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Current Approaches to Change Blindness

Daniel J. Simons

Harvard University, Cambridge, MA, USA

Across saccades, blinks, blank screens, movie cuts, and other interruptions, observers fail to detect substantial changes to the visual details of objects and scenes. This inability to spot changes ("change blindness") is the focus of this special issue of *Visual Cognition*. This introductory paper briefly reviews recent studies of change blindness, noting the relation of these findings to earlier research and discussing the inferences we can draw from them. Most explanations of change blindness assume that we fail to detect changes because the changed display masks or overwrites the initial display. Here I draw a distinction between intentional and incidental change detection tasks and consider how alternatives to the "overwriting" explanation may provide better explanations for change blindness.

Imagine you are watching a movie in which an actor is sitting in a cafeteria with a jacket slung over his shoulder. The camera then cuts to a close-up and his jacket is now over the back of his chair. You might think that everyone would notice this obvious editing mistake. Yet, recent research on visual memory has found that people are surprisingly poor at noticing large changes to objects, photographs, and motion pictures from one instant to the next (see Simons & Levin, 1997 for a review). Although researchers have long noted the existence of such "change blindness" (e.g. Bridgeman, Hendry, & Stark, 1975; French, 1953; Friedman, 1979; Hochberg, 1986; Kuleshov, 1987; McConkie & Zola, 1979; Pashler, 1988; Phillips, 1974), recent demonstrations by John Grimes and others have led to a renewed interest in the problem of change detection. The new theoretical ideas and paradigms resulting from this resurgence in the study of visual memory are the focus of this special issue.

Please address all correspondence to Daniel J. Simons, Department of Psychology, Harvard University, 33 Kirkland Street, Room 820, Cambridge, MA 02138, USA. Email: dsimons@wjh.harvard.edu

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In his demonstration, Grimes (1996) showed observers photographs of natural scenes for a later memory test. While they were studying an image, scanning from one object to another, details of the scene were changed during a saccade. Observers often missed surprisingly large changes (e.g. two people exchanging heads). This finding was consistent with earlier work on the failure to integrate information across saccades (e.g. Henderson, 1997; Irwin, 1991; Rayner & Pollatsek, 1983), but in some ways was a more striking demonstration because the changes were so clearly visible to observers when the change occurred during a fixation. Furthermore, Grimes used photographs rather than simple novel objects or letters, thereby bringing demonstrations of change blindness closer to everyday perceptual experience.

More recently, several labs have shown that change blindness for objects in natural scenes can occur during a fixation if the effects of a saccade are simulated by disrupting the retinal transient normally accompanying a change. For example, change blindness can occur when a blank screen is inserted between the original and changed image (e.g. Blackmore, Brelstaff, Nelson, & Troscianko, 1995; French, 1953; Gur & Hilgard, 1975; Pashler, 1988; Rensink, O'Regan, & Clark, 1997; Simons, 1996). People also show change blindness when the original and altered image are separated by a "mudsplash" (O'Regan, Rensink, & Clark, 1999), by a cut or pan in a motion picture (Hochberg, 1986; Levin & Simons, 1997; Simons, 1996), and even by a real-world disruption (Simons & Levin, 1998). Recent studies build on early work on change detection (e.g. French, 1953; Friedman, 1979; McConkie & Zola, 1979; Pashler, 1988; Phillips, 1974) by systematically examining the role of attention in change detection successes and failures (for a review see Simons & Levin, 1997).

These often startling demonstrations of change blindness are consistent with work in other literatures showing an inability to fully perceive, represent, and retain visual information. Work on recall and recognition dating at least to Bartlett (1932/1977) has shown that memory for visual or verbal details is fallible. For example, few people can accurately select the face of a penny from a set of visually similar distracters even though it is a highly familiar object (Nickerson & Adams, 1979). People also confuse semantically equivalent sentences that differ in wording (Bransford & Franks, 1971), and eye witnesses often cannot select a criminal from a well-composed line-up (e.g. Loftus, 1979). Earlier work on the integration of visual information across views suggests that we do not retain a representation of all the visual details of our world from one fixation to the next (e.g. see Bridgeman & Mayer, 1983; Henderson, 1997; Irwin, 1991; Irwin, Yantis, & Jonides, 1983; Jonides, Irwin, & Yantis, 1983; Pollatsek & Rayner, 1992; Pollatsek, Rayner, & Collins, 1984). For example, observers cannot combine dot patterns that project to different retinal locations across an eye movement (Irwin et al., 1983). More recent evidence from work on repetition blindness (e.g. Kanwisher, 1987), the attentional blink (e.g. Shapiro, Arnell, & Raymond, 1997), and inattentional blindness (Mack & Rock, 1998; Mack, Tang, Tuma, & Kahn, 1992) shows that under precisely controlled timing and response conditions, observers sometimes fail to detect stimuli that are otherwise clearly visible.[1]

