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ON THE APPLICATIONS OF CHANGE BLINDNESS

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An overview is presented of the ways that change blindness has been applied to the study of various issues in perception and cognition. Topics include mechanisms of change perception, allocation of attention, nonconscious perception, and cognitive beliefs. Recent work using change blindness to investigate these topics is surveyed, along with a brief discussion of some of the ways that these approaches may further develop over the next few years.

Key words: ?????

Change blindness is the inability to perceive changes that are easily seen once noticed. This is a striking effect that can be induced under a variety of conditions, such as making the change during a brief flash, during an eyeblink, or during a cut in a film. It is also a highly robust effect, with observers unable to see large changes that occur right in front of them, and even when they have been informed that changes will occur. (For recent reviews, see Rensink, 2002a; Simons & Rensink, 2005).

The strength and robustness of change blindness suggests that it involves mechanisms central to the way that we perceive our world. But what exactly are these mechanisms? And how much of perception and cognition can be investigated this way?

It is suggested here that change blindness is a tool suitable for investigating at least four different aspects of perception and cognition: (i) mechanisms involved in change perception, (ii) allocation of attention, (iii) perceptual modes beyond those associated with the conscious "picture" of our surroundings, and (iv) high-level cognitive beliefs about how we perceive and act it in our world.

Mechanisms of Change Perception

Among the earliest applications of change blindness was the investigation into the mechanisms involved in change perception. Most perceptual abilities can be studied in two ways: (i) inaccuracies in the percept generated (i.e., illusions), or (ii) outright failures of operation. Since no illusions of change perception have yet been found, change blindness is the only way to study this. Consequently, change blindness and change perception can be seen as inverses of each other, with the boundary between them being the source of information for theories and models of the mechanisms involved.

An important development in this regard is the proposal that attention is needed to see—i.e., visually experience—change (Rensink, O'Regan, & Clark, 1997). All studies to date appear to be consistent with this proposal. A further development is the finding that about 4 items can be monitored at any one time when searching for change (Pashler, 1988; Luck & Vogel, 1997; Rensink, 2000a), a value consistent with the capacity of visual attention obtained via other kinds of tests (e.g. Pylyshyn & Storm, 1988).

At the moment, the exact nature of this limit is unclear. Change perception appears to be an elementary operation at the subjective level. However, considered objectively it actually involves a number of steps: (i) gate the information into a memory store, (ii) consolidate it into a form usable by other processes, (iii) maintain this information for at least several hundred milliseconds, (iv) compare it to the stimulus at the appropriate location, (v) clear the memory store, and (vi) shift processing to the next item. Since all are needed for change perception, a restriction on any affects the entire process. Consequently, it is difficult to determine which step is the limited one in a given situation.

All proposals to date regarding mechanisms involve either visual attention or visual short-term memory (vSTM); these are largely similar in the kinds of mechanisms put forward. Much of this similarity is due to the extensive overlap found between the mechanisms associated with attention and the mechanisms associated with vSTM; some is also due to the vagueness that exists in the words “attention” and “memory”. In any event, change blindness has been applied in distinguishing some of the component steps, such as consolidation (Vogel, Woodman, & Luck., 2006). It may well be that it can be further applied to separate out and investigate the other steps as well.

Related work has also focused on the nature of the elements that are attended/held in vSTM. Evidence from visual search experiments suggests that these may be proto-objects, which already have a considerable local binding of features in the absence of attention (Rensink & Enns, 1995, 1998). Evidence from change detection studies appears to support this (Luck & Vogel, 1997; Gajewski & Brockmole, 2006), although this interpretation has been contested (Wheeler & Treisman, 2002). Further work on change detection should be able to resolve this issue.

Another line of research suggests that the 4 items are not independent, but are constrained to be part of a single higher-level *complex* (Rensink, 2000b). More precisely, about 4 objects can be attended and held in a short-term memory, but their contents are pooled into a single collection point (or nexus) that supports the perception of an object or group complex. Thus, about 4 items can still be monitored for change. However, because they are not independent several other effects emerge. For example, it is difficult to detect switches between the properties of attended items (Saiki, 2003). In addition, observers cannot see more than one change at a time, a phenomenon termed *change simultanagnosia* (Rensink, 2002b). Such results are highly counterintuitive, and this line of investigation may become an important source of insight into how objects and groups (as collections of items) are perceived.

