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Overview

Change blindness and inattentional blindness

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Change blindness and inattentional blindness are both failures of visual awareness. Change blindness is the failure to notice an obvious change. Inattentional blindness is the failure to notice the existence of an unexpected item. In each case, we fail to notice something that is clearly visible once we know to look for it. Despite similarities, each type of blindness has a unique background and distinct theoretical implications. Here, we discuss the central paradigms used to explore each phenomenon in a historical context. We also outline the central findings from each field and discuss their implications for visual perception and attention. In addition, we examine the impact of task and observer effects on both types of blindness as well as common pitfalls and confusions people make while studying these topics. *WIREs Cogn Sci* 2011 2 529–546 DOI: 10.1002/wcs.130

INTRODUCTION

Psychologists have identified a variety of failures of awareness, such as the attentional blink,[1] repetition blindness,[2] and object masking.[3,4] Here we focus on two cases in which people fail to 'see' something right in front of their eyes: inattentional blindness and change blindness. Inattentional blindness is defined as a failure to notice an unexpected, but fully-visible item when attention is diverted to other aspects of a display. Change blindness is the surprising failure to detect a substantial visual change. Both types of blindness expose the startling mismatch between what we believe we will see and what we actually see.[5–11] Despite their similar phenomenology—people miss something obvious despite looking right at it—change blindness and inattentional blindness have different etiologies and different implications for visual perception, representation, and awareness. In this article, we review the history of each phenomenon and discuss similarities and differences in their theoretical implications.

A BRIEF HISTORY OF INATTENTIONAL BLINDNESS AND CHANGE BLINDNESS

Although inattentional blindness and change blindness are often studied together, the two phenomena grew out of distinct research traditions. Both had precursors in the early history of psychology, but we focus here on the research traditions that led to modern research on such failures of awareness.

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Inattentional Blindness

The term 'inattentional blindness' was coined by Arien Mack and Irv Rock in their book by that name,[12] but the phenomenon has its origins in a much older literature on selective attention.[13–17] Much of the early work on selective attention adopted a task known as dichotic listening in which subjects focused attention on one auditory stream of information while ignoring a second. Often, the two streams were presented to different ears, and subjects were asked to 'shadow' or repeat each word or sound presented to the attended ear as they heard it. These early studies focused on whether unattended information could be processed, and if so, how richly. After subjects performed the task, they often were queried about unexpected information presented to the 'unattended' ear. For example, while subjects are shadowing a story or sequence of words being played to their right ear, experimenters might unexpectedly play the subject's name to their left ear (see Ref 18 for a recent example). If subjects notice their own name but not other less-important stimuli, that would provide evidence for partial processing of the unattended speech stream. To somewhat oversimplify the results of this literature, subjects typically do not notice the semantic content of the unattended stream, although they do notice changes to certain physical properties. For example, subjects often do not notice when the language in the unattended stream changes,[19] but they do notice when the speaker changes from male to female.[17,20] Critically, subjects also occasionally notice important stimuli like their own name in the unattended stream.[14,18]

Much of the selective listening literature focused on the kind of information that people can notice in the unattended stream. In particular, evidence of semantic processing in the unattended stream (like people hearing their own name or other semantic information) was often interpreted as evidence that information can be processed without attention. However, that conclusion might not be justified. The selective listening task (and as we will see, inattentional blindness tasks as well) is ill-suited to the study of such implicit processing because it is difficult to verify that subjects devoted no attention to the purportedly unattended stream (see Ref 21). Subjects might occasionally focus attention on that stream, or shadowing in the attended stream might be spotty or incomplete. However, evidence for processing of unattended information in these tasks is of secondary importance to the primary finding in the selective listening literature: People typically do not notice information in the unattended stream, even when that information is unexpected, distinctive, or semantically meaningful. More recent work on inattentional blindness builds on this failure of awareness.

Convinced that selective listening effects were not modality specific, Ulric Neisser and his colleagues designed a visual analog of dichotic listening known as the selective looking paradigm. The studies were designed to explore the nature of focused visual attention: do people focus attention on regions of space, taking in everything falling within the attentional spotlight, or do people focus attention on objects? If attention is focused on objects rather than space, then people might miss unattended objects appearing in the same location as the attended objects. To test this hypothesis, Neisser and colleagues filmed two separate events and then combined them into a single display using a half-silvered mirror. In the composite display, all of the actors and events were partially transparent and overlapping, occupying the same locations on screen. In perhaps the best-known example, one video contained people passing a basketball and the other showed two people playing a hand slapping game.[22] Observers were asked either to monitor the ball passes or the hand slaps, ignoring the other video. As with dichotic listening paradigms, subjects could attend selectively to one video and ignore the other,[22] even though in this case, the events occupied the same locations in space. In addition, just as in the dichotic listening literature, subjects often missed an unexpected event in the unattended stream. For example, when subjects were counting passes, they failed to notice when the people playing the hand slapping game stopped playing and shook hands.[22,23] Alternatively, those watching the hand slapping game did not notice when the basketball disappeared from the ball passing game. Critically, these unexpected events were obvious to observers who were not performing a task that required focused attention.

The selective looking task extended beyond the original designs of the selective listening tasks by allowing multiple information streams to be superimposed in space. In a series of striking demonstrations, Neisser and colleagues superimposed two separate videos of people passing a basketball. In one video, the players wore white and in the other they wore black (the players were actually the same three people in both cases). Subjects were asked to count the passes in one of the videos (e.g., by the players wearing white) and to ignore the passes by the other team, pressing a key each time they saw a pass. At some point during the trial, a woman unexpectedly walked through the scene carrying an open umbrella. After the task, subjects were asked whether they had noticed anything other than the players, and 79% missed the umbrella woman.[23]

Later replications tested alternative explanations for these apparent selective attention effects in vision. For instance, the failure to notice the umbrella woman could be due to memory limitations: subjects actually see the umbrella woman but forget about her appearance by the time they are asked if anything unusual occurred. If true, increasing the amount of time after the unexpected content should decrease reported noticing. However, observers were no more likely to report noticing the umbrella woman when asked immediately after she appeared than after viewing an additional 30 s of the overlaid videos.[24] Alternatively, observers who fail to notice the umbrella woman may never have fixated the region with the unexpected content. In this case, a failure to notice the umbrella woman would be evidence for a location-based attentional spotlight, but not selective attention. But, observers noticed the umbrella woman equally often when maintaining fixation at a central point she always crossed as when free viewing.[25] Selective attention effects in vision might also be unique to dynamic displays or an artifact of motion processing. However, participants can selectively attend to one of two superimposed line drawings or an afterimage projected onto geometric figures. As with selective listening, observers often fail to later recognize information in the unattended image.[26,27] Taken together, such studies show that attention can be focused on objects rather than spatial locations; even when unattended information appears in the center of an attended region, people often fail to notice it.

