Change Blindness and Inattentional Blindness: The Neural Substrate and Implications for Human Factors

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Abstract

Change blindness is the phenomenon where humans are inept at detecting changes in stimuli when the change signal is masked or otherwise hidden from view. Inattentional blindness is the failure to detect objects or events that are unexpected while your attention is engaged in other aspects of a given task. The causes of both phenomena are also discussed, including Simons' five different explanations for change blindness and Mack and Rock's two classifications of inattentional blindness. The neural substrate for the existence of the altered percepts in change and inattentional blindness are discussed, with an emphasis on the frontal lobes of the brain and the executive control of attention. The implications of both change blindness and inattentional blindness in the field of human factors are examined, including applications in transportation and safety, medicine, military, and interface design. Finally, I envision the future study of change blindness and inattentional blindness in a cognitive neuroscience context.

Keywords: cognitive neuroscience, sensation and perception, change blindness, inattentional blindness, flicker paradigm, control and monitoring systems, medical errors, transportation, safety

Change Blindness and Inattentional Blindness: The Neural Substrate and Implications for Human Factors

What if a pilot monitoring their aircraft's flight path on a screen was interrupted, and when they returned to their previous task, they missed an important change on their display critical to safety? You may wonder why people do not see salient changes to stimuli in their visual field, or why they missed something obvious while attending to a task. These situations are examples of the phenomena of change blindness and inattentional blindness.

According to Simons and Ambinder (2005), change blindness is described as the phenomenon where humans are inept at detecting changes in stimuli when the change signal is masked or otherwise hidden from view. These changes are difficult to perceive even if an individual is actively searching for them. According to Simons (2000), retinal transients can be disrupted through masking, timing the transient to a blink, or by making the changes slowly, which is enough to induce change blindness in individuals.

Inattentional blindness, on the other hand, is the failure to detect objects or events that are unexpected while your attention is engaged on other aspects of a given task (Yantis & Abrams, 2017). Inattentional blindness is similar to change blindness in that there is a failure of visual awareness; we clearly notice the stimuli of interest when we know to attend to them, except the stimuli of interest in inattentional blindness is constant and fully visible. This phenomenon is unlike change blindness where we are trying to detect a change in stimuli.

In this paper, I will first review existing literature on both the phenomena of change blindness, and inattentional blindness, explaining important studies and developments throughout the existing literature. Secondly, I will examine the cognitive neuroscience aspects of change blindness and inattentional blindness: first presenting different explanations for the phenomena, then examining the different neuroscience methods used to investigate change blindness and inattentional blindness. In addition, the implications of both change blindness and inattentional blindness for the field of human factors is explored, with focus on interface design, vigilance tasks, and errors in medicine. Finally, I will provide insight into the future study of change blindness and inattentional blindness.

History of Change/Inattentional Blindness Research

History of Change Blindness Research

While the research interest of the phenomenon of change blindness boomed in the mid-1990s, the concept was explored externally to the field of psychology about a century earlier. Filmmakers informally reported issues with viewers not noticing set changes and continuity errors between scenes in their movies when the transitions are edited as jump cuts, compared to when the editor used smooth transitions (Simons & Levin, 1997).

Initial studies on individuals' ability to detect change arose from studies on saccadic eye movements and working memory. In the late 1970s, McConkie and Zola (1979) conducted a study where college students read a passage written in alternating letter case while their eye movements were monitored. The researchers introduced a change in the letter case during some saccades, where a capital letter would switch to a lower-case letter. A survey conducted at the conclusion of the experiment asked whether they noticed any irregularities in the sentences they were reading and found that all the students reported not perceiving the change in letter case. These findings suggest that certain information about stimuli (like letter case) is not integrated across gaze fixations while reading.

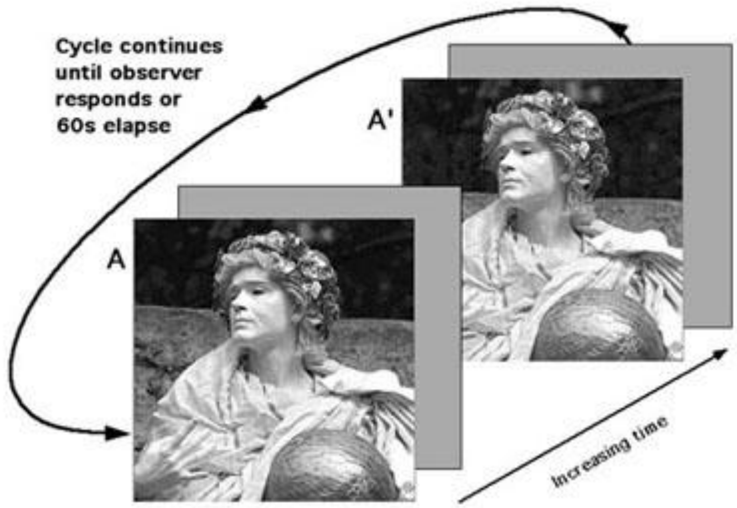

Figure 1. A graphical representation of the "flicker" paradigm utilized in change blindness research. A subject is presented with the first scene, then a "blank" is introduced to simulate a saccade before introducing the second, changed scene.

The interest in change blindness exploded during the 1990s, where multiple studies utilizing the "flicker" paradigm (see Figure 1) demonstrated that people fail to detect significant changes made between presentations of two pictures of objects and real-world scenes where instead of locking the change to a saccade, a visual mask is introduced (called a "blank") (Blackmore, Brelstaff, Neelson, & Troscianko, 1995; Simons & Levin, 1997; Simons & Levin, 1998). These findings suggested that individuals do not store an accurate visual representation of the real-world across fixation points. There was also conflicting evidence for the individual's ability to detect change during stable and unchanging visual fixations in the literature. McConkie and Currie (1996) discovered through their study on visual stability across saccades, that change is easily detected if the eye is fixated on the area of change. During their study on change blindness, Rensink, O'Regan and Clark (1999) found that individuals still fail to detect change even when their gaze is fixed.

