety or operational limits.

Researchers have stated several plausible causes for Change Blindness but the phenomenon have not yet been fully explained. Many have focused their studies on the brain’s internal representations of what we see, while others have attempted to study our inability to detect changes by analyzing memory and attention.

Based on an Emergent Themes Analysis approach, we have identified 5 effects or properties of Change Blindness which should be taken into account when designing interfaces for complex systems.

This report is structured in six main chapters:

The first chapter explains the different types of perception-blindness. It attempts to give a comprehensive review of the empirical evidence of these phenomena. It also presents other empirical studies done in operational environments in which change blindness occurs.

The second part looks at various hypotheses that attempt to explain our inability to detect changes. Several of them deal with our visual representations, while others claimed that attention is required to detect changes. A short comparison is made in order to understand the factors that might enhance change detection according to the studies that have been conducted.

The third section covers the introduction of a new device known as the MLD or Multi-Layered Display. It has the ability to present increasing amounts of data due to the way it is built. This

section presents several highlighting techniques that have been used in the design of computer interfaces but that have not been 100% successful for change detection tasks. Perceptual depth as a cue to enhance change detection is introduced as a new possible way to enhance change detection. Previous research conducted in the MLD is presented.

The fourth part presents a brief overview of the processes of perception and attention that come into play to enable us to perceive in depth. It also presents an overview of several depth cues needed for depth perception.

The fifth section covers the results obtained from an Emergent Theme Analysis. From this analysis we identified 5 effects of change blindness that influence the design of computer interfaces. The 5 effects are: (i) the effect of rate of change, (ii) the effect of eccentricity, (iii) the effect of proximity, (iv) the effect of significance, and (v) the effect of task relevance.

The final chapter put together the lessons derived from previous studies and our analysis. We attempt to provide some guidelines for computer interface designers, especially for those involved in complex domains.

Chapter 1

Are we really blind to changes?

Contrary to our belief we see far less than what we think. Our eyes acquire visual information in between blinks and eye saccades and most of this information is very volatile since we just need it for very short periods of time. Studies in change detection and visual perception have shown that we are “blind” to some events that happen straight in front of us while we are looking at them. These failures of perception have raised studies about different types of induced-“blindness” which are known as Change, Inattentional, Comparison and Repetition Blindness

This Blindness become extremely problematic if operators in dynamic complex work domains such as nuclear plants, air traffic control, and ambulance dispatch centres, fail to notice a change that occurs in the display: Missing a red light can costs lives. Operational environments maintain large volumes of rapidly changing information which need to be kept within given safety or operational limits. These phenomena show that possibly dangerous events occurring in full view may go unnoticed if they coincide with small apparently innocuous disturbances or interruptions such as a phone call, becoming crucial due to the enormous human and environmental costs that a failure in such systems could cause.

Change Blindness

Change Blindness is a phenomenon in visual perception where large changes within a visual scene are undetected by the viewer when occur during a visual disruption such as a flicker, an eye movement, a saccade or a movie-cut (O'Regan 2000; Simons 2000; Rensink 2002).

This phenomenon was first explored systematically by George McConkie and his colleagues in the late 1970's focusing only on changes introduced to words and text during eye movements. Later, John Grimes (1996) studied this phenomenon in the domain of scene perception demonstrating that people miss large changes to scenes when the changes are introduced during an eye movement.

O'Regan (2000) showed that elements of the picture that occupied as much as a fifth of the picture area would not be seen. These experiments required observers to view high-resolution, full-colour daily visual scenes presented on a computer monitor, while their eye movements were being measured. The application was programmed to make changes in the scene as a function of where the observer looked. For instance, when the observer looked from the door of a house to the window; the window (or some other element of the scene such as the sky, or the car parked in front of the house) changed either disappearing, being replaced by a different element, changing colour or position (e.g. Henderson & Hollingworth, 1999; McConkie & Currie, 1996 cf. O'Regan 2000).

It was also demonstrated that when observers' eyes were directly fixated on the location of change, they still failed to detect the change 40% of the time. Thus, direct fixation aids detection but does not ensure it. Fixation was not a guarantee of detection (Rensink, O'Regan et al. 1997).

Experiments showed that change blindness was not specifically related to eye movements. Rensink et al (1997) popularized the "flicker" technique in which two images alternate repeatedly with a brief (80ms) blank screen after each image (Figure 1). It was found that large changes could be made to the scene without the observer noticing when the blank screen was inserted. On the contrary, where no flicker was inserted in between the pictures, the change was immediately visible and totally obvious. (See <http://www.usd.edu/psyc301/Rensink.htm> for a demonstration of these videos)

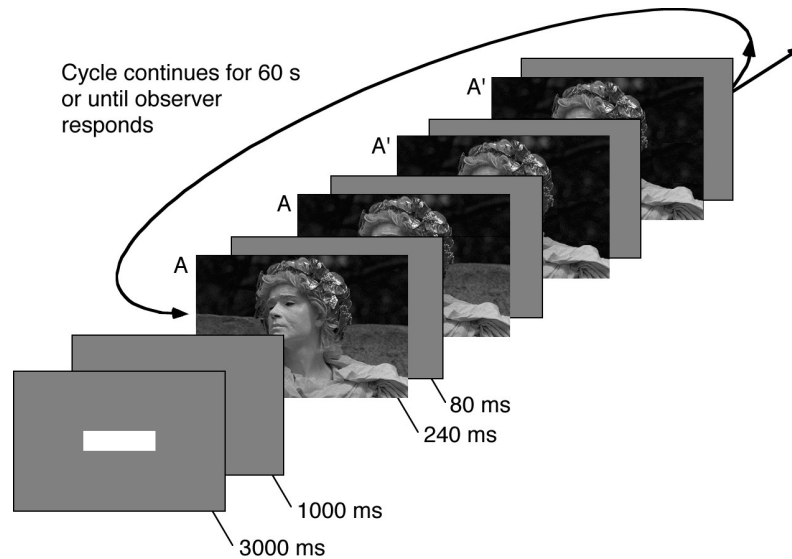


Figure 1: Flicker Paradigm
Source: <http://www.cs.ubc.ca/~rensink/flicker/index.html>

A variant from the flicker paradigm is the mud-splash technique: Experimenters flashed some dot patterns located sparsely on top of an image appearing at the same time as the change occurs but without covering the change location (Figure 2). Although responses were considerably faster than when the blank screen was used, people failed to detect changes (Rensink, O'Regan et al. 1997; Simons and Levin 1997b). This occurrence showed that possibly dangerous events occurring in full view might go unnoticed if they coincide with even small apparently innocuous disturbances. (See <http://nivea.psycho.univ-paris5.fr/ASSChtml/dottedline.gif> for a demonstration of these videos).

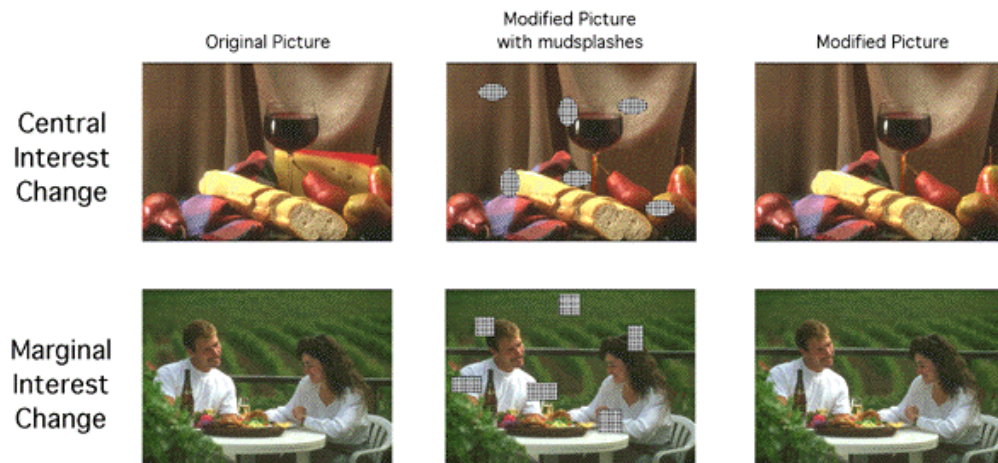


Figure 2: Mud-splash Technique

Source: <http://www.cs.bris.ac.uk/~cater/PhD/ChangeBlindInfo/Examples.html>

Other studies showed that change blindness occur when the change is introduced during a cut in a motion picture, even when the change was to the central actor in a scene, 67% of observers failed to detect the change from one actor to another. (Simons and Levin 1997a; Simons and Levin 1997b). (See <http://viscog.beckman.uiuc.edu/grafs/demos/23.html> for a demonstration of these videos).

In a compelling real-world demonstration an experimenter asked pedestrians for directions. While the pedestrian was providing directions, two additional experimenters, carrying a door, passed between the initial experimenter and the pedestrian. During this brief interruption, a different person replaced the original experimenter. Even though the two experimenters looked quite different and had distinctly different voices, half the subjects failed to notice that they were talking to a different person (1998) (Figure 3). However, those who noticed tended to be from the same social group (students) as the experimenters, and those who failed to notice tended to be older than the experimenters. (See <http://viscog.beckman.uiuc.edu/grafs/demos/12.html> for a demonstration of the experiment).

To explore this in-group/out-group effect, they conducted a second experiment in which the same two experimenters were dressed as construction workers. By making the

experimenters members of an out-group for the younger subjects, change detection was reduced to only 35%. However when both the direction-asker and the direction-giver were students, change detection was almost 100%.



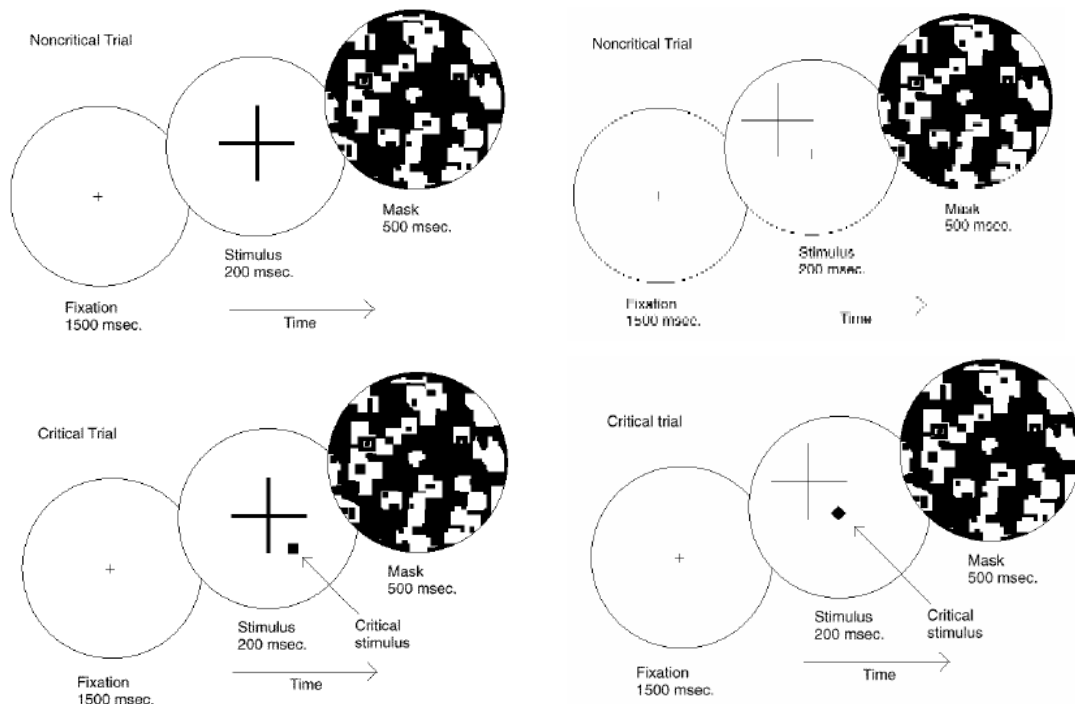
Figure 3: Failure to Detect Changes to People in Real-World Interactions

Source: Varakin, Levin et al (2004)

(Simons and Levin 1998). Box A: initial experimenter approaches a pedestrian. B: the initial experimenter walks away behind a passing door, and another experimenter finishes the interaction (box C). D: the switching experimenters side by side.