All of these results are closely related to findings that observers do not notice changes to scenes, but few would have predicted the degree of change blindness that people show (although many might in hindsight). Although the conclusion that we often do not consciously perceive above-threshold stimuli is consistent with findings of inattentional and repetition blindness, it is not at all obvious from such studies that observers would fail to detect large, meaningful changes to natural scenes from one view to the next. Similarly, studies of visual integration typically used simple visual patterns presented to different retinal positions across eye movements. Although these early studies of integration did reveal a surprising degree of change blindness, it is unclear that the inability to integrate simple patterns or even line drawings across saccades should lead to the prediction that people will fail to notice large changes to natural scenes projected to the same retinal position. Research on distortion in recognition memory did use meaningful, naturalistic stimuli, but often focused on the effects of interference or distortion over time. Again, the theoretical conclusions are similar, but few of these studies would have predicted an inability to detect a change so soon after viewing the initial display. One of the goals of more recent change detection work has been to systematically explore the limits of change blindness: What sorts of changes do we miss? Under what conditions? What are the limits of our ability to remember scenes? With what precision do we retain visual details?

CHANGE DETECTION PARADIGMS

Although a number of paradigms have been used to study changed detection, the two most frequently used are the “Flicker” paradigm (Rensink et al., 1997) and the “Forced Choice Detection” paradigm (e.g. Pashler, 1988; Phillips, 1974; Simons, 1996). In the flicker paradigm, an original and modified image are presented in rapid alternation with a blank screen between them. Observers respond as soon as they detect the changing object. Research using this paradigm has produced two primary findings: (1) observers rarely detect changes during the first cycle of alternation, and some changes are not detected even after nearly 1 minute of alternation (Rensink et al., 1997); and (2) changes to objects in the “centre of interest” of a scene are detected more readily than peripheral or “marginal interest” changes (Rensink et al., 1997), suggesting

[1]They may also perceive features and objects, and then forget them (“inattentional amnesia”) once attention leaves (Wolfe, 1999).

that attention is focused on central objects either more rapidly or more often, thereby allowing faster change detection. In the forced choice detection paradigm, observers only receive one view of each scene before responding, so the total duration of exposure to the initial scene can be controlled more precisely. Furthermore, because only a sub-set of the images have changes, signal detection analyses can be used and both accuracy and latency can be used as dependent measures.[2]

Both the flicker paradigm and the forced choice detection paradigm are *intentional* change detection tasks in that observers know that changes will occur and actively search the display to find differences. This work demonstrates that observers are change blind even when their primary task is to search for change. Other change detection studies examine detection performance under divided attention conditions. For example, observers in Grimes' (1996) study were aware that changes might occur and were asked to report the changes when they happened, but their primary task was to study the images for a later recognition task. Another recent approach has been to examine change detection with completely *incidental* encoding—observers view the display without knowing that it might change (see Mack & Rock, 1998 for a discussion of the difference between inattention and divided attention). Many of these studies use motion picture or real-world methodologies, allowing richer insights into the sorts of representations people spontaneously form under natural viewing conditions (see Simons & Levin, 1997 for a review). As with intentional change detection tasks, under incidental encoding conditions, observers are blind to marginal interest changes. For example, when viewing motion picture stimuli, naïve observers consistently miss changes to marginal interest objects occurring across shifts in camera position, or "cuts" (Levin & Simons, 1997).

Findings of change blindness for marginal interest objects in scenes and motion pictures, together with evidence from the flicker paradigm that changes to central objects are detected more readily, lead to the conclusion that attention is necessary for change detection—the details of an object will only be retained if attention is focused on the changing feature. If observers could "take in" an entire scene with a single attentional fixation, they could detect changes anywhere in an image with equal facility. Instead, observers apparently must scan an image, encoding the scene piecemeal (Rensink et al., 1997). In order to retain information about an object or its properties from one view to the next, observers must recode the information, explicitly comparing the abstracted