One of the most famous studies on change blindness is Simon and Levin's "door study" (1998), which took the study of change blindness from a laboratory setting using arrays of dots and colored blocks and video studies using carefully shot scenes involving actors and objects, to a more naturalistic setting involving real-world interactions. In this study, a confederate asks a passerby for directions. During their conversation, they are interrupted by "construction workers" carrying a door between them. In the moment where the door passes between the initial confederate asking directions and the subject, the confederate is replaced by a different confederate, and the conversation carries on from before the interruption (see Figure 2.). The findings of this study were surprising—50% of the participants did not notice the substitution of the confederates, and those who did notice the change were in a similar age group as the confederates, suggesting that the younger subjects encode individual features of an individual perceived to be in their own social group, which allowed them to detect the change. Simons and Levin replicated this study using different ages for the confederates and the participants and found that less than half recognized the change (1997). These findings suggest that if the gist of the scene remains the same as before the interruption, then the change is not likely to be detected. This study also illuminated that change blindness is not something which is only present in a lab but is instead a general failure of our ability to compare and retain information from one moment to the next (Simons & Rensink, 2005).

Figure 2. Stills from Simons (1998) “door study”. The initial confederate asking for directions is switched for another actor, and the subject fails to notice this salient change. The last panel is the two confederates side-by-side

The current research on change blindness involves the use of brain imaging methods, which will be discussed in the section entitled, “Cognitive Neuroscience Methods: Change Blindness”.

History of Inattentional Blindness Research

The term "inattentional blindness", a phenomenon closely related to change blindness, was first introduced in the 1990s by Rock and Mack (1998). Before their book on the subject, there were studies which explored the failure of auditory awareness during selective attention tasks, the earliest being dichotic listening tasks (Moray, 1959; Treisman, 1960). Subjects in these experiments failed to notice content changes presented to one of their ears (e.g. a change in the language spoken), while focusing on the information presented in their other ear. Interestingly enough, the subjects noticed their own name being spoken and salient pitch changes (male to female voice) in the unattended auditory stream, suggesting that information is partially processed in the unattended stream (Jensen, Yao, Street, & Simons, 2011). The findings of these early studies on audition and attention demonstrate the ability of humans to filter out certain information from our consciousness, while focusing on other information. Furthermore, these studies highlighted the ability to miss critical information coming into the ears in the auditory modality; next, studies exploring the phenomenon of missing critical information entering the eyes via the visual modality will be discussed.

Rock and Mack (1998) extensively studied the visual perception of unexpected objects and events. These studies were typically computer-based studies, an example being the "cross" task. During the "cross" task, subjects must attend to a cross on a computer screen and make a judgement whether one arm of the cross is longer than the other. On one of the trials, another shape appears on the screen, different from the cross. After the trial, the subject is asked if they saw anything other than the cross. Trials after this initial unexpected event are completed to see if the noticing rate changes when the subjects know another shape can appear. In another trial, the subjects are instructed to ignore the cross on the display and instead report if they saw anything else. Across these trials, the noticing rate of the unexpected event was the lowest when the event was totally unexpected (25%) and increased up to 75% when full attention was placed on noticing unexpected events. The findings from this study shows that the lack of expectation or priming during the trials can increase the occurrence of inattentional blindness (missing the unexpected stimulus on the critical trial), and brings into question whether or not the unattended and unexpected stimulus was perceptually processed or encoded at all (Rock & Mack, 1998).

Another important (and fun) study of inattentional blindness was conducted by Simons and Chabris (1999). This was an experiment inspired by Neisser's (1979) work where subjects view a video of two basketball teams passing the ball to each other. The subjects are instructed to count the number of passes of one team by pressing a key, but during the video, a woman with an umbrella walks through the scene (see Figure 3.). Only a small fraction of the subjects noticed the umbrella woman while attending to the pass-counting task, while everyone noticed the umbrella woman while not attending to any task except watching the video. Future replications of this study with the elimination of a time delay between the umbrella woman's appearance and the questioning of the subjects disproved the theory of inattentional amnesia, which posited that the unexpected event is consciously perceived, but immediately forgotten. The subjects were still unable to detect the umbrella woman, providing evidence that inattentional blindness results from a failure of perception, rather than a failure of memory (Simons & Chabris, 1999).

Figure 3. A scene from Neissner's (1979) "Umbrella Woman" study. The critical stimulus for the attention task is the tall woman with the white umbrella walking through the basketball players.

Figure 4. Scenes from Simons and Chabris' (1999) study, demonstrating examples of four conditions of the experiment.

In Simon and Chabris's study, one condition was an Umbrella-Woman, where a person holding an umbrella walked from left to right in the camera view, and the Gorilla condition, where a shorter person wearing a gorilla suit would walk through the scene in the same manner. In addition, there were two different styles of video shot in this experiment: one was a transparent condition, where the gorilla or the umbrella woman would be superimposed over the scene of the team passing the ball amongst each other and be partially transparent, while the opaque condition involved the gorilla or umbrella woman being completely physically present within the scene (requiring coordination of the actors movements to prevent unnatural movement) (see Figure 4.). Lastly, there was an easy task, where participants counted the total number of passes by the attended team, and a hard task, where participants counted separate simultaneous counts of the overhead and ground passes made by the attended team. Overall, 54% noticed the unexpected event, and more noticed this event during the opaque condition. Additionally, more participants noticed the event in the easy condition compared to the hard condition. This study was important because it not only replicated Neisser's study, but also generalized and extended the phenomenon of inattentional blindness. Simons and Chabris argued that because these results are consistent with computer-based studies (Mack & Rock, 1998), we can generalize to real-world situations. The findings also suggest that the level of inattentional blindness depends on the difficulty of a task and can be varied by manipulating the difficulty of the task.