Inattentional Blindness

Inattentional Blindness occurs when attention is diverted to a specific task, observers often fail to perceive an unexpected object, even if it appears at fixation (Mack and Rock 1999). Mack and Rock (1998) conducted an experiment where a small cross was shown briefly on a computer screen for each of several experimental trials and asked participants to judge which arm of the cross was longer. After several trials, an unexpected object, such as a brightly coloured rectangle, appeared on the screen along with the cross (Figure 4). They reported that participants—busy paying attention to the cross—often failed to notice the unexpected object, even when it had appeared in the centre of their field of view. When the cross did not divert participants' attention, they easily noticed those unexpected stimuli such as the rectangle.



Cross centred at fixation - Critical Stimulus centred parafoveally **Cross centred parafoveally - critical stimulus centred**

Figure 4: Screen shots Inattentional Blindness Experiment

Source: Mack and Rock 1999 <http://psyche.cs.monash.edu.au/v5/psyche-5-03-mack.html>

They also found that while the inattentional blindness effect was robust for meaningless stimuli, their participants almost invariably noticed when their own names were presented. Even more amazingly, inattentional blindness returned if the participant's name was slightly misspelt.

Arising from this set of experiments, they supported a flexible selection theory of attention which states that depending on the nature of the stimuli (high- or low-level attributes), it may be that the system operates to minimize effort and so will select on the basis of a low-level attribute like size if possible but, if not, will process the input more deeply, as seems to be the case with lexical stimuli (Mack and Rock 1999).

If the critical stimulus falls within the zone of attention, the probability that it will receive some benefit from attentional processing seems high. If, however, the critical stimulus has no particular intrinsic signal value and is irrelevant to the subject's assigned task, the attentional warrant that permits a stimulus to pass from implicit to explicit perception is

minimal, so that only its presence or its bare bone features are perceived. If the same stimulus were to fall outside the zone of attention, then it is far more likely that even its presence will go undetected, because it does not have the benefit of even minimal attentional processing.

In another set of experiments, participants were asked to view dynamic scenes of four white and four black shapes (T's and L's or circles and squares) independently moving on a computer screen (Figure 5). Periodically, these shapes would bounce off the edge of the display. The participants' task was to count the number of times shapes of a designated colour (either black or white) touched the edge of the display ignoring shapes of the other colour. Each trial lasted for 15 seconds. On the third trial, an unexpected object appeared from the right side of the display and moved across it, remaining visible for 5 seconds. The most striking result was that less than half the observers (47%) noticed the unexpected object when it passed right through the centre of the screen, even though the object always stayed on what was presumably the focus of attention and was clearly visible for 5 seconds. (Most, Simons et al. 2000)

Consistent with the findings of Mack and Rock (1998), Most et al (2000) results demonstrated a role for distance from the focus of attention (i.e., the region around the horizontal line). The farther the unexpected cross was from the horizontal line (Figure 5), the fewer the observers who noticed its appearance on the critical trial, with detection dropping to only 21% noticing overall in the *Very Far* condition. (See <http://viscog.beckman.uiuc.edu/grafs/demos/6.html> for demo)

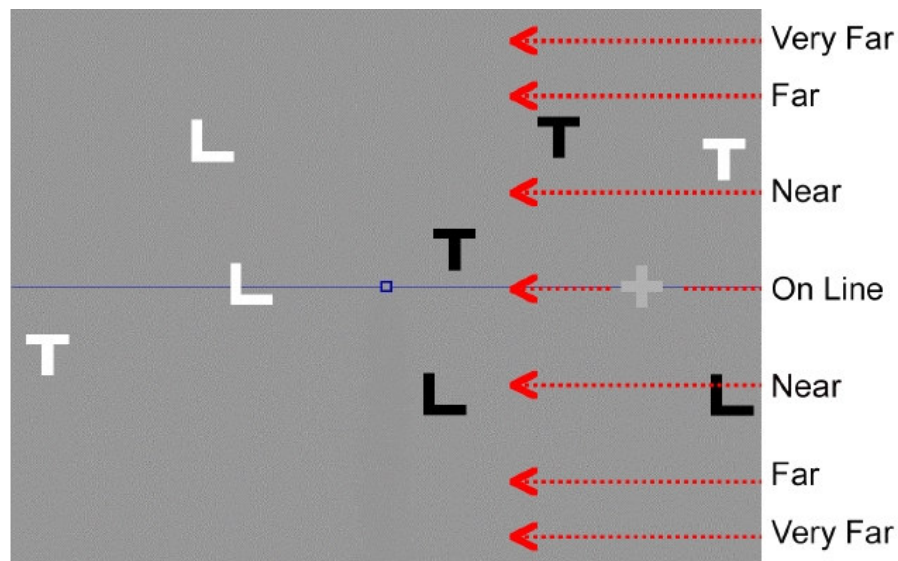


Figure 5: Most et al. 2000 Experiment

Source: <http://psyche.cs.monash.edu.au/v6/psyche-6-14-most.html>

In 1975, Neisser and Becklen conducted a different set of Inattentional Blindness' experiments. Participants were asked to monitor one of two overlapping, simultaneous events in a computer display: two people playing a hand game or a team passing the ball to each other. If they monitored the hand game, they pressed a button with each attempted slap. If they monitored the ball game, they pressed the button for each pass (Neisser 1976).

On the last four trials, an unexpected event would occur, for instance, the two hand-game players stopped and shook hands or one of the ball-game players threw the ball out of the game and the players continued to pretend to be passing the ball. In total, 50% of the subjects showed no indication of having seen any of the unexpected events, and even subjects who did notice could not accurately report the details of them. Researches argued that the video superimposition gave the scenes an odd appearance making it difficult to see as they would without the superimposition.

To demonstrate that the superimposition was the cause of the inattentional blindness problem, Simons and Chabris (1999) set up an experiment with two styles of video: a transparent condition, replicating Neisser and Becklen's superimposition, and a standard video which they called "opaque condition". The opaque condition showed all seven actors simultaneously causing some occlusions between actors and basketballs (Figure 6).

The video lasted for 75 seconds. It showed 2 teams of 3 players each wearing either white or black T-shirts. For the unexpected event, a short woman dressed up as a black gorilla or a woman with an umbrella was recorded walking through the room. The unexpected event lasted for 5 seconds.

Observers were asked to monitor one of the two teams. They should keep either a silent mental count of the total number of passes made by the attended team (the Easy condition) or separate silent mental counts of the number of bounce passes and aerial passes made by the attended team (the Hard condition).

The results revealed a substantial level of inattention blindness for these dynamic events confirming the basic results of Neisser and colleagues. Out of all 192 observers across all conditions, only 54% noticed the unexpected event. More observers noticed the gorilla event in the opaque condition (67%) than in the transparent condition (42%). The authors suggested that for those monitoring the black team was easier to detect the black gorilla due to the similar colours. However, even in the opaque condition, 33% of observers failed to report the event, despite its visibility and the repeated questions about it.



Figure 6: Gorillas in the Midst (Simons and Chabris 1999)
Source: Varakin, Levin et al. 2004

Comparison Blindness

Another type of blindness is the difficulty in comparing two simultaneously present stimuli. This inability to compare 2 concurrent stimuli seems to be due to transsaccadic memory limitations in tasks requiring saccades.

Scott-Brown et al. (2000) stated that people fail to notice changes in tasks where two stimuli are presented in the central visual field within a single fixation and where there are no transients present. Studies in comparison blindness have demonstrated that comparisons over space within a single fixation to be as difficult as comparison over time showing that memory is not essential to produce change blindness (Wright, Green et al. 2000; Scott-Brown, Baker et al 2000)

Repetition Blindness

A wide variety of visual phenomena reported in the literature have considered an effect known as repetition blindness which refers to the impairment in detecting or reporting repetition of visually presented stimuli such as words, alphanumeric characters or pictures. Repetition Blindness has typically been studied using rapid serial visual presentation (RSVP) in which a sequence of items is presented within the same spatial locus at a high spatial presentation rate (Kanwisher, Kim et al. 1996; Chun and Cavanagh 1997; Shapiro, Driver et al. 1997). If the character they are looking for appears twice, participants usually detect only one of them and fail to notice the other one.

In conclusion, recent evidence from work on change, inattentional, comparison and repetition blindness shows that under precisely controlled timing and response conditions, observers sometimes fail to detect stimuli that are otherwise clearly visible.

Repetition Blindness contradicts our common belief that repeated items are easily recalled. It is not an attentional problem, it seems to be a retrieval failure, not an encoding failure, which is not relevant in the study of change detection and therefore is not going to be taken into account.

Comparison Blindness analyzes how poor we are at comparisons that do not require memory. Rensink (2002) makes a clear distinction between change and difference claiming that “*change* refers to the transformation over time of a single structure [while] *difference* refers to a lack of similarity in the properties of two structures” (p. 250). Consequently, since we are interested in change and not differences, we will not explore this topic any further.

Change Blindness and Inattentional Blindness share a condition of inattention that prevents observers to become aware of salient visual changes in their visual field. Researchers have suggested that these experiments showed that without attention, for Inattentional Blindness experiments, we often do not see unanticipated events, and even with attention, for Change Blindness experiments, we cannot encode and retain all the details of what we see.

Change Blindness in Operational Environments

Studies in change detection have been performed in driving, aviation (Wickens and Muthard 2003), and combat environments (DiVita, Nugent et al. 2004). They generally found that the main predictor of change detection was the relevance of the change to the task being performed. Accuracy improved as the relevance increased. Lesser effects, such as the number of objects monitored, the positioning of monitored objects and the method of presentation were also found.

Niklolic and Sarter (2001) investigated pilot performance in detecting mode changes in their flight management system when monitoring peripheral displays. They found that, using the peripheral display that performed the best, pilots still missed over 10% of the changes, and that this rate substantially increased to almost 20% with competition for visual attention. DiVita, Nugent et al. (2004) verified the magnitude of change blindness in a realistic scenarios that simulated tasks performed by naval CIC operators showing that in applied work settings, diversion of attention creates an opportunity for changes to occur to unattended computer monitors. For instance, for changes in airplane course, only 68% of changes were correctly identified on the first selection.

Podczerwinski et al (2002) demonstrated that detection of relevant changes, changes that cause a potential conflict, in both traffic and weather systems was superior to that of irrelevant changes. Change detection was only at 50% accuracy, but improved by changes that were more salient (spatially, not digitally represented), and were more meaningful (causing a conflict with the flight path). Changes that were relevant to the pilot's flight planning task were detected nearly four seconds faster than irrelevant changes.

Wickens and Muthard's (2003b) suggested that change detection was dominantly driven by meaningfulness. They used dynamic integrated hazard displays which are able to present pilots with the changing status of traffic and weather overlaid upon the dynamic information related to route guidance. They also assessed the influence of the monitor size, highlighting levels, and event eccentricity in surveillance tasks.

Wickens and Muthard (2003) hypothesised that physical differences in a cockpit hazard display influence the ability to detect changes and this influence itself is modulated by top-down influences of change relevance or importance. In their experiments, pilots were asked to detect changes in the movement or altitude of weather systems or traffic aircraft, which were represented in integrated hazard displays.

They examined change detection as a function of the distance of the event from own-ship, known as eccentricity or distance from the foveal vision, and the presence of the event in a highlighted or low-lighted hazard domain. Analyses revealed that change detection was superior for events that were in the highlighted display database and that performance was slightly degraded for more eccentric events. In the highlighted domain of the display, either traffic or weather information, search was found to focus more frequently on the highlighted elements, and to a lesser extent, to the elements that were located more closely to the centre of focused attention, both of which are consistent with models of visual search and strategies of map search (cf. Wickens, Muthard et al. 2003). Therefore, since highlighting and location correlate with meaningfulness in the aviation domain, it is more likely that a changed element in a low-lighted display domain or in the periphery will go unnoticed or be noticed at greater latencies.

When assessing the role of computer screen size, results showed that change detection was unaffected by the size of the screen, however, although not statistically significant, accuracy revealed a meaningful degradation in performance for small displays likely because of the minimisation of the display elements which decreased legibility and resolution.