[2]Note that accuracy can also be used as a dependent measure in the flicker task: Not all changes are correctly reported and some are not detected within the allotted time. However, it is somewhat less natural to include no-change trials in the flicker task given that detection latency is the typically the primary dependent measure. Given that the two tasks use different primary measures, they can serve as complementary approaches to studying change blindness.

representation of the initial object to the changed object (Simons, 1996). Objects that are not recoded are not remembered in any detail. Given the number of potential features and objects in a typical natural scene (effectively an infinite number), many, if not most aspects of a scene will not be preserved across views. Because observers are more likely to focus attention on important objects, they are more likely to notice changes to objects in the centre of interest of a scene.[3]

Although attention appears to be necessary for change detection, it may not be sufficient. With incidental encoding, observers sometimes miss changes to central objects as well. For example, all observers failed to notice when the central object in a brief motion picture (a soda bottle) was replaced by a box following a brief pan away from the table (Simons, 1996). Furthermore, when naïve observers viewed films of simple action sequences, nearly two-thirds of them failed to notice when the central actor in the scene was replaced by a different actor (Levin & Simons, 1997; see also Simons, 1996). Change blindness for central objects can occur in the real world as well (Simons & Levin, 1998). In a recent study, one experimenter approached a pedestrian (the subject) to ask for directions. During their conversation, two other people rudely interrupted them by carrying a door between the experimenter and the pedestrian. During the time that the subject's view was obstructed, the first experimenter was replaced by a different experimenter. Only 50% of observers noticed the change even though the two experimenters wore different clothing, were different heights and builds, had different haircuts, and had noticeably different voices (Simons & Levin, 1998). Unless observers attend to and encode the specific features that change, they will not detect the difference. Simply attending to an object does not guarantee a complete representation of its features.

Summary

All of these findings of change blindness seem to contradict earlier studies of scene perception and recognition that revealed what appeared to be rapid and accurate representations of scenes: People can recognize large numbers of images viewed only once (Shepard, 1967; Standing, 1973; Standing, Conezio, & Haber, 1970). Furthermore, studies of iconic memory showed that the details of a scene are at least briefly available in a perceptual representation (e.g. Sperling, 1960). These findings raised the intriguing possibility that our visual system might integrate such icons or images from consecutive views to form a detailed, coherent representation. Essentially, one view would be stored in a

[3]In order to recognize which objects are central, observers must in some sense understand the meaning of a scene, and this must be done without focused attention. This conclusion is consistent with work suggesting that objects and scenes can be identified rapidly, even when immersed in a stream of images (Intraub, 1980, 1981; Potter, 1976; Potter & Levy, 1969).

detailed visual buffer until the next view arrived. Such a buffer could help to explain our phenomenal experience of a stable, continuous world despite changes to the retinal projection of our environment as we move (McConkie & Rayner, 1976).

However, experimental evidence repeatedly revealed only very limited ability to integrate detailed information about stable objects across eye movements (Bridgeman & Mayer, 1983; Feldman, 1985; Irwin, 1991; Irwin, Brown, & Sun, 1988; Irwin et al., 1983; Irwin & Yeomans, 1986; Rayner & Pollatsek, 1983; but see Trehub, 1994). Findings of change blindness provide added evidence against a visually integrative buffer. By using different methods (e.g. saccades, flashed blank screens, mudsplashes, movie cuts, etc.) to obscure the motion transient caused by the change, these studies show that visual details, even those for naturalistic displays, are not preserved following a disruption to the local transient. One might have expected that the added richness of natural scenes might make integration possible—observers could potentially match a much larger number of available features across views. The inability to detect changes to such images suggests that detailed visual representations do not provide the basis for integration across views, even for complex, naturalistic stimuli.

As this review suggests, recent studies of change detection have used displays that are closer to our real-world perceptual experiences, and have explored the role of attention in the representation of scenes. Furthermore, these new experiments illustrate a striking convergence in the conclusions drawn from fields ranging from sensory discrimination to visual search to eyewitness memory and memory distortion. Collectively, the articles in this special issue illustrate the connections among these fields. The initial section of this issue presents theoretical interpretations of change blindness findings and links between this growing body of research and other literatures. The second section then introduces a number of new empirical findings that provide initial tests of many of these theoretical ideas. Together, these theoretical and empirical papers provide an overview of the current state of knowledge about change detection and extend our understanding of visual representations and attention. They also suggest a number of important new directions for future research. For example, several of the papers suggest the possibility that even when observers cannot report a change, they may have an implicit representation. Further research using more sensitive implicit measures such as priming or forced-choice recognition is clearly needed to provide a complete understanding of visual integration.