During these studies on both change blindness and inattentional blindness, there were multiple psychophysiological reasons for the occurrence of these phenomenon. These explanations will be discussed in the following section.

The Cognitive Neuroscience of Change Blindness and Inattentional Blindness

To understand the phenomena of change and inattentional blindness, one must understand the structure and function of the three attentional networks in the human brain: the alerting, the orienting, and the executive control network. According to Fan et al. (2009), the alerting network serves to increase vigilance in preparation for an impending stimulus. The orienting network of attention supports the selection of specific stimuli from sensory inputs where orienting can either be exogenous due to highly salient stimuli drawing attention, or endogenous, where a person voluntarily searches for stimuli through their sensory inputs. The third attentional network, the executive control network is the most important to change and inattentional blindness research because the executive control function of attention uses complex mental operations to arrive at a decision to resolve conflicts in percepts. The executive control network is activated in decision making, non-expert responses, absolute judgement tasks, and in error detection. The anterior cingulate cortex and the lateral prefrontal cortex are the brain areas where the executive control network of attention reside (Fan et al., 2009).

There are multiple explanations for the phenomenon of change blindness and inattentional blindness in the literature, as well as methods to find areas in the cortex which modulates these phenomena. This section will examine the explanations for change blindness, as proposed by Simons (2000), then explore Mack and Rock's (1998) two classifications of explanations for change blindness and inattentional blindness. Finally, summaries of findings for the phenomena of inattentional and change blindness in the context of neuroscience will be discussed, including identifying brain areas associated with these phenomena through neuroscience methods such as functional imaging and computer models.

Explanations for the Phenomenon of Change Blindness

Simons (2000) proposed five different explanations for the phenomenon of change blindness. First, Simons explains the most intuitively plausible explanation, termed "overwriting". This means that the initial representation is overwritten or replaced by either the blank or next image, or that any information that the individual does not abstract from the initial display of an image or scene is just replaced by the new scene, leaving no visual record of the initial scene. Simons highlights that while this explanation is consistent with the previous studies on change blindness, it cannot account for all the findings of these studies.

An alternative hypothesis Simons (2000) proposed was that the individuals accurately encode the features of the initial scene, but then fail to encode the details of the current percept, or the changed scene. This potential explanation results from our understanding of the goals of perception; humans need to understand the meaning and importance of our surroundings, so when we process the features of the initial scene, that goal has been met, making the details of the scene irrelevant after that (the changed scene), accounting for change blindness after the blank.

Simons' third explanation for change blindness is that absolutely nothing is stored visually about the visual world (2000). This means that the world itself operates as a memory store, so information that is abstracted from the original scene (percept) will be still there after the scene is gone, so the blank disruption is only needed to mask the motion signal produced by change. An offshoot of this explanation, the "just-in-time" models of perceptual representation claim that some information is stored so that we can be successful in our actions in the environment, but not enough to be detailed (Ballard, Hayhoe, Pook, & Rao, 1997). According to these models, we can store information about the spatial location of objects, but not visual features like color, shape, etc. (O'Regan, Rensink, & Clark, 1999).

Simons' (2000) fourth explanation for change blindness is that everything is stored visually about the visual world, but nothing is compared across scenes. This explanation is inspired by research on human reasoning, where an individual can hold two beliefs that are absolutely contradictory, and they will only notice this when it is pointed out to them (their attention is drawn to the inconsistencies (Simons, 2000). Similarly, individuals may form mental representations of both visual scenes (the initial scene and the changed scene), and not realize that these two percepts are different until their attention is drawn to this fact. According to Simons, multiple studies suggest that an implicit trace from the initial visual scene is preserved, even when the subjects were not aware of this (Shapiro, Raymond, & Arnell, 1997; McCloskey & Zaragoza, 1985; Loftus, Schooler, & Wagenaar, 1985).

Simons' (2000) final explanation for the phenomenon of change blindness is feature combination. In this explanation, we keep some features and objects from the initial scene, and some features and objects from the changed scene, creating one percept that is an amalgamation of both scenes (Simons, 2000). With this hypothesized distorted percept, the individual is unaware that there were two separate scenes because they are essentially unable to keep both percepts of the scenes separate from each other (Simons, 2000). An issue with this model, however, is that this does not explain large, nonsensical shifts in the gist of a scene (e.g. if the initial scene involves a petite woman who is switched for a large, male clown in the second, changed scene).

Explanations for the Phenomenon of Inattentional Blindness

Mack and Rock (1998), the preeminent researchers on the topic of inattentional blindness proposed two different classifications for the explanation of inattentional blindness: perceptual vs. memorial explanations.

Perceptual explanations argue that inattentional blindness arises from a failure of our perception—where our perceptual process fail to engage in stimuli we are not attending to (Moore 2001). Conversely, Mack and Rock (1998) propose that memorial explanations argue that information about unattended stimuli fails to become encoded into a person's memory (not that the information is forgotten—that the information is never encoded in the first place). Moore's (2001) explanation for Mack and Rock's (1998) two proposed classifications of explanations result from the inattention research paradigm employed by many studies asking their subjects to report what they saw only after the fact, making both explanations possible by a report that they did not perceive the information of interest.

While it is argued that there cannot be perception of a stimulus without attention, Moore and Egeth's (1997) findings from a study involving unattended patterns of dots argue that attention is not necessary for engaging perceptual processing. In this study, participants engage in a complex perceptual task in which they report whether one of the two lines on a display are longer. The lines are superimposed over colored dots on the display. During the noncritical trials, there are dots in the background of the display that are colored randomly either white or black. On the critical trial, dots appearing in the background of the display were colored in a way which would elicit the gestalt principle of grouping by similarity. At the end of the trial, a forced choice response unexpectedly appears asking the participant what pattern appeared in the background. The assumption is that if grouping occurs without attention, participants would be able to say which pattern appeared. The participants failed to group the dots when they were not attending to the background, but their responses to line-length discrimination were negatively affected by illusions arising from coloring the dots to create visual illusions (Ponzo and Muller-Lyer illusions). The findings suggest that while Gestalt grouping was found to occur without attention, attention must exist for encoding the products of perceptual processing in working memory so they can be reported later.