For elements located in the periphery, performance was again degraded for changes located near the perimeter of the display, probably because in the aviation domain, event eccentricity is confounded with relevance: In the case of a CDTI (Cockpit Displayed Traffic Information), events (changes) closer to own-ship generally are more relevant to flight safety (Wickens, Muthard et al. 2003b). These findings imply that surveillance of the display perimeters will depreciate and additional methods should be used to ensure that attention is sufficiently directed to these areas.

Finally, attention guidance aids have shown to assist performance in directing attention to the relevant elements of a scene, which according to the authors is beneficial in improving plan selection accuracy and confidence, especially in the high workload conditions by improving situation awareness (Wickens and Muthard 2003). Negative effects, such as cognitive tunnelling, are also associated with imperfect automation. Consequently, if an aid fails to highlight a relevant element of the visual scene, the pilot may fail to detect the important, but uncued element. Imperfect automation guidance resulted in greater frequency of missed critical events (61% misses with imperfect automation vs. 39% misses in control condition). Analyses of ASRS (aviation safety reporting system) reports have provided evidence of monitoring failures linked to excessive trust in, or over-reliance on automated systems (Wickens 1998)

These studies demonstrated that change blindness is likely to occur in operational environments. We have to keep in mind that even when the computer screen size does not affect change detection performance, eccentricity and intensity of the elements in a visual display have a significant influence on change detection. On the other hand, if automation aids are implemented in change detection tasks, they have to be very precise to prevent bias and untrustworthiness.

Chapter 2

Why does change blindness occur?

The answer to this question is not straightforward. The current hypotheses can not explain by themselves all the change blindness effects that have been identified.

For centuries, scholars assumed the need for precise, veridical representations of our visual world. However, change blindness studies have provided evidence against the existence of detailed internal models (Simons and Levin 1997b; Noe, Pessoa et al. 2000), instead change blindness supports the phenomenal experience of continuity by not preserving too much information from one view to the next (Simons and Levin 1997, p. 267).

In Simons' review of the current approaches of Change Blindness (2000), he presents 5 plausible causes based on the nature of our visual representations (Figure 7) stating a wide range of hypotheses from the extreme belief that none of our visual representations are stored, to the belief that all of our visual representations are stored but are not compared until something triggers the comparison. These five hypotheses are detailed below:

Overwriting Hypothesis

The most plausible explanation for change blindness is that the initial visual representation is simply overwritten or replaced by the blank interval or by the subsequent image. Overwriting models have been used to explain visual masking as well as poor recognition of scenes from RSVP (rapid serial visual presentation) streams (cf. Simons 2000). "Information that was not abstracted from the initial scene is simply replaced in the representation by the new scene" (p. 8)

Gist/First Impressions

The First Impressions hypothesis supports the idea that observers encode the features of the initial object or scene and fail to encode the details of the changed scene. Observers "encode the gist of the scene and ignore visual details. As long as the gist remains the same, change detection seems

unlikely because observers have not expended the effort to encode more details” (Simons and Levin 1997b, p. 266). To verify that the meaning is constant, observers do not need to re-encode all of the details of a scene with each view, but to check a few features to make sure they are seeing the same scene. By identifying the scene’s meaning, they can avoid the need to encode and update all the details related to that schema from one view to the next. If a change affects the meaning of a scene, observers will be more likely to compare the details of the scene to their representations and thereby detect the change. The meaning serves as a trigger for spontaneous detection of unexpected changes. This hypothesis is supported by the movie-cut experiments in which subjects who failed to detect a change in the central object in motion pictures, described the features of the object in the initial scene rather than in the changed view (Simons and Levin 1997a).

Nothing is stored

A number of theorists have claimed that nothing is stored and the world serves as a memory store (see Gibson 1979; Simons 2000, p. 10). Given that none of the details of the first image are represented in a visual store, change detection should be impossible without abstraction. A somewhat weaker form of this model suggests that some detail is preserved between scenes (*e.g.* the details of the objects in the viewer's focus of attention). In this way, we are blind to change unless it affects our abstracted knowledge of the scene.

Everything is stored

Another possibility is that details about each new scene are stored, but cannot be accessed until an external stimulus forces the access. The visual cognitive system may assume the views are consistent unless something about the meaning of the scene triggers comparison (Simons 2000, p. 10). For instance, in one of the adaptations of Simons and Levin’s real-world experiments, the person who asked for directions was holding a basketball that was taken away by a group of students who passed between the pedestrian and the experimenter. Only three of the subjects spontaneously reported the disappearance of the basketball. When the remaining participants were asked specifically if the experimenter used to have a basketball, more than half say yes. Subjects were initially blind to the change, but when prompted, they could recall the presence of the basketball and its features.

Combination of features

A final hypothesis is that details from an initial view might be combined with new features from a second view to form a combined “coherent” representation of the scene. Presumably, viewers would not be aware of which parts of their mental image come from the first scene, and which come from the second. The details being combined must make sense, and must be consistent with the viewer's abstract understanding of the scene, otherwise the change will be recognized as "impossible" or "out of place".

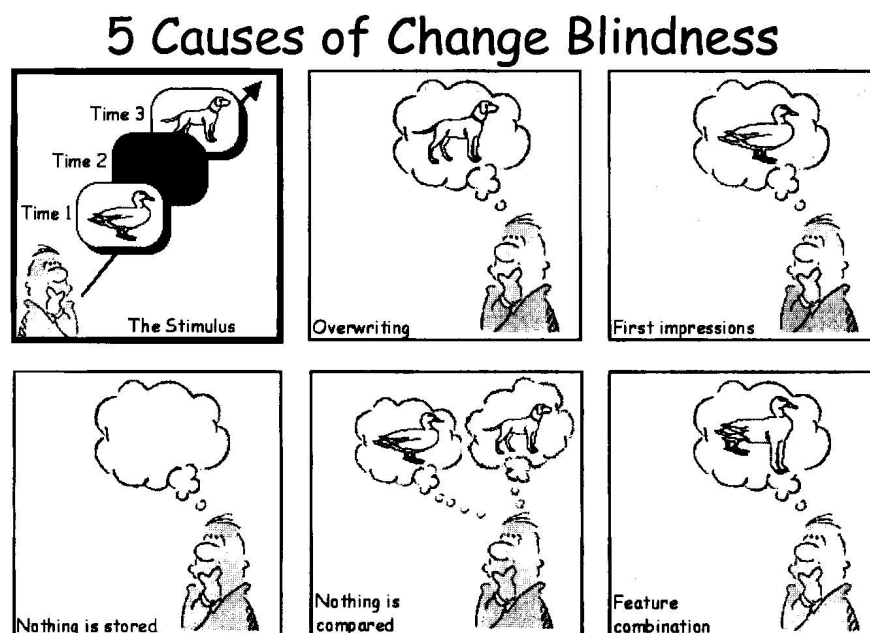


Figure 7: Current Approaches to Change Blindness
Source: Visual Cognition (Simons 2000)

Simons and Levin's review (1997) presented an example of a busy city street in which several changes occur during the normal set of events: We could see people walking in a busy crowd, going behind cars, kiosks, telephone booths; someone shifting a handbag to the other shoulder, someone taking a mobile phone out of a pocket and so on.

In such a rapidly changing environment, if our visual system would encode in detail every change, it would become very confusing and chaotic. Instead our visual system seems to focus on the information we need to know while ignoring uninteresting object property information. This

example raises the question if, in fact, we really have time to check the environment we perceive continuously for changes that have no meaning and do not change important affordances.

On the other hand, Rensink support the coherence theory which states that focus attention is required for change detection and it acts as a hand that ‘grasps’ several volatile structures called proto-objects that describe several aspects of a scene structure (Rensink 2000). This interaction between attention and proto-objects, allows attended proto-object properties to be held in a coherent form, both in time and in space. When this loop is broken, “coherence dissolves, with the previously attended proto-objects reverting to a volatile state. A change in a stimulus can be seen only if it is given focused attention at the time the change occurs” (Rensink 2000, p. 20). Since only a small number of items can be attended at any time, most items in a scene will not have a stable representation (Pashler 1998) provoking change blindness if attention was not automatically directed to the change.

Thus, vision enables us to learn about the environment but there is a good deal that goes on around us that we fail to notice. The reasons why we are unable to detect some changes are still open to question. Over the past years, researchers have focused increasingly on change blindness as a means to examine the nature of our representations. Failure to detect changes provided evidence of the absence of richly detailed internal representations. The debate is still open if whether the world serves as a memory store (Gibson 1979, Simons 2000), or our visual system encode some or all the features but fail to make them available to memory or to verbal report (Noe, Pessoa et al. 2000). Rensink and colleagues (1997) assume that attention functions as a bottleneck on what is encoded but Noe et al. (2000) argued that perhaps memory or other access limitations provide a bottleneck on what information can be used in making reports about the detection changes.

Chapter 3

Perceptual Depth as an alternative technique

So far we have reported the change blindness phenomena, its empirical evidence and the possible causes for this “blindness” to occur. We understand that in operational environments, namely safety-critical ones, being blind to changes that might occur in a computer display could cause immense economic or human costs.

We want to take a different step by proposing the use of a new physical device that due to its properties might enhance change detection. This new device is called the MLD (Multi-Layered Display). Current 3D computer graphics systems include perspective, stereoscopic, rotating, head-motion tracking, holographic, and multi-planar displays. All these three-dimensional technologies present high costs, the necessity of additional glasses or additional input/output devices and intensive computational requirements, which does not make them a viable option to implement in safety critical environments or other surveillance and operation rooms. However, we propose that transparent depth displays such as the MLD form a promising development because it overcomes these drawbacks. Additionally, it provides a perceptual depth cue that can be used to enhance change detection; however, this hypothesis requires further evaluation.

Visual displays often use *transients* (detectable visual cues that signal a change in the environment over time) – techniques such as highlighting, changing colours, boxing, reverse video or flashing have been used to notify users about important events. However, recent research and operational experiences in complex domains suggest that those design approaches are not always successful.

The highlighting paradox

Many different techniques have been used to make objects in a computer display more salient and more noticeable. Researchers have studied techniques such as boxing, reverse video, blinking, use of different colours and different levels of intensities (bold). Studies have shown contradictory

results. While Gomberg (1985) (cf. Fisher and Tan 1989) conducted an experiment in which subjects were required to search for a single target digit in a background of 4 distracter digits. Results demonstrated that participants were slower on average to find the target in each of the highlighting conditions: boxing, blinking and reverse video compared to a standard condition. The negative outcome for the highlighting conditions might have occurred because it takes longer on average to identify the blinking digit when it is off; and the boxing and the reverse video might have caused a lateral masking that delayed the identification process.

Fisher and Tan (1989) replicated Gomberg's experiment using colour, reverse video and blinking as the highlighting conditions. They demonstrated that colour did not create lateral masking or temporal delays, and clearly attract the attention almost immediately. However, Fisher and Tan (1989) reported that performance depend on the validity which is the proportion of trials on which the highlighting correctly indicated the target. When the validity was only 50%, response times to detect the target in the colour condition was faster than reverse video or blinking but did not help participants find the target faster than in the control trials (no highlighting). When validity was increased to 100%, the colour condition presented the fastest response times overall, participants took 192 ms less in the colour condition than in the control one, and 207 ms faster than the colour condition when the highlighting validity was 50%.

Since it was not clear from Fisher and Tan's (1989) experiment what would occur at other levels of validity, Tamborello and Byrne (2006) replicated the experiment and extended the results. They only examined colour (red) as the highlighting condition but at 9 different validity levels: 0%, 12.5%, 25%, 37.5%, 50%, 67.5%, 75%, 82.5% or 100%. There were three conditions: control (no highlighting), valid highlighting (target -red) and invalid highlighting (distracter-red). Results showed that subjects became faster on valid trials and slower on invalid ones, which means that sensitivity increased as validity increased. For instance, subjects in the 87.5% validity percentage condition were 201 ms more sensitive to trial validity than were subjects in the 12.5% condition (Tamborello and Byrne 2006). This indicates that subjects learned rapidly whether or not they could take advantage of the highlighting in their visual search.