ALLOCATION OF ATTENTION

Given that attention is needed to see change, and that we can only attend about 4 items, it follows that our ability to see dynamic aspects of the scene in front of us is highly limited. In order to explain why we do not experience these limits subjectively, it has been proposed that our representation of a scene is a dynamic one, with objects created on a "just in time" basis (Rensink, 2000b). More precisely, a detailed and dense description is constantly formed, but it is not coherent—i.e., its contents are not linked into complex structures. It is also volatile, and begins to disintegrate as soon as the incoming light stops. Some information is nevertheless maintained in more durable form: about 4 items are given coherent representations in attention/vSTM, along with a dozen or so items in a sparse, schematic "layout" that is used to guide attention. When the management of this system is successful, the result is a virtual representation with almost all the power of a representation that is everywhere dense and coherent. This view emphasizes that interaction with the real world should be seen in terms of dynamic rather than static considerations—as *co-ordination* rather than *construction* of representations.

The key to the successful management of a dynamic representation is to allocate attention to the right item at the right time. This can be done via two different kinds of attentional control: external (or exogenous) and internal (or endogenous). External control is based on the contents of the stimulus, such as a blinking light or waving hand. This form of control is rapid and involuntary, and automatically sends attention to the appropriate location. Considerable work has been done over the past several years on the particular low-level properties which can draw attention this way (see Itti, 2005). Work on change blindness has been part of this effort, showing that several low-level properties can draw attention and so increase the speed at which changes are detected (Scholl, 2000). More recent work has shown that higher-level social properties such as gaze direction can also control attention this way (Ishibashi, Ide, Nagai, & Kita, 2008).

Meanwhile, endogenous control also plays an important role, with knowledge of the scene—and the objects in it—playing a major part in deciding what is attended, and therefore, what is seen. Since different people have different kinds of knowledge and interests, this means that different people can literally see the same scene in different ways. As such, change blindness provides a powerful way to study individual differences in the perception of complex stimuli.

These individual differences can show up in at least three different ways. One is the *priority* given to items in a display. Attention is believed to be allocated first to those items that are most interesting (Rensink et al., 1997); consequently, the speed at which a change is detected can be used to infer how interesting the associated item is to that observer. For example, observers addicted to alcohol are faster and more likely to detect changes to items associated with alcohol than are other observers (Jones, Jones, Smith, & Copely, 2003). Another interesting example concerns vision scientists themselves, who tend to send their attention to an expected location in a well-known example of change blindness stimulus, even when they know that a change would not occur there (Takahashi & Watanabe, 2008).

Another difference is the *way* that observers encode items. Experts at American football can more quickly detect meaningful changes to football scenes than novices, suggesting that the experts have learned to see particular aspects of the scene not perceived by others. Cultural differences may also be explored by change blindness. Based on their ability to detect various kinds of changes, it has been suggested that Westerners are less able to detect changes in physical contexts than are East Asians, indicating differences in the encoding of foreground and background elements of a scene (Masuda & Nisbett, 2006).

Finally, differences also appear to exist in the abilities of observers to *control* attention. For example, proofreaders appear to have better attentional control than novices on detecting changes in scenes (Asano, Kanaya, & Yokosawa, 2008). Interestingly, the degree of change blindness helped measure these differences in ability, even when other kinds of test (such as visual search for a predesignated target) failed to do so.

In summary, then, change blindness motivated the proposal of a dynamic representation of scenes that can account for the effects of training and individual differences in perception. In addition, the duration of change blindness for a given observer and stimulus can help determine the interests and abilities of the observer, even if the observer does not know what these are. Thus, change blindness will likely become an increasingly powerful technique for examining many questions involving individual differences, including perceptual development, and cultural differences.

NONCONSCIOUS PERCEPTION

Moving beyond the change blindness/detection boundary, insight into several other perceptual processes can also be obtained by taking advantage of the fact that during change blindness, the observer has no visual experience of a change occurring. As such, this creates a good opportunity to investigate those aspects of perception that might be carried out in the absence of any visual "picture".

Early work on visuomotor responses showed that eye fixation responded to position changes that were not consciously noticed by the observer (Bridgeman, Lewis, Heit, & Nagle, 1979). Similar effects were also found for pointing with the finger (Goodale, Pelisson, & Prablanc,1986). Later work on forced-choice guessing showed that observers could guess with above-chance accuracy the location of an unseen change, suggesting the existence of nonconscious (or implicit) change perception that did not involve a motor system (Fernandez-Duque & Thornton, 2000). No attentional effects were found, suggesting that such perception did not require visual attention.