Cognitive Neuroscience Methods: Change Blindness

There are multiple neuroscientific studies exploring the topic of change blindness, including those which use brain imaging studies while subjects complete a task. This section will discuss an overview of these studies, describe their methods, and report any relevant neuroscientific findings.

First, a study conducted by Beck, Muggleton, Walsh, Lavie (2005) used a combination of functional magnetic resonance imaging (fMRI) and repetitive transcranial magnetic stimulation (rTMS) to investigate which brain areas play a critical role in change blindness. In this study, the authors recognize that the occiptotemporal cortex plays a role in visual awareness, where lesions on the extrastriate cortex correspond with certain deficits in awareness in different visual features or attributes. The authors explain that activation of the ventral stream is argued by neuroscientists to be necessary for awareness, but recently, evidence from fMRI studies revealed that the dorsal stream may also play a role in visual awareness. To explore this further, Beck et al. (2005) used rTMS to create a temporary lesion in either a subject's right or left parietal cortex while they performed a change blindness task (where they must detect changes in scenes separated by a blank interval). The authors found that when the right parietal cortex is lesioned during the change detection task, there were longer delays in detecting changes and a higher overall rate of change blindness compared to both subjects with temporary lesions to their left parietal cortex, or no temporary lesions at all. Beck et al. (2005) extracted from these findings that the right parietal cortex, part of the dorsal stream of information plays a critical role in change blindness.

fMRI studies were also employed in a study conducted by Beck, Rees, Frith, and Lavie (2001), that examined which neural systems are activated when subjects detect a visual change, versus when they experience change blindness. The standard flicker paradigm was employed, where the subjects must fixate at a point in the center of a monitor and are presented two images, with a blank inserted between them. The fMRI system used in this study was used to continuously acquire blood oxygenation level-dependent (BOLD) responses through contrast image volumes every 2800ms. The trials occurred every 6200ms, creating a total of 888 functional volumes. fMRI studies of the subjects during sole change detection showed activation in the parietal and right dorsolateral prefrontal cortex, and some activation in extrastriate visual cortex for certain objects (like activation in the fusiform gyrus if a face changed). The fMRI data suggested that there was joint activation in both the ventral stream and the dorsal stream during the trials where change detection occurred, but during the trials where subjects experienced change blindness, dorsal pathway activation was noticeably absent, while ventral pathway activation was present. According to Beck et al. (2001), previous research solely focused on the ventral pathway’s role in the visual awareness of change (ignoring dorsal pathway activation), hence data suggesting that there may be critical interactions between the dorsal and ventral pathways in visual awareness contrasts with the traditional viewpoint. The findings of this study suggest the importance of the parietal and dorsolateral frontal activations for conscious change detection (Beck et al., 2001). The authors explain that the two most common functions associated with the frontoparietal network are eye movements and selective attention, suggesting that selective attention is important in awareness due to evidence that the phenomenon of change blindness is not reducible to just visual masking, or the simultaneous appearance of additional stimuli (as in “mudsplashes”, described later), just that there must be no transients. The activation of this area during a change detection task may suggest that change blindness occurs when our attention is deployed elsewhere when the change occurs (2001).

A third study (Tseng et al. , 2009), inspired by the previous two studies (Beck et al., 2001; Beck, Muggleton, Walsh, & Lavie, 2005), used TMS (transcranial magnetic stimulation) on the right posterior parietal cortex, an area previously found to be important in updating spatial representations, directing visuospatial attention, and in action planning. Disrupting this area was found to increase the rate of change blindness in a previous study (Beck, Muggleton, Walsh, & Lavie, 2005). The same flicker paradigm used in the previous Beck study was employed (picture one, blank, picture two), but TMS was utilized to illuminate the stages in processing where the right posterior parietal cortex was most involved. The 240-trial experiment consisted of two blocks: one using TMS (120 trials) and one without the use of TMS (120 trials), with the order of the two blocks counter-balanced between subjects. In the TMS condition, there were two further conditions where the TMS was applied during two different timeframes, either when picture one was presented and the subjects were encoding and maintaining information into visual working memory (during 60 of the 120 TMS condition trials), or when picture two was presented and subjects were retrieving information related to picture one and comparing it to the second picture. The findings indicate that change blindness occurred most frequently when TMS was applied at picture one, which suggests that the right posterior parietal cortex plays a role in encoding and maintaining information in visual working memory (2009).

As stated in the previous section, change blindness researchers are unsure whether changes between the visual scenes can be detected without a percept of the changing object. Researchers today debate whether change blindness builds on entirely different perceptual processes, and neurologists are interested whether simply sensing a change versus specifically identifying a change relies on different or similar neural processes. Bush, Fründ, and Herrmann (2009) conducted a series of two experiments investigating whether sensing versus seeing a change in a change detection task (where there is the introduction of one display, then a blank interval, followed by the introduction of the changed display) involve different perceptual processes. The authors measured the subjects' event-related potentials (ERPs) using an electroencephalogram (EEG). In the first experiment, the researchers were interested in investigating whether subjects in a change detection task were able to detect a change (sense a change) without relevance to whether the subjects were able to identify the object(s) which changed. In the second experiment, the researchers compared the results from the ERPs gathered from change blindness task in experiment one to those in a visual search task (a well-studied effect) They found that measures of visual awareness negativity were similar for detecting change with or without the identification of the change, but when the subjects fully identified the change, measures of N2pc (a posterior negativity contralateral to the side of a change) were found, suggesting that identifying a change requires perceptual (and by extension, neural) processes that are not present when a participant is simply sensing a change (2009). Busch, Fründ, and Herrmann (2009) concluded that changes can be detected without actually perceiving the identity of the change.