Another technique employed to highlight important information has been the use of different intensities as a pre-attentive cue for selective filtering. Some studies that have focused on operational environments such as air traffic control used intensity techniques to de-clutter maps by "*low-lighting*" certain information and keeping the rest at a higher intensity level (Wickens, Ambinder et al. 2004). Consistent with visual search models, when more information is presented

in the display, the time to detect an element increases as the amount of clutter does. One way to reduce the penalty of increased clutter in a map search is to increase the visual salience of particular domains of information. Wickens, Ambinder et al. (2004) showed that increasing intensity, increases the salience and attention-capturing properties of the items in a map, however the intensity difference does not have to be too large to achieve adequate levels of discriminability since participants processed any dissimilarity between intensities as a categorical difference. The experimenters suggested that intensity coding techniques support both focused and divided attention tasks in a map display.

Highlighting techniques such as boxing, reverse video, blinking or use of different intensities have not proven to be 100% successful, therefore we propose the use of a perceptual depth cue to make information more noticeable. This perceptual depth, still to be examined, is obtained by using a new display technology called the MLD.

Multi-Layered Display (MLDTM)

The MLD is a new display technology that incorporates 2 LCD panels, one in front of the other separated by a Perspex layer giving it the potential to present physical depth. The MLD is not a three-dimensional display, however, it has the capability of using perceptual depth to present increasing amount of information on a monitor of a given display size, and more importantly, it has the potential of increasing the informativeness of the presented data in subtle ways.

It is important to mention that the MLDTM is an affordable technology, easy to acquire, in contrast with other stereo-display technologies that raise formidable costs, sophisticated high-speed graphic software and acceptance barriers in operational environments. Due to its layering capability, the MLD is able to de-clutter information; we assume that it may reduce the number of orthographic displays currently required in surveillance and control rooms. Additionally, the MLD makes use of the WIMP paradigm (Windows, Icons, Menu and Pointer) which is commonly used by most computers users compare to other 3D displays that may require replacing the mouse and keyboard-based interactions with ad-hoc 3D input devices (Tavanti 2004).

However, the MLD presents some disadvantages: Its novelty produces unfamiliarity that will require additional costs on training and time to get use to it. Designers should pay special attention to how elements are positioned in the visual display due to a “depth ordering” effect that cause objects in the front layer to be occluded by other objects located in the same layer, which at the

same time become transparent so objects in the back layer remain visible. Finally, the way light is reflected through both layers slightly changes the hue of the colours presented in the visual display. Although it is not a major difference, it might become problematic especially when using a dark background on the back layer.

Although the MLD has some disadvantages, they can be overcome with an interface design that tackles these factors. Its capabilities such as layering and de-cluttering become an outstanding advantage over conventional displays which strengthen its practicality and the possibility to introduce it in surveillance and control environments.

It has been shown in studies on the MLD that it can improve human performance in visual information search (Duenser, Billingham et al. 2006; Duenser, Mancero et al. 2006), association and comparison tasks especially in monitoring behaviour and supervisory control (Joyekurun, Wong et al. 2005; Wong, Mansour et al. 2005). These studies have evaluated factors such as legibility, layering, visual search and multiple-object tracking.

Studies conducted on the MLD

Several studies have been conducted during the past years since Pure Depth created the MLD. Fred Angelopoulos, CEO of the Redwood Shores (California) start-up, affirmed that “when stuff moves towards us we naturally react quicker”(TechNow 2001). This claim has partially been demonstrated in studies conducted in the MLD when comparing participants’ performance to a single-layered display (SLD). Although results have been contradictory, they have provided important insights on design techniques for the MLD.

Visual Search Tasks

A number of studies have demonstrated that depth can be used as a segregation cue to separate target from distracters (cf. Wickens and Hollands 2000; Wong, Mansour et al. 2005). The results showed that the search times were faster when the target and the distracters were separated in different depth planes.

An experiment was conducted to investigate whether the depth-information provided by the MLD would lead to a better performance in a visual conjunction search task compared to single-layered displays. Twenty participants were asked to detect a target (red circle) among several distracters which differ in colour, shape or depth. The results showed that depth cues alone behaved similarly to search times with shape or colour cues alone in which regardless the number of stimuli, the time remained almost constant but participants were twice as slow compared to the colour condition. However, when combining depth with other cues such as colour and shape, reaction times became faster due to parallel processing (Duenser, Billingham et al. 2006).

Legibility

A study investigated legibility at different levels of transparency and colour combinations for visual perception tasks (Nees, Villanueva et al. 2003). Forty students participated in this experiment. They were presented with a random series of six different readings, each with different text colour and background pairings. The readings were either presented in a traditional single-layered display (control) or in the MLD with different levels of transparency (no transparency, 30% and 70%). Reading speeds, error detection, comprehension speeds and accuracy were measured. The results showed that no further transparency should be applied to the MLD although it was shown that a higher percentage of transparency can enhance tasks such as error detection. It was also demonstrated that foreground and background colour pairings of colour text that have lead to poor legibility on conventional displays, provoked faster reading times in the

MLD, emphasizing the importance of reassessing design recommendations for the MLD (Nees, Villanueva et al. 2003).

Information Layering and De-cluttering

Participants were presented with several moving circles labelled with a specific height. They had to identify all the moving circles in a certain designated height for the easy level, or identify those moving circles that were above a certain height for the more difficult level. The moving circles were presented either in a single-layered display (SLD) (control) or in two layers using the MLD, and in different transparency levels (0%, 30%, 60% or 90%). The results showed that for the easy level, participants' response time on the MLD were only slightly better than on the SLD. However, for the more demanding task, response times for the MLD were superior than their counterparts in the SLD at all levels of transparency provoking faster response times ranging between 1.5 to 4.5 seconds (Joyekurun, Wong et al. 2005). However, because there were only six students participating in this study, it is difficult to generalize from these results.

Another study focused on de-cluttering displays for emergency ambulance dispatch centres redesigned the current map-based dispatch display for the MLD. The information locating the map and other contextual information was shown in the back layer and only significant incident-relevant information on the front layer (Hayes 2006). The new design using the MLD was evaluated with forty students where they were presented with 4 different levels of difficulty. Participants had to choose a centre to dispatch an ambulance based on the location of the incident and the location of the centre where they were sending the ambulance from.

For the first level of difficulty, participants had only one appropriate centre in the area from which to dispatch an ambulance. In the most difficult level (level 4), participants had to balance the ambulance coverage over an area so that there won't be 'gaps in coverage' as a result of sending ambulances to an incident (Hayes 2006).

The results of this study did not present any significant difference between the MLD and the SLD. However, in the fourth level of difficulty, participants made more errors using the MLD than the SLD. The author justified this higher percentage of errors by a phenomenon called "tunnelling of vision" since the participants chose the incorrect ambulance dispatch centre because they did not observe a river illustrated in the map that presented an obstruction in the way the ambulance had to take in order to get to the incident.

Even when the results were negative, it raised some interesting points: First, it seemed that the visual depth had a significant impact on user performance, but it was a negative impact that led to mistakes (Wong 2006). Again, the interface design used in the experiment has to be evaluated. It seemed that the design choice was extremely biased towards the information labels. Therefore, only task outcomes directly arising from the labels were bound to succeed. Amaldi (2006) pointed out that visual displays have the objective of attracting people's attention on the "relevant" information, but if some information is made too relevant the risk is that the operators will focus inappropriately on the information when it is no longer necessary.

Multiple Object Tracking

Duenser et al. (2006) replicated Viswanathan's experiment of allocation of attention in different depth planes using a MLD instead of a stereoscopic display. They found that using the depth properties of the MLD increased users' performance when tracking multiple moving objects on a computer screen. In the experiment, users could track more objects correctly when they were equally distributed over two depth layers.

These studies have demonstrated the potential that the MLD has above conventional single-layered displays, especially in search, monitoring and tracking tasks. However, it is important to emphasize that traditional design techniques have to be reconsidered when designing for the MLD. Its different configuration forces designers to rethink on ways to keep the relationship between the front and the back layer as well as keeping the task compatibility with the suitability of the display for the desired perceptual task since different displays are compatible with different tasks (cf. Wong, Mansour et al. 2005)

Chapter 4

Cognitive Processes for the MLD and Change Detection

Using an MLD implies a new set of cognitive analyses since the use of perceptual depth as a cue to enhance change detection has not yet been investigated. The following sections provide an overview of visual and attentional processes analyzed under the change blindness phenomena and the use of the MLD. Concepts such as depth perception and the deployment of attention in depth are evaluated.

Vision and Attention in the Eyes of Change Blindness

Early theories of attention states that our brains construct an exact representation of what we see. In 1985, Feldman hypothesised the existence of a visual buffer, a spatiotopic memory store believed to accumulate the contents of successive fixations. However, change blindness suggests that no such buffer exists. Irwin (1996) stated that it appears that the detailed contents of successive presentations - including successive fixations - can never be added, compared or otherwise combined in their entirety, ruling out any large-scale accumulation of information (cf. Rensink 2002). Noe, Pessoa et al. (2000) stated that change blindness is not surprising because "seeing is a temporally extended activity of visually exploring the environment"(p. 95). Since we blink once or twice a second, and saccadic suppression occurs 3 or 4 times a second, our eye acquires visual information only during these brief and interrupted windows, so they suggested that it is mistaken to suppose that the visual system has to build up integrated world-models and it is mistaken to suppose that vision in general requires such models.

In fact, studies on monkeys' brains conducted in 1982 raised interesting findings about the visual system. Ungerleider and Mishkin found that there were two perception streams in the brain: the dorsal and the ventral stream. The dorsal stream said 'where' things were, the ventral stream said 'what' things were. Thus, when people suffered dorsal stream insult (stroke or brain injury) they

would be able to identify things, but not be able to reach out to them. When people suffered ventral stream insult they could interact with things but not describe them to others.

In 1991, Goodale and Milner extended this to ‘*how*’ and ‘*what*’ distinguishing between “a vision for perception and a vision for action” (Goodale and Milner 2006, p. 660). Their findings showed that the dorsal stream picks up affordances requiring precise spatial knowledge to prompt action, while the ventral stream picks up representations and only general spatial relations are necessary. The problem with accurate spatial knowledge is that it takes a lot of space and is only useful for short periods of time - if a person moves an inch to the left then the precise knowledge is no longer useful (Gaukrodger 2007). Because the dorsal stream is concerned with action, not cognition, it is expected people to notice only those changes that affect interaction with that specific object.

Change Blindness studies have attempted to distinguish the neural correlates of change detection from those of change blindness. By using functional magnetic resonance imaging (fMRI) of subjects attempting to detect a visual change occurring during a screen flicker, results demonstrated that although change blindness resulted in some activity, *the dorsal activations were clearly absent* (Beck, Rees et al. 2001; Pessoa and Ungerleider 2004). These results demonstrated the importance of parietal and dorso-lateral frontal activations for conscious detection of changes in properties coded in the ventral visual pathway, and thus suggest a key involvement of dorsal-ventral interactions in visual awareness (Beck, Rees et al. 2001)

If it has been shown that during visual disruptions, the dorsal stream is not activated, and visual disruptions apparently swamp the visual transients away, then how are we still capable of detecting changes? Based on an ecological theory, we suggest that we are able to notice those changes that affect interaction with that specific object that the observer is interacting with.

How do we perceive in depth?

The ability for humans to perceive depth is a complex neural activity which takes advantage of physiological and environmental resources, as a means of maximising the chances of producing the least ambiguous percept of distance in a three-dimensional space as possible (see review by Joyekurun 2006). One of the most complicated feats achieved by the human brain, more specifically the human visual system is in the computation of the third dimension of our world. Also known as the reverse-optical problem, it arises from the postulate that the human brain needs

to infer all three-dimensional qualities and quantities of a saccadic-image from the two-dimensional properties of a retinal projection.

If the spatial characteristics of our environment are computed from a relatively flat retinal image, then it is safe to assume that a flat and synthetic image augmented with an appropriate number of ecologically valid, visual cues would be sufficient to provide any percept of space and depth. Photographic and moving pictures sequences are a proof of the process as they capture a snapshot of our environment but still allow the human visual system to infer an excellent number of spatial percepts from them. The reproduction of such ecological cues has proved harder to achieve in spatially flat presentation interfaces and displays. The shortcut taken by many in adopting a direct simulation of the three-dimensional world by reproducing its basic spatial and lighting conditions, for instance virtual realities, has proved immensely useful in untangling many issues (Joyekurun 2006).