Despite the surprising nature of these results and the magnitude of the effects, few other laboratories built on these early findings, and research on selective looking all but disappeared by the mid-1980s. In part, this hiatus from research on inattentional blindness resulted from the technical challenges of conducting the research in the era before camcorders and digital editing, and in part it resulted from a shift in the field of cognitive psychology toward more computer-based attention tasks. Although the findings were covered in many cognitive psychology textbooks of the era, they did not fit easily into the zeitgeist of the time.[28]

The original results were revisited nearly 20 years later in a set of replications and extensions of the selective looking method.[29] The more recent studies used digital editing to create the same superimposition effect that Neisser had achieved using a mirror, and they replicated the original results. When subjects monitored the passes made by one of two basketball teams, approximately 42% did not see the 'umbrella woman'. Many also failed to notice a woman in a full-body gorilla suit passing through the scene. Unlike the original studies, the more recent studies examined whether the failure to notice an unexpected object resulted from the unnatural appearance of the partially transparent displays by recording all of the action in a single camera shot. As before, when people were focused on counting the passes by one of the teams, they often failed to notice an unexpected gorilla or umbrella woman. Even when the gorilla stopped mid-frame, faced the camera, and thumped its chest, approximately half of the viewers failed to notice it. Additional conditions showed that noticing rates were even lower when the monitoring task was more difficult.

The advantage of the selective looking paradigm lies in its realistic and dynamic nature, allowing greater generalization to the real world. For example, the selective looking paradigm easily translates to real-world analogs like driving while holding cell phone conversations. Like other selective looking situations, drivers must attend to driving-related information while ignoring distracting visual information. When executing an additional attention-demanding task (like talking on a cell phone), unattended visual information is less likely to reach awareness. For example, drivers talking on a cell phone are less likely to notice a car breaking in front of them, recognize road signs or billboards, or see traffic signals.[30–32] In a driving simulator, drivers talking on a cell phone are also more likely to crash into a breaking car.[31] One limitation of selective looking tasks, however, is that it is difficult to systematically vary the nature of the displays, as every study requires new videos or simulations.

During the 1990s, another paradigm emerged as the standard way to study inattentional blindness.[12] In this task, participants make a judgment about a static display, such as identifying the longer arm of a briefly presented cross.[12,33] On a critical trial, an unexpected item also appears in the display, and then subjects are asked whether they saw anything that had not been present in earlier displays. When participants noticed the unexpected item, they typically also knew its location and color.[33] However, as in the selective looking task, 25–75% of subjects failed to notice the unexpected item entirely.

Even when the unexpected object was unique in the display—a bright red square—many subjects missed it. In their seminal book, Mack and Rock described an extensive series of studies using this task and its variants to explore inattentional blindness and the factors leading to noticing or missing of unexpected objects. The flexibility of this task and the ease of implementing it allow for more systematic study of the factors underlying of inattentional blindness.[12,34–37] Static inattentional blindness tasks are less naturalistic than selective looking tasks because they use short presentations and sparse displays, but the pattern of results is similar to those from the more naturalistic video-based tasks.

The third primary task used to study inattentional blindness combines the benefits of a dynamic display with the control of a laboratory task.[38,39] In this computer-based task, simple shapes or letters move around a computer display, and on a critical trial, an unexpected object moves across the display. In most cases, participants count the number of times one set of shapes bounces off of the edges of the window, and on a critical trial, an unexpected item (generally a cross) moves across the screen. Participants then report whether they noticed anything other than the shapes on that trial. As with the static inattentional blindness task and the selective looking studies, many people fail to notice the unexpected item.[39] Additional dynamic tracking experiments examined factors that might predict noticing, including proximity of unexpected object to task,[38] similarity of the unexpected object to the attended and ignored items,[39] the contents of the observer's attentional set,[28] and individual differences.[40]

All inattentional blindness tasks (and their real-world analogs) share the following characteristics.

First, the observer is engaged in some attention-demanding task, which we call the primary task. The primary task can be anything, as long as it requires focused attention. Second, each task involves an unexpected event that occurs while the observer carries out the primary task. The unexpected event should be obvious to people who are not engaged in the primary attention-demanding task. The event must also be immediately identifiable as something new, distinctive, or unusual so that people are likely to report it when asked. Finally, the critical event must be truly unexpected. When events are expected, we allocate attentional resources differently between the primary task and the critical event, which makes interpreting the role of attention in noticing more difficult. That is one reason why inattentional blindness studies of all types typically have just one critical trial. Once the experimenter asks subjects if they had noticed anything unusual or unexpected, subjects will subsequently look for such events, invalidating the method as a way to study unattended objects.

Change Blindness

The term 'change blindness' was coined by Ronald Rensink et al.[41] to describe the surprising failure to notice large changes to photographs when those changes occurred during a brief visual disruption. Just like inattentional blindness, change blindness originated in older literatures. Here we distinguish change blindness from other examples of failed change detection based on a somewhat subjective criterion: is the extent of change detection failure counter-intuitive or surprising. Although change detection has been used as a task for decades, change blindness refers specifically to the failure to detect surprisingly large changes, often, but not always, to natural scenes.