Although the new studies in this issue address a number of open questions in the field, they also create new ones. For example, studies of change blindness reveal our inability to notice changes, but they generally do not emphasize what is preserved from one view to the next. One important empirical goal is to determine what *is* and *is not* preserved across views. The next section discusses several possibilities for the nature of our representations given the findings of change blindness discussed throughout this issue.

EXPLANATIONS FOR CHANGE BLINDNESS

Most studies of change detection have been interested in the types of changes observers fail to notice rather than in the changes they do notice, hence the emphasis on "change blindness" rather than "change detection". One reason for this emphasis derives from the questionable assumption that change detection failures imply the absence of a representation of the original features. Successful change detection does require either a motion transient signaling the change or the representation of the feature that changed. Provided that motion transients have been eliminated or masked by an eye movement or a flashed blank screen, detecting a change to the colour of a person's shirt from blue to red would require that observers have represented the colour of the shirt in enough detail to notice that the red shirt is different. This inference seems reasonable, although the precision and level of detail needed in such representations remains an empirical issue.

In contrast, the inference of the absence of a representation does not logically follow from a finding of change blindness. For example, we might retain all of the visual details across views, but never compare the initial representation to the current percept. Or, we might simply lack conscious access to the visual representation (or to the change itself) thereby precluding conscious report of the change. The inference that we lack a representation of the changed object seems to follow from the pervasive assumption that change blindness occurs when a new display replaces, or overwrites the initial display. This assumption does rest on solid empirical evidence from the visual masking literature (e.g. Kahneman, 1968). And, the conclusion that we lack detailed representations could be supported by additional empirical evidence. Anecdotally, our conscious experience and the phenomenology of change blindness do appear to support the idea that we lack detailed representations, or at least, conscious access to such representations. Furthermore, this conclusion is consistent with inferences drawn from over two decades of work on visual integration in pattern perception and in reading (e.g. Irwin, 1991; Pollatsek & Rayner, 1992): Relatively little precise, detailed visual information is preserved across views. Instead, more abstract information is used to bind one view to the next.

However, other evidence suggests the existence of preserved implicit representations without conscious awareness (e.g. Schacter, 1987). For example, recent work on the attentional blink provides evidence for the existence of a representation in the absence of a verbal report of the "blinked" stimulus (Shapiro et al., 1997). Several papers in this issue discuss the possibility of preserved representations in the face of change blindness. However, the flavour of these implicit representations seems somehow different than the rich, consciously available representations we have when we successfully detect changes. Change blindness may well imply the absence of a consciously accessible representation of the changed object, even if it does not require the absence of representations altogether.

Such findings represent a clear challenge to the overriding interpretation of change blindness, that the initial representation is overwritten by the new percept. In fact, a number of distinct alternative explanations for change blindness are possible. This section describes the overwriting hypothesis as well as four alternatives that are each logically consistent with some findings of change blindness. This list of logically possible explanations may not be exhaustive, but it does seem to include all of the plausible models that have been considered. Furthermore, some of the models may be more appropriate explanations for intentional change detection tasks than for incidental tasks, and others may better account for performance with simple displays than complex displays. By considering all of these logical possibilities, we can gain a better appreciation for the sorts of representations that might persist in spite of change blindness. In so doing, we may also hope to appreciate the role of visual representations in achieving an experience of a continuous, rich, stable environment. The models are illustrated in cartoon form in Fig. 1.

Overwriting

The most intuitively plausible explanation for change blindness—and the one most often assumed to be true in the literature—is that the initial representation is simply overwritten or replaced by the blank interval or by the subsequent image. Overwriting models have been used to explain visual masking (Kahneman, 1968) as well as poor recognition of scenes from RSVP streams (despite accurate identification, see Intraub, 1980, 1981; Potter, 1976; Potter & Levy, 1969). Information that was not abstracted from the initial display is simply replaced in the representation by the new scene. No visual record of the initial scene remains. When new visual information comes along, it simply replaces the old representation, leaving only the abstract representations of the initial display. Accordingly, successful change detection occurs only for attended objects, and even then, it may be limited to a comparison of abstracted information rather than of visual representations. The overwriting hypothesis is consistent with much of the work on change blindness. However, as discussed later, it cannot account for all of the findings.