Although many have pointed out that we do not see ‘depth’ at all, Gibson went to the extreme to claim that “there is no such thing as flat form perception, just as there is no such thing as depth perception” (1979, p. 150). Hence to talk about ‘depth perception’ is possibly somewhat misleading. What we see is not ‘depth’ but surfaces and textures of objects. However, for convenience, we will refer to this phenomenon as ‘depth perception’ and we will explain a number of mechanisms that come into play to enable us to perceive depth.

The depth cues

Stereopsis

Stereoscopic vision relies on two factors: binocular disparity and vergence. *Binocular disparity* is the name given to the fact that, because our eyes are set about 6-7cm apart, our retinas receive slightly different, but considerably overlapping images (Lansdown 1996). Joseph Harris in his posthumously published *Treatise of Opticks* (1775) was perhaps the first to suggest that the two disparate images we receive in binocular vision might be used to produce depth. But it wasn’t until 1832 when Charles Wheatstone showed that a 3D effect could be produced by viewing two-dimensional images using his stereoscope. The 3D image formed by 2 separate views enables us to estimate the depth of objects which provokes *stereoscopic cues*.

Motion parallax

The apparent relative motion of several stationary objects against a background when the observer moves gives hints about their relative distance. This effect can be seen clearly when driving in a car, nearby things pass quickly, while far off objects appear stationary. Therefore, moving the head sideways or up or down has two effects: it provides a depth percept during the motion from the optic flow, and it provides different points of view (Kooi 2001).

Gibson took the view that it is not just motion parallax but the more general concept of *motion perspective* that is the primary factor in our perception of depth: We perceive in order to move, but we must also move in order to perceive (Gibson 1979, p. 223). Motion perspective is the continuous change in the way objects —especially collections of objects — look as an observer moves about.

Obviously detection of movement plays a vital role in the survival of animals: they must be good at perceiving movement of predators and of likely prey. Sekuler (2002) proposed that during evolution, motion perception was probably shaped by selective pressures that were stronger and more direct than those shaping other aspects of vision. As a result of such selective pressures, our visual systems contain neural mechanisms specialised for the analysis of motion.

Texture gradients

Gibson (1979) claimed that a key function of the visual system is to extract properties of the surfaces. He pointed out that surface texture is one of the fundamental visual properties of an object. The texture of an object helps us see where an object is and what shape it has. On a larger scale, the texture of the ground plane on which we walk produces a characteristic texture gradient that is important in space perception. It is difficult to design textured surfaces in computer visualizations, but in 3D environments it provides an essential cue to the orientation, shape and spatial layout of a surface. Gibson went so far as to claim that texture gradients were sufficient for the guidance of ego motion.

Overlapping and partial occlusion

One of the elements we use in depth perception is our knowledge of the fact that objects that are nearer partially obscure are farther away. Strong empirical findings have recently shown that although monocular occlusion provides depth cues, binocular occlusion gives an added feature in the form of metric depth (see review Joyekurun 2006).

Overlaying is used to convey an understanding of depth but it is not without its problems. Gibson suggested that the phenomenon of the superposition of objects is actually not a clue to the depth of objects but a perception which requires explanation (1950, p.142). A man knows that a near object can partially obscure a far object but his retina does not, and a retinal explanation should be sought first. He proposes that the contours of partially occluded objects are different from those that are not occluded.

Deployment of attention in depth

One of the presumed functions of the visual system is to facilitate navigation within a three-dimensional world, therefore, one might hypothesize that attention is allocated within a representation that includes depth information (Marrara and Moore 2000). Object-based theories of attention claim that selective attention can operate on perceptual objects and not on the basis of spatial location alone. They comprised 2 kinds of studies: those in which two or more objects are displayed at the same spatial location and those in which the spatial location of one or more objects changes with time (multi-element tracking). The first kind of study showed that in scenes with superimposed event sequences or overlapping shapes, human observers can selectively attend to one of the sequences or shapes and ignore the other; despite the physical overlap of spatial location (cf. Viswanathan and Mingolla 2002)

Downing and Pinker (1985) & Hoffman and Mueller (1997) provided some of the earliest evidence that attention can be allocated in depth. Studies have shown that it is possible to focus attention on a particular depth plane defined by binocular disparity (cf. Theeuwes, Atchley et al. 1998). For example, Nakayama and Silverman found parallel search for a conjunction of colour and depth. Because participants could direct attention to a particular plane in depth, a target defined by a conjunction of features became—within the attended depth plane—a target defined by a single feature (Theeuwes, Atchley et al. 1998).

Other studies have used the Multiple Object Tracking (MOT) paradigm to investigate conditions under which depth may aid the allocation of attention when the visual system must simultaneously track a subset of identical moving objects. Pylyshyn and Storm (1988) conducted MOT experiments which suggested that the elements must be tracked in parallel instead of performing a serial process. Holliday and Braddick (1991) and Nakayama and Silverman (1986) showed that attention can be allocated to a specific location defined by disparity where there is no interference from distracters in other depth planes, making it easier to allocate attention in a multi-element tracking task across two surfaces than within a single surface.

These findings were corroborated by Viswanathan and Mingolla (2002). Their experiments were conducted using stereoscopic depth to produce depth perception. The displays were viewed through stereo glasses. Results showed that both the depth factor and the surface factor proved to have strong influence on performance in a multi-element tracking task. They demonstrated that “performance in a multi-element tracking task [does] not deteriorate when attention must be

allocated across two depth planes instead of within a single depth plane, it actually improves” (Viswanathan and Mingolla 2002, p. 1427).

We have seen that visual perception makes free use of all cues available to us as a means of allowing us to perceive in depth. Studies have demonstrated that attention can be allocated to different depth planes without impairing performance. The next step is to use the lessons learned from the studies about visual and attentional processes and the use of depth cues to propose a representational design technique that will allow utilizing the MLD as a tool to reduce Change Blindness.

Depth perception in change detection tasks has to be analyzed in a laboratory environment to investigate cognitive perceptual processes that have not been investigated yet. However the analysis of the relations of the observer with the environment will be taken into account in further research.

Chapter 5

The 5 Effects of Change Blindness

We have detailed the various types of perceptual “blindness, the cognitive hypothesis that have attempted to explain it, and its consequences in operational environments. By conducting an Emergent Themes Analysis, we found some commonalities between twenty five studies conducted on these types of perception-“blindness”. These commonalities allowed us to systematically compare these studies to find themes that intersect among them.

The details of these 25 studies, including an explanation of the experiments and the authors’ key findings were inserted in a table (See Appendix 1). Once this information was in place, we add an additional column indicating our interpretations of those results. Once we analyzed the data in this table, we identified 5 effects, or properties, common across the different forms of change blindness, and hence the likely effects that designers need to consider when designing visual interfaces to reduce it.

These five effects are (i) the effect of rate of change, (ii) the effect of eccentricity, (iii) the effect of proximity, (iv) the effect of significance, and (v) the effect of task relevance.

Effect of the Rate of Change

An important distinction is that between the detection of dynamic versus completed change. The former refers to “the perception of the transformation itself, [the latter] refers to the perception that the structure changed at some point” (Rensink 2002, p. 249). Studies in which a change is presented at a slow rate, without any visual disruption, have demonstrated a high degree of change blindness. Therefore, not only the visual disruption can mask the change but also the rate in which the change occurs influences its detection significantly.

Simons, Franconeri et al (2000) studied the effect of gradual changes in the absence of visual disruptions. They found a great degree of change blindness when a change happens gradually over a period of time. They tested the addition or deletion of objects and changes in colour presented gradually versus the same changes presented with the flicker technique. Gradual changes in the existence of an object (addition/deletion) were detected 64.3% of the time, compared to 57.4% when the flicker was included. Detection of colour changes was better detected in the flicker condition (41%) than in the gradual condition (31%). However, in both cases, a high degree of change blindness occurred.

Effect of Eccentricity

Eccentricity is the distance of an element in a visual display from the foveal vision. Elements in the periphery usually go undetected. However, eccentricity is not fixed to the periphery of the visual display but it varies according to where in a visual display the observant is looking at.

Generally eccentricity is confounded with relevance (Podczerwinski, Wickens et al. 2002; Wickens, Muthard et al. 2003a). For instance, in the aviation domain, when pilots have to select a flight path, events that are close to own-ship are more relevant to flight safety than those located in the periphery (Wickens, Muthard et al. 2003a). Participants showed a greater accuracy at closer distances. Eccentricity had a small, but significantly detrimental effect on detection speed. These findings imply that surveillance of the display perimeters will deteriorate and additional methods should be used to ensure that attention is sufficiently directed to these areas.

Nikolik and Sarter (2001) investigated pilot performance in detecting mode changes in their flight management system. They found that pilots missed over 10% of the changes when using the peripheral display that presented the best performance, and that this rate substantially increased to almost 20% with competition for visual attention. They showed that a feasible method for supporting data-driven monitoring and human-automation communication and coordination is the use of effective peripheral visual cues and the distribution of tasks and information across sensory channels.

Podczerwinski et al (2002) found that eccentricity had a small, but significant effect on detection speed ($F = 1.93$, $p < .05$). The limited magnitude of this effect is reflected in the regression slope of approximately 0.16 sec/degree of visual angle, or one second of slowing for every 6 degrees of eccentricity. Participants showed a greater accuracy at closer distances.

In Mack and Rock's (1999) experiment, in which one of the arms of a cross changed in length, showed that about 25% of subjects were inattentionally blind when the cross was presented at fixation and the unexpected object was presented parafoveally (subjects typically detected the critical stimulus on divided-attention and full-attention trials). They also found that about 75% of subjects were inattentionally blind when the cross was presented parafoveally and the unexpected object was presented at fixation, suggesting an effortful shift of attention away from fixation to the cross and possible inhibition of processing at the ignored fixation location.

Effect of Proximity

Proximity refers to the relationship established between elements in a visual display determined by its nearness. According to their position, observers establish relations between them.

For instance, in the context of the human-computer interface, a web site company was analyzed due to the low response it had for a specific training class. Exploring the Web site, they discovered a striking flaw in the site's interface: Employees tried to sign up but failed to find the proper page. The interesting thing about this failure was that the page was prominently advertised with a colourful banner that was linked to the sign-up page. The banner however, was not close to other link-rich areas of the display. Many employees had, indeed, found the page containing the banner but still failed to read it so they could follow the link. This failure was replicated in the lab and dubbed it "Banner Blindness" because participants appeared to be completely unaware of a prominent signal that was directly related to their current goals (Varakin, Levin et al. 2004).

This experiment showed that users have expectations of where in the display to look and may ignore most of what is visible at any given time.

Effect of Significance

Change detection is definitely influenced by meaning and significance of the elements shown in a picture or any visual interface. Observers categorize elements in a scene according by judging how elements convey meaning to it.

Rensink et al (1997) classified objects in a scene as of central or marginal interest according to the degree of interest in the part of the scene being changed (obtained from independent judges in a prior pilot experiment). Central interest changes were most often detected as soon as they occurred

while marginal interest changes were generally seen after some occurrences. This classification, although named in a different way, is seen repeatedly in several experiments, if participants feel more familiar with the stimuli changing, whether is a person or an object, they will detect the changes faster than if they do not find any meaning in the changed stimuli.

According to Rensink (2000), if a change affects the meaning of a scene, observers will be more likely to compare the details of the scene to their representations and thereby detect the change. For instance, Richard et al. (2002) found that detection of changes in driving scenes was significantly faster for driving-relevant than driving-irrelevant changes (cf. Durlach 2004). Rensink, O' Regan et al. (1997) concluded that change detection depended greatly on the significance of the part of the scene being changed, with fastest identification for those structures of greatest interest (p. 8).

Studies in Human Factors have emphasized the importance of meaning in relation with the activity participants are performing. In most laboratory experiments participants are usually passively looking at a screen. However, a study conducted in the London Underground (London railway public transport network) to develop technologies that support 'awareness', showed that station supervisors and other control room personnel, do not passively monitor the displays waiting for 'something to happen' or just glance at the screens to gain a general 'awareness' of the activities occurring within the station, but actively undertake analysis of the conduct they see on the screens and through the window of the control room (Luff, Heath et al. 2006).