Much of the current change blindness literature originated in the study of transsaccadic integration, the ability to combine information acquired from separate glances into a unified representation; the visual system must preserve some information across saccadic eye movements in order to build and maintain a coherent representation of our world. Research on transsaccadic integration sought to understand what information is preserved and how it is integrated over time. Much of the work on transsaccadic integration came from studies of eye movements in reading.[42,43] For example, researchers might limit the visual information available to a few letters or words at the center of gaze and systematically vary how many letters were visible for upcoming words.[44] The idea was to explore how previews of upcoming information facilitated reading. In some cases, the studies adopted change detection as a tool: experimenters changed words while people were saccading to them to see if the change affected reading speed or comprehension.[45] If the change did affect reading, then the prechange information must have been represented and used for visual integration. If the change had no effect, then that information might not be integrated across glances at the display. In general, these studies revealed substantial change blindness across saccades.

For example, participants reading lines of mixed case text (e.g., 'The fLoRiDa EvErGlAdEs') do not notice when all the letters change case (e.g., 'tHE FlOrIdA eVeRgLaDeS') during an eye movement. Observers experience no disruption in reading and do not report noticing the changes at all. The experimenters themselves could only verify that a change had occurred by intentionally remembering the original case of the letters for comparison after a saccade.[46] Across many such studies, changes during eye movements go unnoticed and are minimally disruptive to reading, word naming, or picture naming.[47–49]

Interest in change blindness as a topic of study in its own right grew as demonstrations of the phenomenon began using photographs and videos as stimuli. Much of the current interest in the phenomenon can be traced to a single conference presentation by John Grimes, a student of George McConkie, in 1991.[50] In his experiment, subjects viewed photos on a gaze-contingent display, and as subjects scanned the image, the original image was swapped with a changed version during a saccade. In Grimes's experiment, subjects often failed to notice substantial changes such as two people on a bench exchanging heads. In his conference presentation, Grimes showed some of the same image sequences to illustrate the sorts of changes he used. The subset of people in the audience who happened to saccade during a change, failed to notice the change just like participants in the study. That demonstration of change blindness inspired a number of researchers to seek ways of inducing change blindness that did not require expensive eye tracking equipment.

In perhaps the best-known approach to studying change blindness, an original and changed image alternate back and forth, separated by a brief blank screen. Under these 'flicker task' conditions, subjects often need multiple alternations of the original and changed images to localize the change.[41] Earlier research on change detection had used a 'one-shot' task in which observers view an original display, a blank, and then the changed display.[51] Unlike the flicker task, though, the one-shot task did not provide a rich phenomenological experience of change blindness. In the flicker task, subjects feel that they are searching the scene for the change; once it is found, they cannot imagine that they missed it for so long—the change becomes obvious once they know where it is. This experience of change blindness followed by change detection highlighted the surprising extent of change blindness. And, as we noted, it is this surprise that distinguishes change blindness demonstrations from other failures of change detection.

One-shot tasks share some commonalities with the flicker task, but differ in theoretically important ways. In a standard flicker task, observers can focus attention on individual objects or small sections of the display at a time. By moving from location to location, they can hold smaller sections of the image in memory to compare across the blank. In contrast, a one-shot task requires an observer hold as much of the prechange display in memory as possible to increase the odds of detecting the target. As a result, the one-shot task is often used to test the capacity of visual memory for scenes.[52–54]

Although much of the modern empirical study of change blindness has its roots in the literature on visual integration, it also took inspiration from more anecdotal analyses of motion picture perception (see Ref 55). Filmmakers are well aware that people often fail to notice continuity errors, mistakes in which an object or person unintentionally changes from one shot to the next.[56–58] Such errors are an almost inevitable consequence of modern film editing techniques in which separate shots are combined after the fact. Although many books on film errors have been published, relatively few laboratory experiments explored the extent of blindness to film errors. In the mid-1990s, a series of studies created a set of simple films with intentional editing mistakes and showed that subjects reliably fail to notice major changes that occurred across film cuts.[59] In fact, nearly two-thirds of subjects failed to notice when the only actor in a brief movie was replaced by a different person during a brief action sequence.[59] Such effects generalize to real-world situations as well. In one study, a researcher asked an unsuspecting pedestrian for directions, and during the conversation, two confederates carrying a door walked between the researcher and pedestrian. During the brief obstruction, one of the 'workers' switched places with the experimenter and continued the conversation as if nothing had happened. Half of the subjects had no idea that their conversation partner had changed.[60] There is additional evidence for change blindness during a number of real-world tasks, including driving,[61,62] naval command monitoring tasks,[63] object sorting and reproduction,[64,65] flight simulations,[66] and making tea,[67] among others.[68]

Real-world studies are often like one-shot tasks in that the change only occurs once. However, both the flicker and the one-shot tasks typically are 'intentional' tasks in that subjects know that a change will take place and they actively search for it.[69] In contrast, most video-based and real-world studies are 'incidental' change detection tasks in which subjects do not anticipate a change. Such tasks are better suited to examining what subjects do by default under more naturalistic situations. Subjects generally show some degree of change blindness whether or not they actively search for a change, and many of the same theoretical principles apply to these various task types.

Change detection occurs naturally when a change draws attention but often fails when it does not. Most visual changes, when they occur abruptly, produce a luminance signal at the change location. For example, a yellow ball rolling across a street produces an easily detectable change in luminance as well as a motion signal. In an otherwise static scene, such luminance signals 'pop out' and capture attention. When signals are masked or overwhelmed by other luminance changes, though, change blindness often ensues. A variety of stimuli and events create a large enough disruption to mask change signals: saccades,[50,70,71] color and luminance transients,[72] blank screen interruptions,[41] or 'mudsplashes'[73] all impede localization of the change. Interruptions that conceal the occurrence of a change, such as motion picture cuts[59] or visual occlusion[60] also induce change blindness. Change blindness also occurs when the change occurs too slowly (e.g., by a gradual fade) to generate a perceptible motion signal.[74] Although not the focus of this review, failures to detect changes occur in audition[75,76] and touch[77,78] as well. In all such cases, observers miss the change because it does not attract attention to the change automatically. Instead, people must intentionally search for the change by scanning the scene, encoding elements into memory, and comparing what they remember to what they see at a later point.