First impressions

An alternative hypothesis is that observers accurately encode the features of the initial object or scene and then fail to encode the details of the changed scene (which is often the current percept). Although this model seems somewhat counterintuitive, in some cases, particularly for incidental change detection

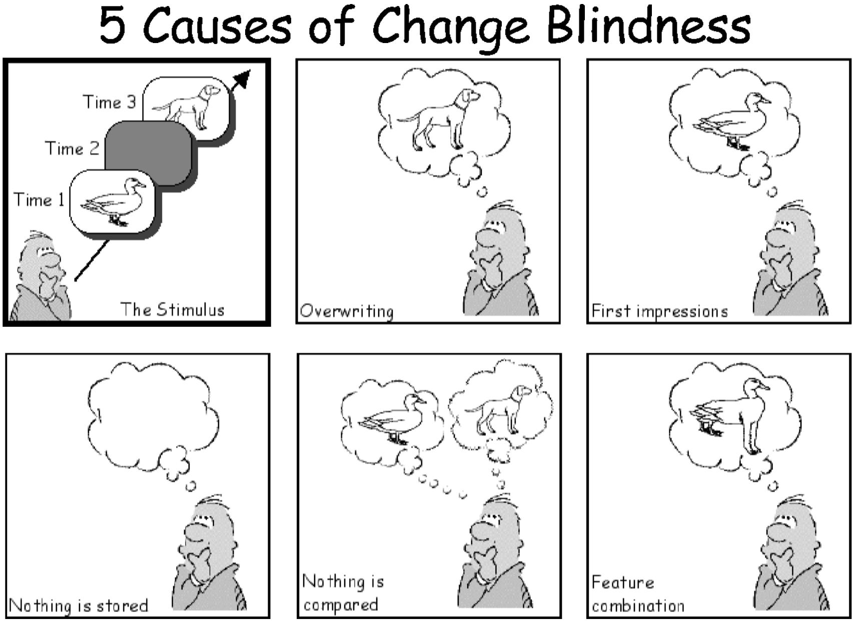

FIG. 1. This figure illustrates five different explanations for change blindness (described in more detail in the text). The upper left frame illustrates a potential sequence in which an observer views a duck followed by a dog. In a real change blindness study, these objects might be replaced by a photographed natural scene. The remaining five frames each illustrate a potential reason why an observer might not detect the change. The "thought bubble" indicates the content of the person's accessible representation of what was seen.

tasks, it may be more plausible than the overwriting hypothesis. One primary goal of perception is to understand the meaning and importance of our surroundings. A number of findings suggest that we can achieve this goal rapidly (Biederman, Rabinowitz, Glass, & Stacy, 1974; Intraub, 1980, 1981; Potter, 1976; Potter & Levy, 1969)—it is likely to be one of the first things we do upon encountering a new scene. If the goal of perception is to understand the meaning of a scene, then the details of the scene will be largely irrelevant once we have achieved that goal. If we encode the features of the initial scene, in order to abstract its meaning, we need not re-examine those features provided that the meaning of the scene is consistent across the change (Friedman, 1979). In other words, we may not check the features of the changed scene provided that the meaning is constant (see also DiGirolamo & Hintzman, 1997). As a result, the visual details of the second, changed image are not represented. Several suggestions from prior work at least partially support this conclusion. First, subjects who failed to detect a change to the central object in a motion picture sometimes described the features of the object in the initial view rather than in the changed view (Levin & Simons, 1997; Simons, 1996). Pilot evidence from a change detection task in which the central actor in a motion picture is replaced across a cut supports this conclusion as well. In ongoing studies, about 70% of observers who fail to detect the change nevertheless select the properties of the initial actor when asked which features they had seen (Simons, Chabris, & Levin, 1999).

Nothing is stored

The strongest form of this model argues that nothing about the visual world is stored internally. Essentially, the world serves as a memory store (Brooks, 1991; Dennett, 1991; see also Gibson, 1986; O'Regan, 1992; Stroud, 1955). Only information that has been abstracted from the percept will be retained once the image or scene is gone. This explanation would suggest that the disruption between views is needed only to eliminate the motion signal produced by the change. Given that none of the details of the first image are represented in a visual store, change detection should be impossible without abstraction. For change detection tasks in which the second display remains visible until a response, this model and the overwriting model predict identical performance. However, this model would also predict that few if any visual details of the second image would be retained after it disappears. A weaker, but possibly more plausible form of this model suggests that some visual information may be preserved across views. Specifically, the only preserved information is that needed on the next fixation. A number of theorists have recently proposed such "just-in-time" models of perceptual representation (Ballard, Hayhoe, Pook, & Rao, 1997). These models accept the notion that some information must be preserved to allow successful action in an environment, but they stop short of positing detailed representation of visual features. For example, they might argue that we represent the locations of objects in the environment even if we do not retain their visual features. Such layout representations may be better preserved because they are more likely to be needed from one instant to the next in the guidance of action (Simons, 1996; Wang & Simons, 1998).