A study conducted by Cavanaugh and Wurtz (2004) involved the direct electrical stimulation of a monkey's superior colliculus (SC) to investigate whether this area contributes to the attentional shift that counters the phenomenon of change blindness by improving the monkey's rate of change detection and increasing their reaction time. Initially, the study involved both human and primate subjects performing a change blindness task where an attentional cue (a square placed on the monitor where the change will occur) was introduced before introducing the initial scene involving clusters of dots moving in one direction, then the blank interval, then the second scene with one of the dot clusters changing where the attentional cue was located. Both the humans' and the monkeys' eye movements were tracked, and if a change was detected, the subjects must saccade to the change—otherwise, staying at the fixation point communicates that there was no change detected. The findings indicated that the addition of an attentional cue in the motion change detection task increased the change detection rate for both humans and monkeys. In the monkeys only study, the superior colliculus was located through single electrode recording and a cylinder with single microelectrodes was implanted and placed midline to the SC. The cylinder allows the electrodes to advance along the monkey's SC rostrally. After recording the SC, the electrodes were set to stimulate the monkeys' SC with enough current to active the SC without evoking saccades. When the monkeys' SCs were stimulated, their performance on the change blindness task increased, compared to no stimulation. Cavanaugh and Wurtz's findings suggests that the superior colliculus is not only responsible for creating the saccades which contributes to change blindness, but also contributes to the shift of our visual attention that helps combat change blindness (a unified percept) (2004). The authors admit that electrical stimulation is not the same as naturally occurring neuronal activity.

Cognitive Neuroscience Methods: Inattentional Blindness

While there are many studies in the academic literature about the behavioral presentations associated with the phenomenon of inattentional blindness, there are not many studying the neural substrates associated with inattentional blindness. In a study conducted by Thakral (2011), fMRI studies were conducted during a task invoking inattentional blindness to study these neural substrates. In this task, subjects were instructed to fixate on a central fixation cross on a monitor with a grey background, followed by two colored numbers (1-9, 350ms). The subjects were asked to name each digit and its color while still maintaining fixation. On critical trials, a black and white checkerboard circle was presented along with the digits for 700ms. Subjects completed trials on each of the three attention conditions, inattention (unaware of extra stimulus), divided attention where they were instructed that an additional stimulus may occur (but not instructed to look for it), full attention (told there is an additional stimulus and told to look for it). The fMRI findings of this study showed marked activation in the prefrontal cortex while inattentional blindness occurred in the subjects. The findings of activation in the prefrontal cortex while subjects experience inattentional blindness where they are not consciously aware of the stimuli. This challenges previous research which claims that activity in the prefrontal cortex only reflects the conscious processing of information because this study suggests unconscious activity in the prefrontal cortex (Thakral, 2011).

In addition to brain imaging methods, computer models can provide some insight into psychological phenomena. Dehaene and Changeux (2005) created a computer model representing the spontaneous neural activity in networks of interconnected thalamocortical columns. When the spontaneous activity in the thalamocortical columns occur, the activity can block external sensory processing. The manipulation of this model can help explain how access to consciousness is blocked in inattentional blindness. The authors suggest that spontaneous trains of thought, unrelated to the current task or any external stimuli can exert a temporary blocking of access to our consciousness, which may explain the phenomenon of inattentional blindness through two predictions: one, an intense prefrontal-parietal-cingulate activation by that distracting thought before the presentation of the target stimulus, or two, a reduction of the target stimulus’s activation to a short bottom-up activation in specialized processors. There is more evidence for the first explanation, as Marois, Yi, and Chun (2004) found that the intensity of the activation in the parieto-frontal area of the brain modulates the extent of inattentional blindness.

From Brain Imaging Studies to Real-World Applications: The Human Factor of Change Blindness and Inattentional Blindness

The previous section discussed the neuroscience and the cognitive aspects of inattentional and change blindness, but without real-world applications of these findings, there cannot be advances made in reducing accidents caused by user error.

As human factors professionals, we take our knowledge of human perceptual processes to help design systems that are safe, effective, easy to learn and use, with good feedback, consistency, and visibility of elements of these systems (among other design principles). Learning more about these phenomena, which have critical implications for the safety of humans and the prevention of accidents, through examining the academic literature (including both laboratory and naturalistic studies) allows us to create an understanding which captures a large subset of information about change and inattentional blindness, enabling us to better design and implement systems with this understanding in mind. Insight into the brain areas where human change detection and attention takes place, in combination with our understanding of cognition and the limitations of humans' perceptual processes, allows us to have a better understanding of how to design systems within these human limitations. For example, designing a monitoring system for a nuclear power plant, without understanding that even the addition of small stimuli in the visual field when a change occurs will negatively affect change detection in the operator, could have deadly consequences.

Likewise, understanding that neuroscience findings suggest that the prefrontal cortex remains active even while processing unconscious visual stimuli, coupled with the understanding of unattended vs. attended stimuli in the auditory domain through dichotic listening studies (where people can understand "important" stimuli like their name despite not attending to that information) might suggest that attentional resources are being devoted to unconscious stimuli in the visual modality as well, highlighting the importance of decreasing disengagement and complacency in a task and the importance of cueing attention to important areas of change. In the next section, applied problems and studies utilizing real-world situations will be discussed.

Implications of Change Blindness and Inattentional Blindness

Previously, most of the studies discussed on the topic of change blindness and inattentional blindness solely involved laboratory studies conducted on computers, with little direct external application to real-world counterparts. In fact, there are real-world implications of change blindness and inattentional blindness, outside of a simple laboratory setting. Naturalistic applications of both phenomena include vigilance tasks involving monitoring surveillance systems, managing critical information in a multitude of real-world applications like air-traffic control, and nuclear power control, and while operating a motor vehicle or aircraft. These real-world applications and their related studies will be discussed in the following sections, divided once again by the phenomenon they belong to.