Simons and Levin (1997) examined the effect of familiarity in a variation of the "changing experimenter" scenario described in Chapter 1. If the experimenter was dressed as a student and he asked other students for directions (in-group effect), the change of conversation partner was noticed almost 100% of the time. However, if the experimenter was dressed as a construction worker (out-group), students noticed the change only 35% of the time. This in-group/out-group effect relates very closely to central and marginal interests analysis. When participants did not feel familiar to the person they were talking to, they did not notice the change of conversation-partner. Their main task was to provide directions.

Archambault et al. (1999) analyzed a "categorization" effect. For their experiments, participants were presented with a picture of an office that had a desk, a computer monitor, a coffee mug, papers, books, etc. Using the flicker technique, changes were made only to the computer or to the coffee mug. Participants had to learn these objects in a specific level as Mary's mug or Peter's

computer, or in a general level (computer or mug). Participants were divided into 2 groups; one will specifically learn computers in a specific level and the mugs in a general one, the second group will do the opposite.

At a specific level, participants noticed the change faster than if they learned it at a general level. Archambault et al. conducted a second experiment in which each group will learn some coffee mugs and some computers at a general level and some at a specific level. Again, faster detection occurred if objects were learned at a specific level than if they were learned at a general level (2.43 alternations vs. 4.32). Therefore, level of categorization at which an object is learned can affect its visual encoding and perception

On another set of experiments, Mack and Rock (1999) found that while the inattention blindness effect was robust for meaningless stimuli, their participants almost invariably noticed when their own names were presented. According to them, there were a few other stimuli that captured attention under conditions of inattention such as a cartoon-like happy face due its high signal value and a high degree of familiarity. However, if the participant's name was slightly misspelt or a scrambled or sad version of the face was presented, inattention blindness returned.

Effect of Relevance of the Task

Some have argued that the procedures for change blindness experiments, like changes to scenes lacked clarity; the task was relatively vague, asking observers to search for arbitrary changes to pictures with no idea of the magnitude or content of the change (DiVita, Nugent et al. 2004). Consequently, Change Blindness was studied with operational-domain tasks, and it was shown that change detection improved when the changes were meaningful to the task.

The importance of meaning and context has also been studied in other areas such as the theory of activity that affirms that there is a dependent relationship between a computer-based system and the practice in which it is used, in fact, Chaiklin states that while the goal of the task is important, its meaning can only be understood in relation to its function in the activity (2007).

Podczerwinski et al. (2002) compared highlighting benefits and de-cluttering costs of electronic map design in dynamic settings and examined the potential cost of change blindness phenomenon in de-cluttering conditions. They demonstrated that detection of relevant changes (changes that cause a potential conflict) in both traffic and weather systems were superior to that of irrelevant

changes. Change detection was only at 50% accuracy, but improved by changes that were more salient (spatially, not digitally represented), and were more meaningful (causing a conflict with the flight path). Changes that were relevant to the pilot's flight planning task were detected nearly four seconds faster than irrelevant changes. Relevant conflict changes were detected 75% within an average response time of 12 sec, whereas non-relevant changes were detected 35% with an average response time of 18 sec.

One of the attempts to study whether individual characteristic of the observer selectively influence the ability to detect changes is Werner and Thies' study (2000) on expertise in American football domain. An implication is that experts should be superior in detecting changes in domain-relevant material, compared to novices. Participants had to detect changes in American football scenes (semantic changes); their performance was compared to scenes that showed non-relevant changes to the domain like traffic-related information. Results showed that American football experts detected changes about the game faster than novices did. "Novices failed to detect changes in football images twice as often as experts (17.6% vs. 8.3%, 111% difference). [However], for non semantic changes, the difference between novices and experts was 22% (42.1% vs. 35%)" (p. 172). These results demonstrated that expertise in a specific domain appear both to generally ease detection of changes for images from that domain as well as selectively increase observers' sensitivity to domain-related semantic changes in those images.

These commonalities between studies have provided us with a framework to understand change blindness and present some properties of the change blindness phenomenon that designers should pay attention to when designing visual interfaces, especially for complex environments

Chapter 6

Discussion and Conclusions

In this paper we reported on part of a study to understand how information layering techniques can be used to reduce change blindness. Change blindness, in general, is the failure of the human to detect changes to information that occur within his or her visual field. There are several variants of perception- “blindness” known as: change blindness, inattention blindness, comparison blindness, and repetition blindness. Failure or delays in observing changes in complex, dynamic and safety critical systems by, say, operators can lead to disastrous outcomes. Hence, drawing together the different reasons reported in the literature can provide us with a first step towards developing design techniques for reducing change blindness in the hope that we can contribute to better and safer systems.

Change and other perception-“blindness” might occur for a number of reasons: Many authors interpreted these ‘blindness’ as a failure of visual awareness, or as a failure of internal visual representation. Others argued that is not just a lack of visual representations but suggest that we need focus attention to detect changes (Rensink, O'Regan et al. 1997), while others suggest that attention might not be the bottleneck on what is encoded and represented in our brain, but perhaps memory or other “access limitations” provide a bottleneck on what information can be used in making reports about the detection of changes (Noe, Pessoa et al. 2000). Others agree that attention might be required to consciously experience a change, but it is not necessary since unaware detection of change influence performance(Fernandez-Duque and Thornton 2000).

Whether we store internal representations of what we perceive or the world serves as a visual store, is still debatable. If, on the other hand, change blindness is not a problem of internal visual representations but of attention, then how is attention directed in the first place? Although bottom-up cues capture attention, they may be influenced by top-down attentional settings, for instance expectations of where the target will appear (Vecera and Rizzo 2003). Then, do goals, expectations and intentions of the observer influence how attention is deployed?

We propose that the explanations for these phenomena may not lie in the internal representations of the brain but in the relationship of the observer and his/her environment, in the meaning and context of the task they perform as well as the way elements are represented and positioned in the visual display.

Based on an Emergent Themes Analysis approach, we identified 5 effects, or properties, common across the different forms of change blindness, and hence the likely effects that designers need to consider when designing visual interfaces to reduce change blindness. These five effects are (i) the effect of rate of change, (ii) the effect of eccentricity, (iii) the effect of proximity, (iv) the effect of significance, and (v) the effect of task relevance.

The first three effects are related to the way elements in a visual display are represented. The studies mentioned above have shown that eccentricity, rate of change and position of the elements might enhance or deteriorate the accuracy and response times of observers in change detection tasks. Other factors such as the size of the computer screen influence change detection performance negatively, but not significantly, probably because for small displays, the minimisation of the display elements decreased legibility and resolution. Eccentricity of the elements in the display was confounded with relevance. For instance, in the aviation domain, events (changes) closer to own-ship generally are more relevant to flight safety. Saliency of the elements in the display, especially the use of different intensities increased detection accuracy for the highlighted elements but affect the detection for those low-lighted. The speed at which a change occurs also affects detection. Changes that occur gradually might go unnoticed. Finally, position of the elements in a visual display informs observers about the relationship between them, and therefore proximity of related items or links is very important.

The last two effects, effects of significance and relevance of the task are more related with meaning and context. It has been shown that humans are really bad at detecting random changes. Observers pay more attention to elements that convey a meaning, say, to a scene; or are more able to detect those changes that are relevant to their task or conflict with it. Observers detect changes that provide them with a meaning that can only be understood in relation to its function in the activity.

The use of different techniques such as blinking, use of various intensities, reverse video and boxing have proven unsuccessful. We hypothesised that perceptual depth can be used as a cue to grab attention. Studies conducted in a new Multi-Layered Display (MLD) technology have shown

that this display have potential to present increasing amounts of data in one computer display due to its physical depth supporting the allocation of attention in depth, conjunction searches if depth is combined with other cues such as colour, and faster reading times in conditions that have lead to poor legibility on conventional displays.

Further research is required to investigate the influence of perceptual depth for change detection tasks. During the completion of this review, some issues that have been studied in other areas such as scene analysis for artificial intelligence and experiments on Just Noticeable Differences “jnd” seem to offer some plausible explanations and suggestions for future analysis.

Change Blindness and Inattentional Blindness experiments provided simple procedures to study cognitive processes involve in change detection, however they also provided high levels of ecological validity for questions concerning human-computer interaction. From now on, when designing interfaces, it is not enough to evaluate if the elements in the visual display are relevant but we have to start questioning if the elements in the visual display are seen at all.

References

- Amaldi, P. (2006). Personal Communication: Hayes et al ECCE 2006 paper. William Wong, R. Joyekurun, J. Hayes and G. Mancero. London.
- Archambault, A., C. O'Donnell, et al. (1999). "Blind to Object Changes: When Learning the Same Object at Different Levels of Categorization Modifies its Perception." Psychological Science **10**(3): 249-255.
- Beck, D. M., G. Rees, et al. (2001). "Neural Correlates of Change Detection and Change Blindness." Nature Neuroscience **4**: 645 - 650
- Chaiklin, S. (2007). Modular or integrated? — An activity perspective for designing and evaluating computer-based systems. Denmark, The Danish University of Education: 1-19.
- Chun, M. and P. Cavanagh (1997). "Seeing two as One: Linking Apparent Motion with Repetition Blindness." Psychological Science **8**(2): 74-79.
- DiVita, J., W. Nugent, et al. (2004). "Verification of Change Blindness Phenomenon while Managing Critical Events on a Combat Information Display (Attentional Processes)." Human Factors **46**(2): 205-218.
- Duenser, A., M. Billingham, et al. (2006). Evaluating Depth in visual search tasks using a Multi-Layer Display. *Unpublished*. Christchurch, NZ, Human Interface Technology Laboratory (HITLAB) NZ.
- Duenser, A., G. Mancero, et al. (2006). MLD – Multiple Object Tracking and Change Detection. *Unpublished*. Christchurch, NZ, Human Interface Technology Laboratory (HITLAB) NZ.
- Durlach, p. (2004). "Change Blindness and its Implications for Complex and Control Systems Design and Operator Training." Human Computer Interaction **19**: 423-451.
- Fernandez-Duque, D. and I. M. Thornton (2000). "Change Detection Without Awareness: Do Explicit Reports Underestimate the Representation of Change in the Visual System?" Visual Cognition **7**(1/2/3): 323-344.
- Fisher, D. L. and K. C. Tan (1989). "Visual Displays: The Highlighting Paradox." Human Factors **31**(1): 17-30.
- Gaukrodger, S. (2007). Personal Communication: Change Blindness, Attention and Perception.... G. Mancero. Christchurch, NZ: Email.
- Gibson, J. (1979). Ecological Approach to Visual Perception. Boston, MA, Houghton Mifflin Company.

- Goodale, M. and D. Milner (2006). "One brain: Two visual Systems." The Psychologist **19**(11): 660-663.
- Hayes, J. (2006). Information Layering to De-clutter Displays for Emergency Ambulance Dispatch. In *Proceedings for 13th European Conference of Cognitive Ergonomics (ECCE13)*, Zurich.
- Holliday, I. E. and O. J. Braddick (1991). " Pre-attentive detection of a target defined by stereoscopic slant." Perception **20**: 355 - 362.
- Joyekurun, R. (2006). Metric Depth and Multivariate Cue Interactions: M.Phil. Transfer Report. London, Middlesex University & Eurocontrol: 40.
- Joyekurun, R., W. Wong, et al. (2005). Information Layering, Depth and Transparency Effects on Multi-Layer Displays for Command and Control. In *Proceedings of the Human Factors and Ergonomics Society 49th Annual Meeting*.
- Kanwisher, N., J. W. Kim, et al. (1996). "Signal Detection Analyses of Repetition Blindness." Journal of Experimental Psychology: Human Perception and Performance **22**(5): 1249-1260.
- Kooi, F. L. (2001). The Case for Transparent Depth Displays. Soesterberg, Netherlands, TNO Human Factors: 1-8.
- Lansdown, J. (1996). Visual Perception. Centre for Electronic Arts, Middlesex University.
- Luff, P., C. Heath, et al. (2006). "Discriminating Conduct: Deploying systems to support awareness in organisations."
- Mack, A. and I. Rock (1999). " Inattentional Blindness: An Overview." Psyche **5**(3).
- Mack, A. and I. Rock (1999). "Inattentional Blindness: An Overview." Psyche **5**(3).
- Marrara, M. and C. Moore (2000). "Role of Perceptual Organization while Attending in Depth." Perception and Psychophysics **62**(4): 786-799.
- Most, S. B., D. Simons, et al. (2000). "Sustained Inattentional Blindness: The Role of Location in the Detection of Unexpected Dynamic Events " PSYCHE **6**(14).
- Nakayama, K. and G. H. Silverman (1986). "Serial and parallel processing of visual feature conjunctions." Nature **320**(20): 264-265.
- Nees, A., R. Villanueva, et al. (2003). Colour and Transparency on the Multi-Layer Display (MLDTM). Department of Information Science. Dunedin, NZ, University of Otago. **Unpublished Honours Dissertation: 10.**
- Neisser, U. (1976). Cognition and reality : principles and implications of cognitive psychology. San Francisco, W.H. Freeman.
- Nikolic, M. I. and N. B. Sarter (2001). Peripheral visual feedback: A powerful means of supporting effective attention allocation in event-driven, data-rich environments. *Abstract. Human Factors*. **43**: 30-38.