As in the case of implicit perception generally, objections have been raised to the interpretation of this data in terms of implicit change detection (Mitroff, Simons, & Franconeri, 2002). However, recent work has given increased support to the proposal that implicit change perception really does exist (Fernandez-Duque, Grossi, Thornton, & Neville, 2003; Laloyaux, Destrebecqz, & Cleeremans, 2006; Laloyaux, Devue, Doyen, & Cleeremans, 2008). Future studies will hopefully shed more light on the nature of the mechanisms involved.

Another phenomenon encountered in change blindness studies is the ability of observers to have a feeling that a change is occurring, even though they do not yet have a conscious "picture" of it (Rensink, 2004). This experience is informative, and is phenomenologically distinct from seeing, in that observers "sense" a change is occurring, rather than experience a picture of what it is and where. It has been proposed that such sensing is due to a distinct mode of visual perception called *mindsight*, which differs from regular sight in the mechanisms used, and that may be a form of alert based on the matching of expected patterns (Rensink, 2004).

As for the case of implicit change detection, objections have been raised to the proposal for such a mode of vision, arguing that the results may simply be due to observers experiencing a near-threshold state of regular vision (Simons, Nevarez, & Boot, 2005). Support for this has been taken from the finding of increased false-alarm rates for observers that often report sensing.

However, since the increase in false-alarm rates could be due to a variety of causes, such a finding does not refute the existence of mindsight. Furthermore, several effects exist that provide a positive argument for it. One is the *restart effect*, where the average time to see relative to the start of sensing is the same as the average time to see a change when no sensing occurred. In other words, it is as if the seeing process completely restarts after sensing takes place. This is difficult to reconcile with a single mechanism, but is easily explained by two mechanisms running independently. Another is the *no-correlation effect*, in which the durations of sensing and seeing are completely uncorrelated in individual trials. This effect is unlikely to result from a single mechanism, but is highly consistent with separate mechanisms for sensing and seeing.

Further exploration of this issue will be an interesting area of research. To the extent that mindsight can be established as a separate mode of visual perception, it could provide a way to study various forms of visual intelligence, including the "gut feelings" often reported in studies of intuition (see e.g., Gladwell, 2005).

COGNITIVE BELIEFS

Although change blindness has been widely applied to various aspects of perception, it is not limited to these: it can also be applied to the study of higher-level cognitive mechanisms. For example, it has served as the basis of *change blindness blindness*, a metacognitive error in which observers significantly and systematically underestimate their ability to detect a change that would occur in their interactions with the world (Levin, Momen, Drivdahl, & Simons, 2000; Levin, Drivdahl, Momen, & Beck, 2002). Such effects can be important in everyday life, since they may cause people to not be vigilant in demanding circumstances, such as driving a car while talking on a mobile phone. Consequently, understanding the cause of this phenomenon is important from a practical as well as a theoretical point of view.

Another application of change blindness is in creating changes that are not noticed but have consequences for higher-level aspects of cognition. An example of this is *choice blindness*, in which the selection of a user is changed without the user noticing it, so that the resulting selection must be accounted for in other terms (Johansson, Hall, Sikström, &

Olsson 2005; Johansson, Hall, & Sikström, 2008). In this case, what is altered are the observer's beliefs about the reasons for their choice, with the observer believing that they had chosen the resulting selection all along. If there is a general ability of the observer to adjust their belief set to account for various mismatches of perception and reality, this may help explain the prevalence of change blindness blindness. In any event, such phenomena have considerable importance for investigating the way we understand our world, and the way we understand ourselves. It is likely that much will be learned in the next several years by studies of this kind.

CONCLUSIONS

Change blindness is a striking and counterintuitive phenomenon in which large changes can be missed, even though these are obvious once they have been noticed. This phenomenon has been harnessed to provide a powerful tool with which to explore many of the mechanisms involved in perception, such as the nature of visual attention, the ways that it can be controlled, the nature of scene perception, and even the modes of perception not directly involved in the conscious picture that we continually experience. In addition, change blindness has served as a useful component in the study of higher-level cognitive structures, including beliefs about how we see and why we act. Over the past several years, therefore, change blindness has become less a phenomenon in its own right, and more a general tool to help us investigate how we see and think. And chances are good that it will continue to help with such explorations.

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