Implications of Change Blindness

The study of change blindness has important implications for the topic of transportation safety. Adapting the flicker paradigm used in traditional computer and laboratory change blindness studies to a transportation context is important as the phenomenon of change blindness can be deadly if a sudden change on the road accompanied with the addition of visual stimuli of any size or shape occurs. Change detection is a critical process in driving, as important changes in the environment (sudden detours, changes in traffic lights, the addition of elements serving as obstacles onto the road surface) must be perceived in order to have safe transportation.

An article written by O'Regan, Rensink, and Clark (1999) describes a concept of "mudsplashes"(see Figure 5.) or a few, small, high-contrast shapes 'splashed' on a visual scene, just like how driving through a mud puddle in a car creates splatters of mud obstructing multiple places on your windshield. The authors found through experimentation that these mudsplashes cause change blindness to occur, even though they do not obscure the location where a change occurs. O'Regan, Rensink, and Clark (1999) proposed that these small, attention-grabbing luminance transitions splashing the visual field from the "mudsplashes" prevents attention from being focused on the area of change. Further explanation as to why mudsplashes creates change blindness coincides with an explanation for change blindness from Simons (2000), which claims that change blindness may occur because our internal representation of the visual world only contains central-interest information, making the rest of our internal representation of the world sparse. Because our percept of the external world seems rich, it is theorized that our actual internal representations are sparse because we use the external world as a memory store (O'Regan, Rensink, & Clark, 1999). The authors explain that if multiple, small visual stimuli are simultaneously introduced into our visual field while driving (such as splatters of dust and mud) with a change in the environment (like an addition of an animal, person, or debris on the road ahead) this can negatively affect our ability to detect change and may cause a dangerous accident. The concept of mudsplashes also extends past transportation into the topics of surveillance and navigation as well, as dangerous events can go unnoticed if it coincides with even the smallest disturbances in our visual field.

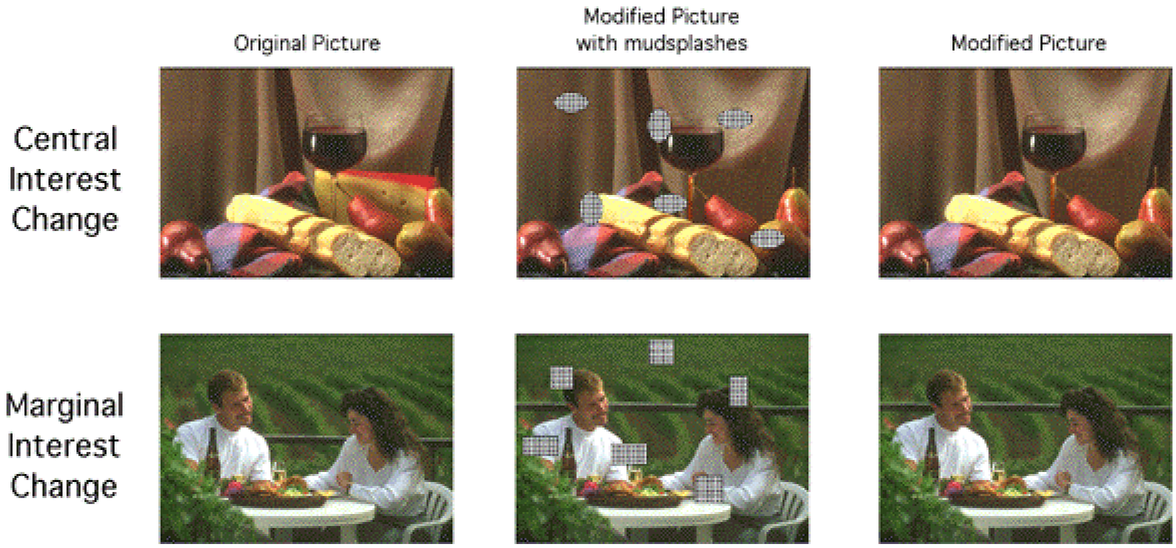

Figure 5. Examples of image sets used in O'Regan, Rensink, and Clark's study on "mudsplashes".

In a driving task study conducted by Beanland, Filtness, and Jeans (2017), findings suggested that the type of environment affects the rate of change detection and the incidence of change blindness while driving. In this study, subjects were to perform change detection tasks while viewing image pairs of either rural scenes, or urban scenes. While viewing the rural image pairs, the participants were more accurate in detecting changes to the environment (an animal crossing the path, changing traffic lights, motorcycles) than while viewing image pairs of urban image pairs (2017). In addition, the subjects were less susceptible to change blindness for objects that are likely to change or move, such as traffic lights versus road signs, as well as moving objects that pose greater damage, such as wild animals versus pedestrians (2017).

Additionally, change blindness has implications in managing critical information in a display, important for applications such as air traffic control, crisis response, emergency rooms, military, and the nuclear power industry (DiVita, Obermayer, Linville, 2004). When operators of complex systems (like DiVita, Obermayer, and Linville's example of naval commanders and control system personnel) complete tasks, they are often heavily overloaded with multiple simultaneous tasks, including visual search, situation assessment, voice communications, and control and display manipulation at multiple large displays often located far apart in space. Change blindness often invites itself into situations where the operator must shift attention from one of these displays to another, with potentially deadly effects for failures to detect changes in the unattended display.