- Noe, A., L. Pessoa, et al. (2000). "Beyond the Grand Illusion: What Change Blindness Really Teaches Us About Vision?" Visual Cognition 7(1/2/3): 93 - 106.
- O'Regan, J. K. (2000). "Change Blindness " Retrieved November 7, 2006, from <http://nivea.psych.univ-paris5.fr/ECS/ECS-CB.html>.
- Pashler, H. (1998). The Psychology of Attention. Cambridge, MA, The MIT Press.
- Pessoa, L. and L. Ungerleider (2004). "Neural Correlates of Change Detection and Change Blindness in a Working Memory Task " Cerebral Cortex 14: 511-520.
- Podczerwinski, E. S., C. D. Wickens, et al. (2002). Exploring the "Out-of-Sight, Out-of-Mind" Phenomenon in Dynamic Settings Across Electronic Map Displays. Moffett Field, CA, Aviation Research Lab Institute of Aviation.
- Pylyshyn, Z. W. and R. W. Storm (1988). "Tracking multiple independent targets: evidence for a parallel tracking mechanism." Spatial Vision 3(3): 1-19.
- Rensink, R. (2000). "The dynamic representations of scenes." Visual Cognition 7: 345-376.
- Rensink, R. (2002). "Change Detection." Annual Review Psychology 53: 245-277.
- Rensink, R., J. K. O'Regan, et al. (1997). "To See or not to See: The Need for Attention to Perceive Changes in the Scene." Psychological Science 8: 368-373.
- Scott-Brown, K. C., M. R. Baker, et al. (2000). "Comparison Blindness." Visual Cognition 7(1/2/3): 253-267.
- Sekuler, R. (2002). Perception, Mc Graw Hill Higher Education.
- Shapiro, K., J. Driver, et al. (1997). "Priming From the Attentional Blink: A Failure to Extract Visual Tokens but not Visual Types." Psychological Science 8(2): 95-100.
- Simons, D., S. Franconeri, et al. (2000). "Change Blindness in the absence of a Visual Disruption." Perception 29: 1143-1154.
- Simons, D. and D. Levin (1997). "Change Blindness." Trends in Cognitive Sciences 1(7): 261-267.
- Simons, D. and D. Levin (1997). "Failure to Detect Changes to Attended Objects in Motion Pictures." Psychonomic Bulletin and Review 4: 501-506.
- Simons, D. J. (2000). "Current approaches to Change Blindness." Visual Cognition 7(1/2/3): 1-15.
- Simons, D. J. and C. F. Chabris (1999). "Gorillas in the midst: Sustained Inattentional Blindness for Dynamic Events." Perception 28(9): 1059-1074.
- Simons, D. J. and D. Levin (1998). "Failure to Detect Changes to People in Real-World Interactions." Psychonomic Bulletin and Review 5(644-649).
- Tamborello, F. and M. Byrne (2006). Adaptive but Non-Optimal Visual Search Behavior in Highlighted Displays. In Proceedings of International Conference on Cognitive Modeling.
- Tavanti, M. (2004). On the Relative Utility of 3D Interfaces. Information Science. Uppsala, Uppsala University. **Phd**: 74.

- TechNow (2001). Videoclip: PureDepth. San Francisco, KNTV-TV (NBC).
- Theeuwes, J., P. Atchley, et al. (1998). "Attentional control within 3-D space." Journal of Experimental Psychology: Human Perception and Performance **24**(5): 1476–1485.
- Varakin, A., D. Levin, et al. (2004). "Unseen and Unaware: Implications of Recent Research on Failures of Visual Awareness for Human-Computer Interface Design." Human-Computer Interaction **19**: 389-422.
- Vecera, S. P. and M. Rizzo (2003). "Spatial attention: normal processes and their breakdown." Neurologic Clinics of North America **21**: 575-607.
- Viswanathan, L. and E. Mingolla (2002). "Dynamics of attention in depth: Evidence from multi-element tracking." Perception **31**(12): 1415-1437.
- Werner, S. and B. Thies (2000). "Is change blindness attenuated by domain-specific expertise? An expert-novices Comparison in Change Detection in Football Images " Visual Cognition **7**: 163-173.
- Wickens, C. D., Ed. (1998). The Future of Air Traffic Control : Human Operators and Automation. Washington, D.C., National Academy Press.
- Wickens, C. D., M. Ambinder, et al. (2004). The Role of Highlighting in Visual Search Through Maps. Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting, Santa Monica.
- Wickens, C. D. and J. Hollands (2000). Engineering Psychology and Human Performance. New Jersey, Prentice Hall.
- Wickens, C. D. and E. K. Muthard (2003). Factors that Mediate Flight Plan Monitoring and Errors in Plan Revision Planning under Automated and High Workload Conditions. 12th International Symposium on Aviation Psychology, Dayton, OH, University of Illinois Aviation Human Factors Division.
- Wickens, C. D., E. K. Muthard, et al. (2003). The Influences of Display Highlighting and Size And Event Eccentricity for Aviation Surveillance. In Proceedings of the 47th Annual Meeting of the Human Factors and Ergonomics Society, Santa Monica, CA.
- Wong, W. (2006). Personal Communication: Hayes et al ECCE 2006 paper. P. Amaldi, R. Joyekurun, J. Hayes and G. Mancero. London.
- Wong, W., H. Mansour, et al. (2005). Depth, Layering and Transparency: Developing Design Techniques. OZCHI 2005, Canberra, Australia.

Appendix 1

AUTHORS	TYPE OF STUDY/TECHNIQUE	EXPERIMENT DESCRIPTION	KEY FINDINGS CONCLUSIONS	OUR INTERPRETATIONS (Properties of Failures of Visual Awareness)
RENSINK, O'REGAN AND CLARK 1997	Change Blindness / flicker	EXPERIMENT 1: flicker sequences were usually composed of an original image A and modified version A' displayed in the sequence A, A, A', A', with grey blank fields placed between successive images. Each image was displayed for 240 ms and each blank for 80 ms. Changes were further divided according to the degree of interest in the part of the scene being changed: Central vs. Marginal Interests (CI vs. MI). EXPERIMENT 2: A, A', A, A' presenting each image for 560 ms. EXPERIMENT 3: =exp 1 with cues. <i>Partially-valid condition</i>, cues were divided equally into valid cues (naming the part of the scene changed) and invalid cues (naming some other part). In the <i>completely-valid condition</i>, cues were always valid.	EXPERIMENT 1: A, A, A', A'.....MI: 17.1 alternations (10.9 sec) to identify change. CI: 7.3 alternations (4.7 sec). Without flicker 1.4 alternations (0.9 sec) to detect both MI and CI changes. EXPERIMENT 2: A, A', A, A' - same effect. EXPERIMENT 3: valid cues always caused identification of both MI and CI changes to be greatly sped up. For completely-valid cues, the difference in response times for MIs and CIs declined to the point where it was no longer significant.	Central interests (CIs) were defined as objects or areas mentioned by three or more observers, marginal interests (MIs) were objects or areas mentioned by none. Changes that are defined as of CENTRAL INTEREST are detected faster than marginal ones. DELETION OF OBJECTS IS DETECTED EASIER THAN ADDITIONS. Elements defined as of central interest provide meaning to the scene

RENSINK, O'REGAN AND CLARK 1999	Change Blindness/Mud-splash	CB can occur even when the disruption does not cover or obscure the changes. The authors used 48 pairs of pictures, consisting of an original and a modified picture (each displayed for 3 sec), each pair presented cyclically with an 80-ms duration "mud splash" superimposed at the moment of the change. There was no disruption in visual continuity at the moment of the change. 10 observers were asked to press a button as soon as they identified the change, which could have been a large object or region of the picture shifting in location, changing colour, or appearing or disappearing. The change could be either a "central interest" or a "marginal interest" element. Results show that central interest changes were usually detected as soon as they occurred, whereas marginal-interest changes were seen only on their 2nd or later occurrences. Findings suggest that CB occurs because the internal representation of the visual world is rather sparse and essentially contains only central-interest information. Only the parts of the environment that observers attend to and encode as "interesting" are available for making comparisons.	Central vs. marginal interest = participants detect meaning from elements of a scene
---------------------------------------	--------------------------------	--	--

MACK AND ROCK 1998 Inattentional Blindness	A small cross was shown briefly on a computer screen for each of several experimental trials and asked participants to judge which arm of the cross was longer. After several trials, an unexpected object, such as a brightly coloured rectangle, appeared on the screen along with the cross.	flexible selection theory of attention: depending on the nature of the stimuli (high- or low-level attributes), System operates to minimize effort and so will select on the basis of a low-level attribute like size if possible but, if not, will process the input more deeply, as seems to be the case with lexical stimuli . If the critical stimulus has no particular intrinsic signal value and is irrelevant to the subject's assigned task, the attentional warrant that permits a stimulus to pass from implicit to explicit perception is minimal, so that only its presence or its bare bone features are perceived. If the same stimulus were to fall outside the zone of attention, then it is far more likely that even its presence will go undetected, because it does not have the benefit of even minimal attentional processing. <i>Drew a distinction between conscious perception and implicit perception. The term 'perceive' (or 'notice' or 'see') mean that observers have at some point had a conscious experience of an object or event. it is important to note that even when observers do not perceive an object, it may still have an implicit influence on their subsequent decisions and performance</i>	Meaningfulness and relevance affect the detection of unexpected events.
---	--	---	--

			(i) About 25% of subjects are inattentionally blind when the cross is presented at fixation and the unexpected object is presented parafoveally (subjects typically detect the critical stimulus on divided-attention and full-attention trials). (ii) About 75% of subjects are inattentionally blind when the cross is presented parafoveally and the unexpected object is presented at fixation, suggesting an effortful shift of attention away from fixation to the cross and possible inhibition of processing at the ignored fixation location. (iii) These levels of detection are no different for features thought to be preattentively processed (e.g. colour, orientation, motion) and those thought to require effort. (iv) Although objects composed of simple visual features are not easily detected, some meaningful stimuli are. Observers typically notice their own name or a smiley face even when they did not expect it.	
SIMON AND CHABRIS 1999	Inattentional Blindness	75sec video of two teams of 3 people each, wearing a white or a black T-shirt respectively. At 44-48 sec an unexpected event, either a woman in a gorilla costume or a woman with an open umbrella walked through the scene. Participants were asked to make silent count of the passes total number of passes for the easy condition or bounces and aerial	Out of all 192 observers across all conditions, 46% failed to notice the unexpected event. More observers noticed the unexpected event in the Opaque condition (67%) than in the Transparent condition (42%). More observers noticed the unexpected event in the Easy (64%) than in the Hard (45%) condition, The Umbrella Woman was noticed more often than the Gorilla overall (65% vs. 44%). Observers are more likely to notice unexpected events if these events are visually	

		passes for the hard condition.	similar to the events they are paying attention to. (On the basis of our results it is logically possible that dissimilarity to the ignored events is instead the crucial factor.) Objects can pass through the spatial extent of attentional focus (and the fovea) and still not be 'seen' if they are not specifically being attended.	
SIMON AND LEVIN 1998	Change Blindness Real- world occlusion	An experimenter approached a pedestrian to ask for directions. While the pedestrian was providing directions, two additional experimenters, carrying a door, passed between the initial experimenter and the pedestrian. During this brief interruption, a different person replaced the original experimenter. Exp 2: in group/out group effect. Experimenter dressed as a student or as a construction worker. EXP3: a female experimenter dressed in athletic clothing and carrying a basketball approaches a passed by in public and asks directions to a gym. During this interaction, a crowd of confederates walked between the two and surreptitiously took the basketball away.	Even though the two experimenters looked quite different and had distinctly different voices, approximately 50% of the subjects failed to notice that they were talking to a different person after the door passed. EXPERIMENT2: Categorization - direction asker and direction-giver students almost 100% detection, d-asker = construction worker & d-giver = student 35% detection. EXP3: When asked if they noticed anything changed or anything different about her appearance, a minority of observers reported noticing that the basketball was gone. But when asked a follow-up question specifically referring to the basketball, most of the remaining observers 'remembered' the basketball and were able to describe its unusual colouring. Thus, a visual change can be encoded but not explicitly reported until a specific retrieval cue is provided.	IN GROUP/OUT GROUP EFFECT. IMPLICIT PERCEPTION