Failure to focus attention on a change precludes awareness of it, but inattention alone cannot account for change blindness. Change detection can fail even when people focus attention directly on the object that changes both before and after the change. For instance, nearly two-thirds of observers fail to notice a change to the identity of the only actor in a brief motion picture,[59] and about half miss a change to a conversation partner.[60] People also miss changes to the only object in a simple animation, provided that the object can change in a number of different ways.[79] When changes are introduced during a blink, people miss them over 40% of the time even when looking directly at a change location.[80] In all these cases, people focus attention on the changing object, but fail to detect the change. Change blindness, then, cannot merely be explained as a failure to attend to a changing item.

Successful change detection requires five distinct steps, and failure at any step leads to change blindness:

1. Direct attention to the change location.
2. Encode into memory what was at the target location before the change.
3. Encode what is at the target location after the change.
4. Compare what you represented from the target location before the change to what was there after the change.
5. Consciously recognize the discrepancy.

Much of the change blindness literature examines evidence of failure in relation to these steps in order to address a broader issue: what can change blindness tell us about the completeness (or sparseness) of visual representations?

Several mechanisms for change blindness have been proposed in the literature. First, the postchange stimulus could overwrite or disrupt access to the prechange stimulus.[41,81,82] In this view, change blindness occurs because the first representation is unavailable for comparison. Second, the prechange representation might never be encoded into memory in the first place.[83–86] In this view, our stored representations of our visual world are inherently sparse and incomplete; the human visual system does not store information about our surroundings to build mental representations, but accesses that information from the external world as necessary.[85] Change blindness, then, occurs because there is no stored information to compare to a current view. Third, subjects might encode the prechange display, but never bother to compare their representation to the postchange display. In this case, change blindness results not from a representation failure but from a comparison failure.[87–89] In most cases of change blindness, the underlying mechanism is indeterminate, and change blindness may reflect a combination of representation and comparison failures. Moreover, none of these mechanisms likely applies to all examples of change blindness.

A few experiments have documented evidence that change blindness can result from comparison failures rather than representation failures. In one study, an experimenter approached a pedestrian to ask for direction to a gymnasium. During their interaction, a group of confederates walked past and removed a basketball the experimenter had been holding. Most people did not notice the change, but when asked specifically if the experimenter had been holding something, they spontaneously remembered that she had been holding a red and white basketball.[90] If the prechange scene were overwritten or never represented, subjects would be unable to recall the prechange state of the object, even when guided toward it.

These prechange representations may influence behavior even when a change is not consciously detected. For instance, observers tend to fixate changed items longer than unchanged items even when they do not report detecting the change.[70,91] And, after failing to detect a change to an array of letters, participants later show priming for degraded letters that were pre or postchange items.[92]

Although these studies show that people may retain some information about the prechange object, they do not directly test whether change blindness can occur despite internal representations of both the pre- and postchange objects. In another set of experiments,[88] subjects tried to detect a change to an array of objects. Following their change detection performance on each trial, they were given a forced choice between two objects and had to decide which had been in the display. They completed the forced choice task for one object in the prechange display and one in the postchange display.

Even when unaware of the change, subjects recognized the pre- and postchange objects significantly more frequently than chance. Similarly, in an incidental change detection study, subjects viewing videos with person or item changes across a film cut were able to select prechange items from a photo line-up at well above chance. Whether or not they had detected the change, participants were equally able to recognize the prechange items.[93] In another study, subjects monitoring and responding to objects experienced high rates of change blindness but were nevertheless able to perform well above chance in recognition tests for those objects.[94] In each of these studies, subjects had in fact encoded objects at the target location, even when blind to the change. Therefore, the failure had to result from a failure to compare those representations rather than a failure to encode the objects in the first place.

Although change blindness may often be the result of a failure to compare mental representations, some overwriting or disruption of initial representations also occurs. In some cases, recognition of prechange items is better for detected changes than undetected changes. In the forced choice recognition task described above, recognition performance for undetected changes was always better than chance. However, observers were 20% less accurate when recognizing objects from undetected changes than from detected changes.[88] In a similar study with a variety of object arrays (from 3 to 16 objects), subjects were better able to recognize postchange items than prechange items. Overall accuracy declined as set size increased, but prechange recognition remained 10–40% worse than postchange item recognition.[82] Similarly, when observers failed to notice an experimenter turn into a different person after ducking behind a counter, they were also unable to identify the prechange person in a photo line-up. Observers who noticed the change were 40% more accurate at identifying the prechange experimenter.[81] In another real-world study, observers who missed a change performed at chance on a prechange and postchange recognition task. However, a subset of subjects who provided high confidence ratings of their recognition performed well above chance on the recognition task. In other words, change blindness may result from comparison failure for some subjects and a representation failure for others.[95] In general, poor memory for prechange items suggests that change blindness may sometimes result from impoverished, nonexistent, or overwritten prechange representations.

Ultimately, change blindness is the single behavioral consequence of a variety of failures in the change detection process. Consequently, change blindness on its own provides little information about the nature of our visual representations. However, successful change detection does require representation, so change detection tasks provide a useful tool for understanding visual attention and memory.

Synopsis

Despite their disparate origins, both inattentional and change blindness research surged in the 1990s with the advent of new technologies. Advances in photograph and film editing made it easier to study change detection and inattentional blindness using complex and realistic stimuli. Likewise, new computer technology allowed for the easy capture, manipulation, and presentation of images. Such naturalistic stimuli, coupled with tasks designed to illustrate failures of awareness, permitted subjects to experience their own failures of awareness more vividly, highlighting the surprising nature of both inattentional and change blindness.

Many people, expert psychologists included, do not always properly distinguish inattentional blindness from change blindness. After all, both phenomena refer to a failure to perceive some perceptual event that appears in plain sight. The distinction, though subtle, is important. Inattentional blindness occurs for unexpected objects or events that become trivially apparent once the subject knows to look for them. Change blindness, on the other hand, can persist through active search for the target object/event, with full attention devoted to detection, and regardless of whether the subject knows for what to search. Furthermore, change blindness necessarily involves memory (in order to encode and compare pre- and postchange stimuli), whereas inattentional blindness does not.