To combat change blindness in monitoring control systems, Durlach (2004) suggests that these systems should include change detection tools instead of leaving change detection solely up to the human operator. An example of this is having unread messages and information displayed in the color red, and read information presented as a different color (such as black) in the monitoring or control system (Durlach, 2004). This is adopted from military displays which "age" information by turning them different colors, representing how new (reliable) versus how much older (less reliable) the information is. Another suggestion made by Durlach is that new information can blink, drawing the attention of the operator to the new information (2004). A concept to keep in mind with displays versus natural environments is that displays tend to be dynamic, with information changing in an instant, unlike the real world, where sudden breaks in spatiotemporal continuity are unusual (Levin, Momem, & Drivdahl, 2000). Therefore, even examples that would seem to combat change blindness, such as introducing highlights into places in online forms where required information is asked of the user can become imperceptible due to the brief interruption of the page updating to display the newly highlighted section(s).

Implications of Inattentional Blindness

The phenomenon of inattentional blindness also has implications for road safety, as the failure to perceive unexpected but salient events can cause accidents and errors. Inattentional blindness can become dangerous when we take in incomplete information about our external world and become misled into forming inaccurate internal representations of that world, causing accidents due to inaccurate decisions. According to Kennedy and Bliss, the National Highway Traffic Safety Administration reported that almost 800 fatal traffic incidents resulted from drivers traveling down the wrong way of clearly-marked streets, and driver inattention was reported as the most reported cognitive influence on crashes in the National Motor Vehicle Crash Causation Survey (2013).

An article by Kennedy and Bliss (2013) explored inattentional blindness in a simulated driving task, with their focus on the relationship between an individual's mental resources and demand and instances of inattentional blindness for task critical stimuli related to driving. In their experiment, they created a simulated driving task where subjects listened to auditory directions coming from a simulated GPS to reach their destination. The final direction tells the subject to turn left on a road with a clearly marked "no left turn" sign (See Figure 6.). The findings of the study suggested a high incidence of inattentional blindness, with 78% of the 44 subjects failing to notice the sign (2013). NASA-TLX measures of the subjects' perceived mental workload during the task revealed that lower subjective measures of mental workload were associated with higher incidences of inattentional blindness, having implications for driving in the real-world due to the increased complexity of the modern driving experience and the increase in disengagement in the driving task (due to cell phones, radios, passengers, etc.) (Kennedy & Bliss, 2013).

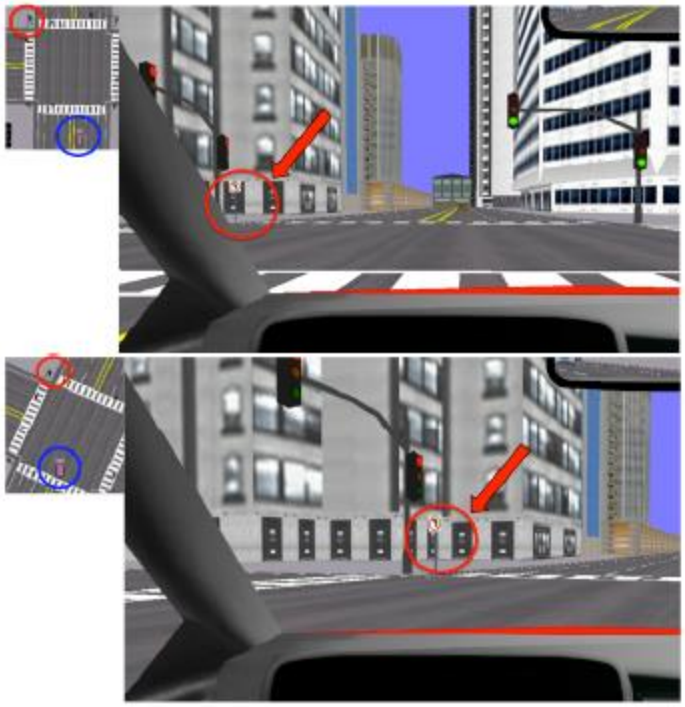

Figure 6. View from the driver's seat in the driving simulation in Kennedy and Bliss' (2013) study, showing the critical stimulus (a no left-turn sign).

Inattentional blindness also has applications in heads-up displays (HUDs) for aviation. A study conducted by Haines (1991) examined whether having flight console information projected onto the windshield of the cockpit, allowing pilots to have simultaneous access to both flight console information and data about the external environment, would have an impact the number of errors pilots make. Haines found that some of the pilots tried to land their aircraft, despite the runway being visibly obstructed by another aircraft. When questioned about the task, the pilots reported that they were completely unaware that there was an obstruction on the runway. Scholl, Clifford, and Simons (2005) recalled this study as a clear example of inattentional blindness—the pilots in Haines' study did not report seeing the other aircraft on the runway despite looking directly at it through the windshield.

This phenomenon is not restricted to a single domain, and can happen in any task where a person encounters an unexpected but salient event, like a surveyor missing a fleet of enemy ships, or a bicyclist blind to a large tree stump ahead on a clear road.

The Future of Change Blindness and Inattentional Blindness Research

While both change blindness and inattentional blindness research has come a long way since the phenomena's increase in popularity during the 1990s, the neurological explanations for both phenomena are not fully understood. Like many psychological phenomena, there is an abundance of literature demonstrating objective behaviors associated with the phenomena, but the recent developments in neuroscience methods leaves much of the information about brain areas and neural networks associated with change and inattentional blindness understood. In the future, with the advent of brain imaging technology that is not only non-invasive and portable for naturalistic study, but also offers high spatial and temporal resolution for monitoring activity during a task, the neural substrates of both change and inattentional blindness will be illuminated. As our tasks become more complex, and our society shifts to utilizing a higher level of automation in our daily lives, change and inattentional blindness research will help increase the effectiveness and efficiency of monitoring and control tasks. The interest in these phenomena will never become irrelevant as long as humans exist and are capable of sight.