Podczerwinski Wickens Alexander 2002	Change Blindness - Out of sight out of mind OOSOOM/Flight simulation highlighting	Eight trials using 4 display formats baseline, traffic highlighted, traffic low lighted, and manual de-cluttering displays. They answered focused and divided attention questions, detected changes in the trajectory of traffic and weather, and avoided conflict events by manoeuvring vertically.	Overall only 38% of changes were detected. The heading changes 40% detection. Changes in digital altitude -12% detection. Heading changes (more salient ones) were poorly detected in the manual de-cluttering condition supporting the OOSOOM. Tracking error was best in the traffic highlighted condition... A highlighting a display element increased the quality (speed and accuracy) of detecting its change. Relevant conflict changes were detected 75% RT 12 sec on average. Non relevant changes were detected 35% RT 18 sec. With relevance removed, distance (eccentricity) had a small, but significant effect on detection speed ($F = 1.93, p < .05$). The limited magnitude of this effect is reflected in the regression slope of approximately 0.16 sec/degree of visual angle, or <i>one second of slowing for every 6 degrees of eccentricity</i>. Greater accuracy at closer distance. The concept of "display proximity" as defined by intensity differences does not appear to behave in the same manner as when proximity is defined by spatial differences.	RELEVANT CHANGES (those that can cause conflict) ARE DETECTED FASTER THAN NO RELEVANT. PCP behave different behaviour when using different intensities than when using spatial differences
--	--	---	--	---

WICKENS C, MUTHARD E, ALEXANDER A 2003	CB/intensity eccentricity	and	Pilots were asked to detect changes in the movement or altitude of weather systems or traffic aircraft, which were represented in integrated hazard displays. Experiment 1: change detection as a function of the distance of the event from own-ship and the presence of the event in a highlighted or low lighted hazard domain. Experiments 2 and 3: role of display size and event eccentricity. Integrated hazard displays depicted mountainous terrain ground map, weather and traffic domain Analyses revealed that change detection was superior for events that were in the highlighted display database and that performance was slightly degraded for more eccentric events. It was hypothesised that display size would impact distance judgements. DISPLAY SIZE WAS NOT SIGNIFICANT BUT IT CAN DEGRADE PERFORMANCE IN SMALL DISPLAYS DUE TO THE MINIFICATION OF THE ELEMENTS WHICH DECREASE LEGIBILITY AND RESOLUTION. Changes within the nearby field of view are more likely to be detected	Eccentricity = changes that occurred nearby were easier to detect
---	------------------------------	-----	--	---

WICKENS MUTHARD 2003	C, E	CB/intensity eccentricity	and	After selecting a flight path, pilots were asked to monitor the safety of the plan by seeking and detecting changes in the altitude or trajectory of weather systems and traffic aircraft. Pilots were instructed to press a key when they detected a change and inform the experimenter of the item that changed and the nature of the change. In one fourth of trials, a change substantially threatened the safety of the flight path. At the midpoint of each trial, participants were asked to recommend the safer plan to a following aircraft that would be confronted with the same flight path choice as the participant, while taking into account the changes that had occurred up to that point. With an automation aid, accuracy and confidence was higher than without (accuracy high workload=78.1%vs control=65.6%. Speed accuracy trade off: changes in the low workload condition were detected 36% more accurate but 6.7 sec slower than high-workload condition. WITH IMPERFECT AUTOMATION 60.9% OF MISSES, NO AUTOMATION AID 39.1% MISSES	TRADE OFF OF HIGHLIGHTING
WERNER AND THIES 2000		Change Blindness Expertise Domain		30 PAIRS OF COLOUR IMAGES. Single modified element. Category1: action football scenes few players and a referee. Category 2: bird's eye view of playing formations. Category 3: traffic-related scenes. 2 type of changes: semantic - alter an item that was important for the interpretation of the scene, and Experts have a distinct advantage over novices for detecting semantic changes in images from their domain, are faster on domain-related images. Significant interaction between expertise and type of change detected. Significant difference between change-type: semantic changes were easier to detect than non-semantic. . For category 3 no significant interaction found except that semantic changes were detected slower than non-semantic	RELEVANCE OF THE CONTEXT MAKE CHANGE DETECTION FASTER = meaning based on expertise

		non-semantic - irrelevant parts of the scene		
KANWISHER 1996	Repetition Blindness (RB)	o selective forgetting of repeated items but failure to assign a distinct episodic representation to the repeated item	RB is not due to selective forgetting repeated items but a failure to assign a distinct episodic representation to the repeated item	RB effects are observed with simultaneously presented letters (LIKE IN COMPARISON BLINDNESS)
DiVITA AND NUGENT 2004	Change Blindness in Naval Combat Displays/ 2 monitors	4 Categories were tested: Course, speed, range and bearing in a simulated CIC (Combat Information Centre) console. 20 critical changes: 14 tactically significant attributes & 6 different new contacts entering the scene.	It is more difficult to detect changes without the graphical display (map/air corridors) at the background. "IF THE OPERATOR'S SITUATIONAL AWARENESS IS POOR, HE OR SHE MAY FAIL TO OBSERVE SOME OF THESE RELATIONSHIPS, WHICH IN TURN LEADS TO A FAILURE IN CHANGE DETECTION" p. 216	ANCHORS OR GRAPHICS THAT ACT AS A REFERENCE SHOULD BE KEPT ALWAYS ON SIGHT

NIKOLIC AND SARTER 2001	PERIPHERAL CHANGE DETECTION/ Flight simulation technique	2 monitors placed in front of the participant. Pilots were required to detect and identify 24 experimenter-induced mode transitions and 24 other scenario events. The mode transition detection task consisted of pressing one of two buttons on the side-stick as soon as a mode transition was detected. In case of other scenario events, pilots were required to indicate orally the observation and nature of the event. Pilots were randomly assigned to one of three types of mode transition displays: (baseline FMA, enhanced FMA, or ambient strip). (1)BASELINE: Transitions between modes are signalled by a thin green rectangular outline box drawn around the new mode for 10 s. The box subtends 2.5° VA. (2) Enhanced FMA signalled a mode transition by the onset and 10-s presentation of a light. The enhanced FMA was shown in the same location as the current FMA, a solid yellow box for a thrust mode transition (left column) and a blue box for a heading mode transition (middle column). (3)The ambient strip signalled mode transitions by the onset of a thin, colour band, using the	Enhanced FMA and ambient strip support faster detection as compared with the baseline FMA. The relatively low detection performance in the baseline condition replicates pilots' difficulties with maintaining mode awareness on modern flight decks and can be explained by the current FMA's low salience relative to its visually saturated surround on the instrument panel. that salience (in the form of greater contrast with the background and competing visual stimuli) is required for an onset to capture attention in data-rich environments like the modern flight deck, especially as the indication in question moves farther into peripheral vision. colour-coding of the 2 peripheral displays allowed pilots to make the choice response without having to reorient foveal visual attention to the FMA (Flight mode annunciations)	Abrupt onsets per se may not be sufficient to capture attention, especially in peripheral displays; greater contrast with the background is required. Eccentricity influence performance
------------------------------------	---	--	--	---

	same colour coding as the enhanced FMA. The strip was located at the bottom of the screens and subtended 60° of VA.		
--	---	--	--

FERNANDEZ DUQUE AND THORNTON 2000	IMPLICIT CB/flicker	EXP 1 &2: 4x4 GRID OF 16 RECTANGLES, half horizontal, half vertical, after a blank ISI (interstimulus interval) 1 rect changes orientation 90 degrees. Response display: 2AFC alternate force choice showing 2rectangles diametrically opposite located. Participants were told to take a conservative approach: only if they had seen the rectangle change orientation, or a liberal approach: they were told to choose aware if they have noticed or felt any change between the displays. EXPERIMENT 2: same layout, use valid or invalid cues in the response display: either an alphanumeric character (&/%) or one of two coloured rectangles (red/green). EXP3: 8 or 12 items, layout clockface design, in the response display, all items remained visible but the change distracter and the target changed hue to light grey. EXP 4: same layout as exp 3 but use of attentional cueing	Only 29% of participants explicitly report changes using a conservative approach compare to liberal approach 45%. For the conservative block: more likely to report change close to fixation (55.5%) vs. 31% peripheral. More accurate in the conservative block 95% vs. 85% liberal block. WHEN REPORTED BEING UNAWARE OF CHANGES: correct detection was more frequent in the conservative block than in the liberal. Accuracy was higher for rect. close to fixation (60.3%) vs. 55.1% peripheral. EXP2: Overall 42% change detection, no significance b/w type of probe (colour/character), type of cue (valid/invalid), eccentricity (near/far) or their interaction. EXP3: set-size had a strong effect on awareness responses. 8 items: 52% reported to be aware, 12 items: 40% reported awareness. IN AWARE TRIALS 89% CHANGE DETECTION. Correct unaware selection (M1127 ms) significantly faster than incorrect ones (M=1176msec). EXP4: THERE WAS A SIGNIFICANT VALIDITY EFFECT FOR AWARE TRIALS BUT NOT FOR UNAWARE TRIALS	Attention is not ALWAYS necessary for the representation of change.
ARCHAMBAULT, O' CONNELL AND P. SCHYNS 1999	CB CATEGORIZATION/ flicker	Participants had to learn a specific set of objects (computer or mug) in a specific level (Mary's mug/Peter's computer) or in a general level. EXPERIMENT1, partic. Group	EXPERIMENT 1: At a specific level, participants notice the change faster than if they learn it at a general level. EXPERIMENT 2: rule out the possible selective weighting interpretation. Faster detection if objects learned at a specific level	CATEGORIZATION EFFECT

		1 learn computers at a general level and mugs at a specific level. Group 2 vice versa. EXPERIMENT 2 both groups will learn to categorize both mugs and computers at both the general and the specific level	2.43 alternations vs. 4.32 in a general level. Therefore, level of categorization at which an object is learned can affect its visual encoding and perception	
Benway (1999) CF VARAKIN 2004	BANNER BLINDNESS	web site design in which they put a banner for a training course but people did not sign for it because they could not find the link	the banner even when it was outstandly salient - bright colors, flashing, big fonts was not seen by the users	RELATIONSHIP BETWEEN OBJECTS IN DISPLAY - IF RELATED THEY SHOULD BE CLOSE TOGETHER - SPATIALLY (consistent with PCP). Users have expectations of where in the display to look = may ignore most of what is visible at any given time.
SIMONS, FRANCONERI AND REIMER 2000	CB / gradual changes	EXP1: Addition/deletion of an object in an image. 3 conditions: gradual changes (a movie presents a gradual change), DISRUPTION flicker technique 1st image stay on view for 11.25 sec, ISI 500 ms, and 2nd image until response. GUESSING present the image and ask participants which object they think will be deleted. EXP 2: CHANGES OF COLOUR	EXP1: gradual changes detected 64.3%, disruption 57.4%. Addition was detected 57.8%, deletion detection 61.5%. The ease with which observers guess was not correlated with the detection of it. EXP2: Detection of colour changes was better detected in the disruption 41% than in the gradual condition 31%. Colour changes were detected less often overall than addition/deletion changes. Guessing where the colour change will happen was directly correlated with detection.	(OUR PERCEPTION IS SENSITIVE TO LUMINANCE CONTRAST THAN TO ABSOULTUE LUMINANCE)