Inattentional blindness is similar to change blindness in that people fail to 'see' an object. However, unlike change blindness, inattentional blindness occurs while attention is engaged in some demanding task.[12] Moreover, where change blindness reflects an inability to identify how the visual world changes over time, inattentional blindness refers to the failure to notice that a fully-visible item exists at all.

A good rule of thumb for distinguishing instances of inattentional and change blindness is the number of displays necessary to induce the phenomenon. Change blindness requires two images: the visual state before the change occurs and after. Inattentional blindness, on the other hand, requires only one: an image in which the target stimulus appears.

The two phenomena have different theoretical implications as well. Change blindness shows how attention is necessary but not sufficient for visual awareness. People can miss changes to attended objects if they do not focus on and compare the features that changed. Inattentional blindness demonstrates that attention can serve as a filter for irrelevant information; items that do not receive attention typically do not reach awareness. More importantly, unexpected but distinctive objects do not automatically attract attention.

For the remainder of this article, we consider some of the salient similarities and differences between these phenomena, separating them into effects of the tasks and effects of individual or group differences in the observers. We end by identifying some of the common pitfalls in studying each phenomenon.

EFFECTS OF THE TASK

Change blindness occurs with a wide range of stimuli and can be induced with a variety of visual disruptions (e.g., blinks, saccades, movement). Likewise, inattentional blindness occurs as long as observers engage in an attention-demanding primary task and an unexpected event occurs. Nevertheless, some aspects of the task can alter blindness rates. Here, we review task characteristics that influence change detection and noticing of unexpected objects.

Inattentional Blindness

Detection of an unexpected stimulus depends on the likelihood of that stimulus attracting attention. Whether a stimulus draws attention depends in part on the resources the subject has available to them when performing the task and in part on how a subject identifies which stimuli are to be attended. Therefore, the likelihood of noticing an unexpected event varies with both the difficulty of the primary task and the similarity of an unexpected object to task-relevant items.

More difficult tasks demand more attentional resources, leaving less available for unexpected object detection. For example, observers were less likely to notice the gorilla in the selective looking paradigm when keeping separate running totals of bounce passes and aerial passes than when just keeping a single count of the total number of passes.[29] In a static inattentional blindness task, noticing rates were lower when judging line lengths than when performing an easier color discrimination task.[37] Finally, in a dynamic tracking task, monitoring faster moving objects resulted in less noticing than when the objects moved more slowly.[40] Together, these results show that when the primary task requires more attentional resources, unexpected events are less likely to reach awareness.

In order to selectively attend to the primary task, the visual system must identify task-relevant items and ignore distracters by using spatial, featural, or semantic information. Consequently, unexpected objects that share features with task-relevant items are more likely to be processed. For example, subjects notice unexpected events more often if they appear near attended items or locations.[12,34,38]

Although spatial proximity contributes to noticing, observers still fail to notice unexpected objects that move through the center of the display and cross fixation.[23,29,39,96] Even when subjects are monitoring how many times the attended items touch a line through the center of the display, only 47% of observers noticed when an unexpected object moved directly along the line.[38] And people can miss unexpected objects in both the static and dynamic tasks even when they fixate them directly.[36,96] Spatial proximity improves unexpected item detection, but location alone does not constrain noticing. This is consistent with evidence for object-based attention from Neisser's selective looking paradigm.

Overlap in feature dimensions between the primary task and unexpected stimulus also increase noticing. For instance, observers notice the black gorilla more often when tracking black-shirted players than when tracking white-shirted players.[29] In dynamic tracking tasks, similarity improves unexpected object detection across several feature dimensions like luminance, shape, and race of faces.[28] For example, when attending to black and white circles, 86% of observers notice a gray circle (same shape). However, when attending to black and white squares, only 7% of observers notice the gray circle. In a driving simulator, observers notice an unexpected motorcyclist more often when it is the same color as task-relevant road signs than when it is a different color.[97] And, when attending to letters, observers are more likely to notice the appearance of another letter than a circle.[36] In sum, observers develop an attention set for the objects and features they must monitor and are more likely to detect unexpected objects that fall within that set.[28] Similarity between attended and unexpected items increases the likelihood that the unexpected item will be erroneously tagged as task-relevant, receive additional processing, and reach awareness.

Change Blindness

Given that change detection requires adequate representation of the pre- and postchange scenes as well as a comparison, any task characteristics that influence the richness of the representation or the tendency to compare representations should affect detection. The semantic importance of the changing object appears to have the biggest influence on the likelihood the subject will attend, and therefore notice, the change. Changes to objects most people consider to be of central interest in the scene tend to be detected faster and more accurately than changes to more marginally interesting objects, regardless of the size or magnitude of the change.[41] Furthermore, the detection benefit for interesting items occurs for upright images, but not inverted ones.[98] Because inverting an image maintains low-level visual features while impairing the ability to perceive the global context and semantic content, the effect of semantic importance must be due to higher-level factors. Visual salience of the target object is less critical. Subjects are more likely to detect changes to regions other humans judge to appear salient but not to regions that are salient as defined by computer vision.[99,100] Ratings of salience apparently incorporate aspects of the scene that are not captured by current salience models.[101]

Devoting more attention to encoding the changing item should and does similarly improve detection.[70,102] Additional encoding time can increase the fidelity of memory representations of prechange items, and better representations, in turn, improve the probability that an observer will maintain the necessary information to detect change. The benefit of better representations may be long lasting as well. As long as visual information is originally well-encoded, visual memory can maintain fidelity for at least 2500 objects.[103] Consistent with demonstrations of long-term memory for visual representations, change blindness rates do not increase with longer lags between encoding and change detection.[41,51,53] Provided ample encoding time, participants can even report the difference between a changed display and the original up to 24 h later.[104]

Consistent with the importance of rich encoding, conditions that impair encoding result in worse change detection. Changes to items that were never foveated are unlikely to be noticed.[70,105,106] Furthermore, when fewer mental resources are available for encoding, subjects exhibit higher rates of change blindness. For example, observers holding conversations detect changes to driving images more slowly and with more errors than those who are not conversing.[107] Change detection performance also declines under conditions of high perceptual load: when participants fixate a central array that has many letters (high perceptual load), they have more difficulty detecting changes to flanking scenes than when fixating an array with few letters.[108]

Real-world studies of change blindness reveal quality-of-representation effects as well. Students were more likely to notice a change in conversation partner when he appeared to be another student than when he belonged to an out-group (i.e., 'construction workers'[60]). The out-group homogeneity bias[109] would suggest that the subjects mentally represented a fellow student better or more distinctly than an out-group member. In turn, they were more likely to encode those features that individuated the pre- and postchange experimenter, making them better able to detect the change.