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Appendix A

Figures used in this document

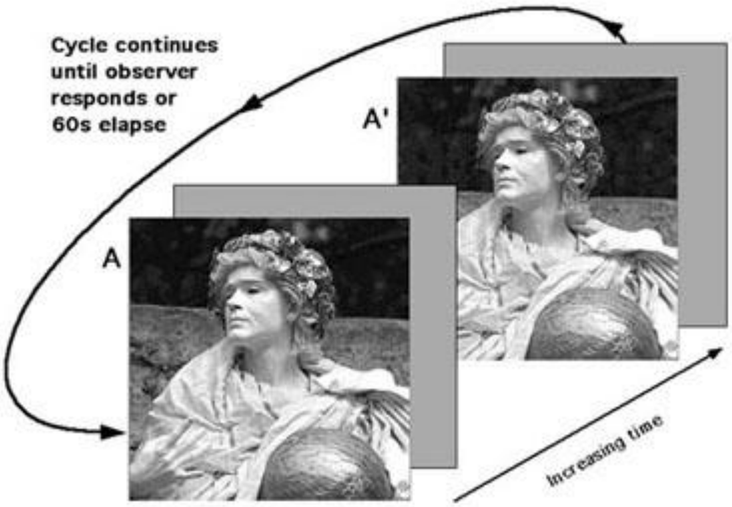

Figure 1. A graphical representation of the "flicker" paradigm utilized in change blindness research. A subject is presented with the first scene, then a "blank" is introduced to simulate a saccade before introducing the second, changed scene.

Figure 2. Stills from Simons (1998) “door study”. The initial confederate asking for directions is switched for another actor, and the subject fails to notice this salient change. The last panel is the two confederates side-by-side

Figure 3. A scene from Neissner's (1979) "Umbrella Woman" study. The critical stimulus for the attention task is the tall woman with the white umbrella walking through the basketball players.

Figure 4. Scenes from Simons and Chabris' (1999) study, demonstrating examples of four conditions of the experiment.

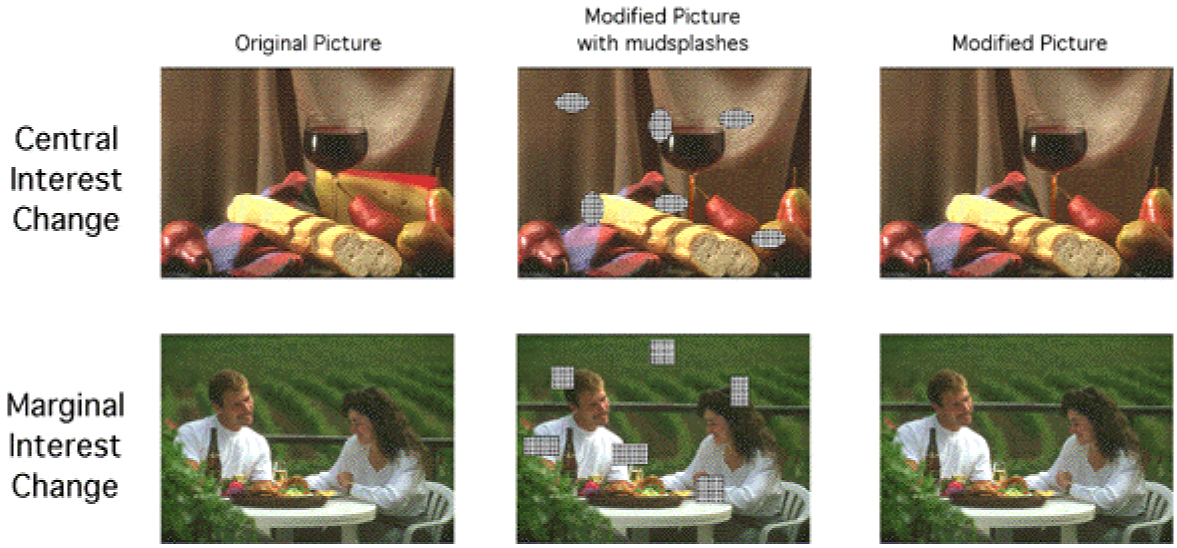

Figure 5. Examples of image sets used in O'Regan, Rensink, and Clark's study on "mudsplashes".

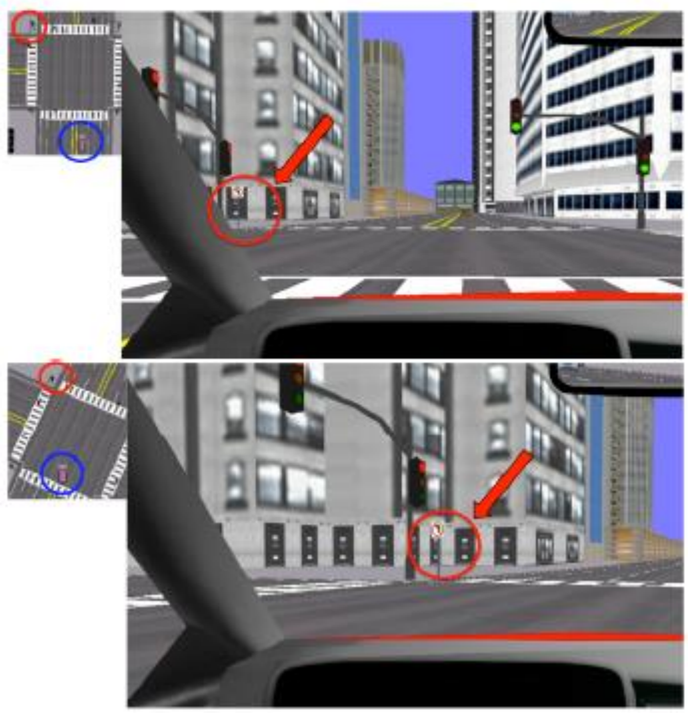

Figure 6. View from the driver's seat in the driving simulation in Kennedy and Bliss' (2013) study, showing the critical stimulus (a no left-turn sign).