Everything is stored but nothing is compared

Research on thinking and reasoning shows that people can firmly hold two beliefs without realizing that they are fundamentally contradictory. When people are made aware of these contradictory "facts", they recognize the inconsistency and find a way to resolve it. However, they often will not spontaneously detect the inconsistency unless attention is drawn to it (Brewer & Samarapungavan, 1991). The same may be true of visual representations: People may form a representation of each view separately without ever becoming cognizant of the differences between the representations. In other words, the visual/cognitive system may assume the views are consistent unless something about the meaning of the scene (or the questioning of an experimenter) triggers a comparison. Observers may fail to detect changes even if they have represented all of the details.

Evidence from a number of literatures suggests the possibility that an implicit trace from a feature or object can be preserved, even when observers do not consciously perceive it (e.g. Shapiro et al., 1997). For example, some evidence from research on eyewitness recognition suggests that the initial display is not replaced or integrated with subsequent misinformation (McCloskey & Zaragoza, 1985) —an accurate trace of the originally perceived event remains (but see Loftus, Schooler, & Wagenaar, 1985). Several papers in this issue argue for the existence of such implicit representations of the changed object as well. However, a stronger form of this model would suggest that observers have representations of both the initial and changed object, and that both representations are accessible to conscious awareness.

Some preliminary evidence from studies of change detection also support this possibility (Simons, Chabris, & Levin, 1999). In this real-world incidental change detection task, one experimenter approached a pedestrian to ask for directions. While the pedestrian gave directions, a group of students passed between them, and one member of this group surreptitiously took a basketball away from the experimenter. Only three of the subjects spontaneously reported noticing the disappearance of the basketball when asked if they had noticed anything unusual, or anything changing, or anything different about the appearance of the experimenter. However, when asked specifically if the experimenter used to have a basketball, more than half said yes. For example, one subject said, “oh yeah, you did have a ball … it was red and white”. These subjects were initially blind to the change, but, when cued, they could recall the initial appearance of the person and could accurately describe the atypical features of the ball. Clearly they had represented the existence of the basketball. Given that they were currently perceiving the experimenter without the basketball, they had both percepts. Yet, they did not explicitly compare the two until prompted.

Feature combination

The strong form of this view is equivalent to the visually integrative buffer hypothesis in which two consecutive views are overlain and combined—as noted earlier, this model was largely debunked during the 1980s. A weaker form of the hypothesis, though, has some support in the attention literature. More specifically, the two views need not be literally superimposed to form a single representation. Instead, some features and objects might be retained from the first view and others might be retained from the second view. The resulting representation would be different from either of the percepts that contributed to it, but observers would be none the wiser. In essence, observers are unable to keep the two views separate, and partial representations of each are combined to form a new, "coherent" representation of the scene. This idea has been used to explain findings from the misinformation paradigm in eyewitness recognition research in which memory for the event is a combination of the initially perceived event and details suggested after the event (e.g. Loftus, 1979).

Note that this model will not work if the features to be combined suggest a contradictory gist (e.g. a women in one view becomes a bearded man in the other, but the resulting representation is a woman with a beard); the combined features must make sense as a whole and must be consistent with the gist of the initial images. Although no evidence from the change blindness literature directly supports this hypothesis, work on feature migration in scenes (e.g. Intraub, 1985, 1989) and on illusory conjunctions (e.g. Treisman, 1993) suggest it is possible.

Summary

Although none of these explanations can account for all of the change blindness findings discussed in this paper and in this issue, each seems to capture some aspects of our representations. Furthermore, they may be differently suited to account for different sorts of change blindness. For example, overwriting may be well-suited to explain failures to notice changes to simple, visual stimuli such as those typically used in studies of masking or of simple visual discrimination. In contrast, the first-impressions model may apply only to more complex, semantically-codable stimuli. The models may also differ in terms of how successfully they can explain performance with different types of change detection tasks. Some may be better able to explain performance when observers perform repeated trials of an intentional detection task. Others may account for performance in single-trial incidental encoding tasks. All of these factors are in need of further investigation, and some of the experiments in this special issue have begun to consider such possibilities.

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