Even with perfectly precise and complete representations, though, people can still fail to detect changes; change detection requires a comparison of the original and changed items. Task characteristics that prompt an observer to compare representations improve change detection. For example, exogenously attracting attention to the change location enhances the detection of changes at that location by indicating which representations to compare.[53,110,111]

Change detection rates also appear closely related to the degree of semantic difference between pre- and postchange stimuli. For example, subjects detect changes that alter an object's category more easily than those in which both objects are from the same category.[70] More broadly, changes that alter the overall semantic meaning or gist of a scene are noticed faster than comparable changes that maintain the same scene gist.[112,113] In fact, one scene can be progressively replaced by an entirely different image over time, provided that the two images share the same gist.[114]

Synopsis

The likelihood of detecting a change or unexpected object is related to the likelihood that it will be attended. For inattentional blindness, unexpected objects that are closer or more similar to task-relevant items are more noticeable. For change blindness, changes to fixated or more semantically interesting items are more detectable. For both change and inattentional blindness, detection rates are tied to task difficulty where more difficultly yields less noticing. Altogether, these results demonstrate the pivotal role attention plays in processing information to awareness. Attended items are far more likely to reach awareness; if a task manipulation alters the probability that a critical item is attended, it will modulate change blindness and inattentional blindness rates.

Task effects for inattentional blindness primarily involve attention allocation. When items receive focused attention, they are more likely to reach awareness and, consequently, be noticed. Change detection also requires that items relevant to a change be noticed. However, in order to identify change, we must also compare mental representations of what was once to what is now. Task effects that alter how fully items will be encoded or that prompt comparison, either by direct cue or through semantics, improve detection. Therefore, for change detection, the quality of our representations and the likelihood that we make comparisons between representations also influence detection rates.

EFFECTS OF THE OBSERVER

Up to this point, we have discussed these visual awareness failures in relation to all people. However, some individuals 'see' objects and changes that others miss. Are there some people who are better able to notice than others? Or, are these differences just due to chance? Here we will discuss the contributions of individual and group differences in perception, attention, and interest to change detection and inattention.

Given that both change detection and the detection of unexpected objects depend on focused attention, individual differences in the ability to focus attention broadly or to shift attention quickly might well predict noticing. Similarly, change detection depends on encoding items into memory and comparing them over time, so individual differences in working memory or processing speed might well affect how much of a scene observers can encode and retain over time. Groups that perform well on basic laboratory measures of these abilities might also outperform groups that do not.

Individuals and groups also differ in terms of their prior experiences and in what they find most interesting in scenes, and those experiences and top-down biases might also influence detection. As we discussed earlier, change detection is better for items of central interest. Some objects are of general interest because of their semantic importance in a scene. However, other objects or regions may hold special interest to certain observers. These individual differences in interest should be reflected in change detection rates. Likewise, in an inattentional blindness task, subjects may more readily detect an object for which they hold a special affinity. Such individual and group differences, to the extent that they exist, can inform us about the mechanisms underlying failures of awareness.

Inattentional Blindness

Relatively few studies have explored individual differences in the detection of unexpected objects, primarily due to the nature of the tasks themselves. Once participants have been asked about the presence of something unexpected, they subsequently look for unexpected objects. Across a number of studies, additional unexpected objects on later trials are far more likely to be noticed.[12] In fact, when using the standard methods to study inattentional blindness,[12] later trials in which an unexpected object appears are called 'divided attention' trials because subjects are assumedly devoting some attention to the detection of additional objects.

Studies of individual differences in inattention have overwhelmingly focused on group differences in noticing to circumvent the difficultly of working with a single critical trial per individual. Intriguingly, most find little or no effect of individual differences in attention and perception on the detection of unexpected objects. For example, in a large study of sports experts and novices, the ability to visually track multiple objects did not predict noticing of the gorilla, nor did attentional breadth.[115] Consider that in dynamic selective looking tasks, the ability to perform the primary task constitutes a measure of attention and tracking ability. Presumably, those subjects who find the monitoring task easy should have more resources available to detect unexpected objects. Surprisingly, though, tracking ability appears to be unrelated to likelihood of noticing unexpected objects.[40]

Together, these findings suggest that individual differences in basic attention and perception skills might not predict the detection of unexpected events. Such basic measures of attention might well predict performance on other effortful, focused attention tasks, but the detection of unexpected objects might not depend on the same abilities. We do not mean to say that perceptual ability never impacts noticing of unexpected objects. Some factors related to perceptual processing do affect performance. For example, slightly intoxicated individuals are less likely to notice the gorilla than those who are sober.[116] The primary task may be more difficult for slightly intoxicated individuals, which generally results in less noticing. Of course, severe intoxication may lead people to be less focused on to the primary task, and as we discussed earlier, if observers are passively observing the display, they typically notice the unexpected object.

Despite the lack of consistent effects of individual differences in perceptual and attention skills on noticing unexpected objects, several studies have revealed group differences in noticing. For instance, basketball players are more likely to notice the gorilla in the basketball pass-counting task than are non-team sport athletes.[96] This benefit appears limited to domain-specific content, as team handball players were no more likely to notice the gorilla.[115] Nevertheless, expertise is no safeguard against inattentional blindness. Even experienced airline pilots can fail to notice an obstructing airplane while making a demanding landing in a flight simulator.[117]

Subjects also tend to notice unexpected objects that are semantically important to them. For instance, in a static inattentional blindness task, observers see their own names more often than a similar name or a different common name.[12] Observers also notice unexpected smiley faces more than scrambled or frowning faces or blank circles.[12,118] And, highly anxious observers were more likely to notice a frowning face when under stress than when not.[118] Biologically meaningful objects such as body silhouettes tend to be of interest to most observers, and they are noticed more frequently than less meaningful objects like scrambled silhouettes.[119] Although children as young as seven are no different from adults in terms of noticing unexpected objects (provided they can engage in the primary task),[23,96] children are more likely than adults to notice the unexpected appearance of another child (as described by Neisser).[23]

These effects of semantic interest are not driven by visual distinctiveness, as people often fail to notice a red cross in a dynamic tracking task even when it is the only colored object appearing at any point in the task.[39] Similarly, in a selective looking task, 60% of observers miss a woman who appears and scratches her fingernails down a chalkboard despite its distinctive, unpleasant, and multimodal nature.[120] Rather, the effect seems to be driven by semantic importance, just as semantic importance carried weight in the earlier dichotic listening literature.

Change Blindness

A number of studies have examined individual and group differences in change detection performance for tasks in which people intentionally search for changes. (Incidental change detection tasks suffer from the same constraints as inattentional blindness tasks in that after subjects experience one unexpected change, they subsequently look for changes.) Unlike the detection of unexpected objects and events, intentional change detection tasks are affected by individual differences in basic perceptual and attention skills. Visuospatial working memory, attentional breadth, and perceptual processing speed all predict change detection speed in a flicker task with driving-related images.[121]

Executive functioning, verbal working memory, and inhibition measures are also correlated with performance, but do not explain unique variance after factoring in visual working memory and other basic measures of attention.[122]

Change detection performance follows the development of perception and attention skills throughout life. Most of these basic measures of perception and attention improve during childhood and then decline again as people age.[123,124] Similarly, children's change detection improves with age and adult change detection declines over time; children aged 5–12 become faster and more accurate with age,[125,126] but older adults show slowed change localization[121] and higher error rates.[107,127] Older adults also make shorter saccades and more fixations of longer duration during change detection, possibly due to reduced attentional breadth and slower processing speed.[127]

Just as basketball players were more likely to notice the gorilla in an inattentional blindness task, extensive experience with the content domain of a change display also enhances change detection. For example, experts in American football detect changes that are meaningful to a play (e.g., location of the ball, location of players in a play formation) more readily than novices. However, both groups show equal performance on nonmeaningful changes (e.g., clothing color, shadows) and changes to nonfootball scenes.[128] Similarly, chess experts are better able to detect changes to meaningful chessboard configurations than novices, but perform similarly with random configurations.[129]

Familiarity with a specific display also influences change detection in that display. In one study, after performing a change detection task with a set of images, subjects were asked to perform a second task with the same images. Under these conditions, observers first scanned the previous change locations and then scanned previously changed objects at new locations.[130] In other words, they used their prior knowledge of the scene and change to guide change detection. They also were faster to find entirely new changes in the same images than they were when they first looked for a change in that image; familiarity with the scene led to faster change detection with that scene (see also Refs 131 and 132 for evidence that people learn to search more efficiently for changes when they are predictable based on the positions of unchanged objects).

In one clever demonstration of this principle, cognitive scientists who were familiar with one of Rensink's change detection images—a scene in which an airplane engine disappears and reappears—tried to detect changes to that same image. Even when the engine no longer changed, subjects still tended to focus on the location of the jet engine,[133] hampering their search for new changes. Such effects illustrate the power of top-down search strategies on change detection in the flicker task. Moreover, they illustrate the potential power of center of interest effects to influence navigation and, consequently, change detection.

One of the strongest predictors of noticing change is an observer's level of interest in the changed item. Observers detect changes to items rated centrally interesting more often and more quickly than changes to lower interest items.[41] Just as expert football players show different center of interest benefits than novices, interests specific to a given observer also influence change detection. For example, frequent alcohol and marijuana users show an advantage for detecting changes to items related to their preferred habit. Heavy users were more likely to detect changes related to their interest than unrelated changes, while light users showed the opposite pattern of results.[134]

Cultural differences in scene processing and scan patterns also produce differences in change detection. For example, East Asian subjects are more likely to attend to contextual information than Westerners,[135] and are therefore more likely to detect changes to the more marginal aspects of the scene that provide context.

In the same vein, patient populations show differential processing of items specific to their interests or fears. For example, Williams syndrome patients, who tend to be socially gifted but suffer learning deficits, show a detection advantage for changes that occur within social interactions.[136] Similarly, insomniacs detect changes to sleep-related items (e.g., a teddy bear) more quickly than noninsomniacs,[137] and patients with specific phobias more quickly and frequently detect changes to the objects of their fears than to nonfeared objects.[138,139]

Synopsis

Both inattentional blindness and change blindness involve perceptual processing, but only change detection performance appears to be associated with individual differences in basic attention and perception abilities. This difference may be explained by the nature of each task. Detection of a change is dependent on many visual processes that are modulated by attention (e.g., search, encoding, comparison, etc.). Detection of an unexpected object, however, requires representation of something that lies outside of focused attention. We see an effect of attentional skills on change blindness because those skills are involved in change detection. It is possible that we fail to see an effect of attentional skill on inattentional blindness because those skills do not enhance the processing of objects and events falling outside the focus of attention.

Expertise and personal interest, however, influence change blindness and inattentional blindness in comparable ways. The reasons behind the benefit of expertise for domain-related tasks are open to conjecture. Expertise might allow more efficient processing of patterns of visual information (e.g., basketball experts may be able to extract more information more quickly from a basketball related display). Alternatively, expertise might alter the relative meaningfulness of aspects of the display—an expert and novice chess player will find different areas of a chess position meaningful, so these groups would show different change detection depending on the region of the change. Given the paucity of studies linking expertise to the detection of unexpected objects, more research is needed to fully understand how expertise alters the link between primary task performance and inattentional blindness.

Taken together, both literatures show that semantic importance influences visual awareness, affecting which objects and changes people notice and report. Nevertheless, how semantic meaning influences the visual system is still unclear. For intentional change detection tasks, such effects of meaning are likely driven by top-down goal setting in scanning the scene[140]; individual differences in performance may co-vary with differences in how people approach the task of parsing the scene. Meaning may further influence how completely you encode information and the likelihood of making a comparison to memory. Fully understanding center of interest effects will require separating out the relative contributions of interest to each component of change detection.

The role of meaning in detecting an unexpected object is even less clear. In an inattentional blindness task, subjects are not looking for the target object, but meaning still plays a role. At the very least, such effects of meaning, as well as priming effects from unseen objects (see Ref 12), appear to support a late selection model of attention in which unattended objects are processed to a level of semantic comprehension. However, as for the dichotic listening literature, the failure to report a critical stimulus does not mean that the stimulus was unseen, unprocessed, or even entirely unattended. It might well have been processed and forgotten (i.e., inattentional amnesia[141]). Or, it might have been processed fairly fully but not registered in the way necessary for a verbal report (i.e., inattentional agnosia[142]).

COMMON MISCONCEPTIONS AND PITFALLS

We conclude our review of change blindness and inattentional blindness by identifying some common mistakes and pitfalls that researchers often make when studying these phenomena. Each phenomenon has its own pitfalls that can muddy the interpretation of experimental results.

Inattentional Blindness Pitfalls

Although individual and group differences in the detection of unexpected objects are inherently interesting, interpreting the results of such differences can be challenging. In order to compare the ability to notice something unexpected, experimenters must first equate the ability of members of each group to perform the primary task. More precisely, they must equate the degree to which each group devotes effort to the focused attention task. For example, if an experimenter wanted to test whether children are more (or less) likely to notice the unexpected object, they must first be certain that these two groups devote similar effort to the focused attention task. Without some independent measure of focused attention, it is difficult to be certain that any differences between groups result from differences in the tendency to notice unexpected events rather than to differences in the ability (or desire) to perform the primary task.

A more fundamental issue in studies of inattentional blindness is that the critical stimulus must be unexpected. In most cases, that means subjects can only experience one critical trial. Although many other failures of awareness occur when observers are performing a focused attention task (e.g., repetition blindness, the attention blink, etc.), unless the critical object is unexpected, the task does not measure inattentional blindness. Inattentional blindness is premised on the theoretical assumption that unexpected objects are unlikely to be the focus of attention in advance. That is, subjects are unlikely to shift attention to a location where something might appear if they have no expectation that anything will appear there. Once people know that something might appear, it is impossible to verify that they did not devote some attention to looking for the target. That is one of the central pitfalls in using tasks like dichotic listening as a measure of unattended processing[21]; if subjects know the target might appear, they may devote some attention to it.

Change Blindness Pitfalls

The literature on change blindness is larger, and in some cases, more fraught with errors of interpretation. When findings of change blindness first emerged in the 1990s, many were eager to argue that change blindness implied the absence of representations[51,84] or at least sparse representations.[41,143] Yet change blindness does not imply the absence of representations, as we noted above (see Ref 144 for details). Perhaps the most common error in interpreting findings of change blindness is to draw too strong an inference about the nature of visual representations from evidence that people did not report a change.

Another common error is to draw strong inferences about visual representations from differential rates of detection across different types of stimuli. Such inferences might well be merited, but only after equating the detectability of the stimuli both physically and psychologically. As a thought experiment, consider a change blindness task in which people notice color changes but fail to detect position changes. If the position changes involved shifting objects by 1 nm and the color changes involved a shift from white to black, the interpretation that color changes are easier to detect would be unmerited—the relative detectability of changes across those dimensions could easily be reversed by varying the magnitudes of the changes. In essence, comparisons of different change types involve a comparison of apples to oranges. Only by putting both on the same scale is it meaningful to compare their overall rates of detection. Of course it might not be necessary to equate the magnitude of each individual change in an experiment. In fact, in our hypothetical thought experiment, it might be better to systematically vary the magnitude of each change type to determine whether the magnitude of a change has a differential effect across dimensions. In essence, a valid approach seeks an interaction between some other variable and detection on each of the dimensions being compared. Such interactions can be interpretable even if the absolute differences in detectability are not.

One study adopting that approach compared the detection of changes to faces and objects.[145] In an initial experiment with upright faces, subjects detected changes to faces faster than changes to objects. Absolute differences in detectability are hard to interpret because the faces and objects could differ in numerous ways (e.g., the faces could be more salient than the objects, the objects may be more complex than the faces). However, the advantage for faces disappeared when the faces were inverted. Across these two conditions, the absolute physical magnitude of the changes was equated, but detection performance varied. Consequently, the authors could infer an advantage in change detection for upright faces. The key factor allowing the interpretation was that the change magnitude was equated on low-level features across the conditions. Furthermore, the authors based their conclusions not on sheer differences in change detection, but on the interaction of inversion with stimulus type.

A third common error in change blindness research comes from a basic design flaw. Recall that in a change blindness task, observers must compare the postchange display to the prechange display in order to detect a change. If the displays are poorly designed, observers could, in principle, detect the change without seeing one of the two displays. For example, experiments that change the number of items in the array can be problematic: if subjects must detect whether an item was removed, and the initial array always has four or five items, then any second array with three items must have changed. For a change blindness task to legitimately measure change detection performance, it is essential that each display, on its own, contain no information about the presence or absence of a change.

CONCLUSION

Change blindness and inattentional blindness both document a surprising failure to notice something that occurred right before our eyes. Change blindness is the failure to identify when something has changed from one moment to another. Inattentional blindness is the failure to notice the existence of something unexpected when attention is focused on some other task. As psychological effects, both phenomena inform theories of perceptual processing, attention, and visual awareness. As human behaviors, they serve as a cautionary reminder of the fallibility of our own visual systems. Despite our impression that we perceive and represent much of our visual world, we often are unaware of important information that passes right before our eyes. Many of the studies reviewed here suggest that in novel, complex, or difficult situations, we will be even more prone to miss unexpected information or fail to see changes in our environment. At the same time, our experiences, interpretations of meaning, goals, and preferences may work to minimize the likelihood that we miss potentially relevant visual information. In both cases, our blindness reveals the struggle between our need to maximize processing of potentially meaningful and useful information while dealing with limited mental resources and noisy, complex sensory information.

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