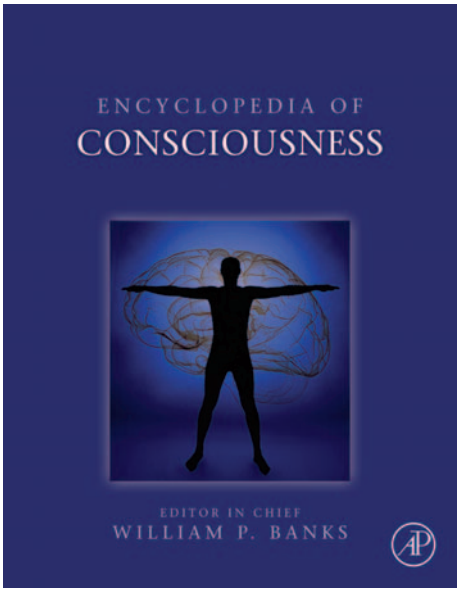
Provided for non-commercial research and educational use.
Not for reproduction, distribution or commercial use.

This article was originally published in the *Encyclopedia of Consciousness* published by Elsevier, and the attached copy is provided by Elsevier for the author's benefit and for the benefit of the author's institution, for non-commercial research and educational use including without limitation use in instruction at your institution, sending it to specific colleagues who you know, and providing a copy to your institution's administrator.



All other uses, reproduction and distribution, including without limitation commercial reprints, selling or licensing copies or access, or posting on open internet sites, your personal or institution's website or repository, are prohibited. For exceptions, permission may be sought for such use through Elsevier's permissions site at:

http://www.elsevier.com/locate/permissionusematerial

Rensink R A (2009), Attention: Change Blindness and Inattentional Blindness. In: William P. Banks, (Editor), Encyclopedia of Consciousness. volume 1, pp. 47-59. Oxford: Elsevier.

Author's personal copy

Attention: Change Blindness and Inattentional Blindness

R A Rensink, University of British Columbia, Vancouver, BC, Canada

© 2009 Elsevier Inc. All rights reserved.

Glossary

Change blindness – The failure to visually experience changes that are easily seen once noticed. This failure therefore cannot be due to physical factors such as poor visibility; perceptual factors must be responsible. Focused attention is believed to be necessary to see change, with change blindness resulting if such attention is not allocated to the object at the moment it changes.
Diffuse attention – A type of attention that is spread out over large areas of space. It is believed to be space-based rather than object-based.
Focused attention – A type of attention restricted to small spatial extents. It is believed to act on small areas of space or on relatively small objects.
Implicit perception – Perception that takes place in the absence of conscious awareness of the stimulus. It is generally believed to take place in the absence of any type of attention.
Inattentional blindness – The failure to visually experience the appearance of an object or event that is easily seen once noticed. Attention (likely, diffuse attention) is thought to be necessary for such an experience. Inattentional blindness typically occurs when attention is diverted, such as when the observer engages in an attentionally demanding task elsewhere, and does not expect the appearance of the object or event.

Introduction

As observers, we generally have a strong impression of seeing everything in front of us at any moment. But compelling as it is, this impression is false – there are severe limits to what we can consciously experience in everyday life. Much of the evidence for this claim has come from two phenomena: change blindness (CB) and inattentional blindness (IB).

CB refers to the failure of an observer to visually experience changes that are easily seen once noticed. This can happen even if the changes are large, constantly repeat, and the observer has been informed that they will occur. A related phenomenon is IB – the failure to visually experience an object or event when attention is directed elsewhere. For example, observers may fail to notice an unexpected object that enters their visual field, even if this object is large, appears for several seconds, and has important consequences for the selection of action.

Both phenomena involve a striking failure to report an object or event that is easily seen once noticed. As such, both are highly counterintuitive, not only in the subjective sense that observers have difficulty believing they could fail so badly at seeing but also in the objective sense that these findings challenge many existing ideas about how we see. But as counterintuitive as these phenomena are, progress has been made in understanding them. Indeed, doing so has allowed us to better understand the limitations of human perception in everyday life and to gain new insights into how our visual systems create the picture of the world that we experience each moment our eyes are open.

Change Blindness

Background

The ability to see change is extremely useful in coping with everyday life: we can monitor the movement of nearby automobiles (as drivers or pedestrians), notice sudden changes in the posture or location of people in front of us, and notice that the sky is quickly darkening. Given the importance

Encyclopedia of Consciousness (2009), vol. 1, pp. 47-59

Author's personal copy

of perceiving change and the fact that most humans can survive reasonably well in the world, it follows that our ability to perceive change must be such that few events in the world escape our notice. This agrees nicely with our impression that we perceive at each moment most, if not all, objects and events in front of us.

Failures to see change have long been noticed, but they were usually taken to be temporary aberrations, with nothing useful to say about vision. This attitude began to change in the early twentieth century, when film editors discovered an interesting effect: when the audience moved their eyes across the entire screen (e.g., when the hero exited on the left side and the femme fatale entered on the right) almost any change made during this time (e.g., a blatant change of costume) would often go unnoticed. A similar blindness to change could be induced by making it during a loud, sudden noise (e.g., a gunshot), during which the audience would momentarily close their eyes.

The scientific study of this effect began in the mid-1950s, with work on position changes in dot arrays and other simple stimuli. Here, a change in one of the items was typically made contingent on a temporal gap that lasted several seconds. A separate line of studies was also begun that investigated the perception of displacements made contingent on an eye movement (or saccade). In all cases, observers were found to be surprisingly poor at detecting changes made under such conditions.

The next wave of studies, begun in the 1970s, was based on a more systematic examination of these effects. This work uncovered a general limit to the ability to detect gap-contingent changes under a wide variety of conditions; this eventually formed the basis for the proposal of a limited-capacity visual short-term memory (vSTM). Likewise, a general lack of ability was found for detection of saccade-contingent changes, which was traced to a limited transsaccadic memory. Both lines of research were eventually linked by the proposal that transsaccadic memory and vSTM were in fact the same system.

A third wave began in the mid-1990s, extending the methodology and results of earlier work in several ways. To begin with, stimuli were often more complex and realistic: images of real-world scenes or dynamic events were used in place of simple figures. Next, changes were often repeated rather than occurring just once, allowing the use of time as well as accuracy to measure performance (Figure 1). Third, blindness was induced via several new kinds of manipulation, such as making changes during a film cut or during the appearance of sudden splats elsewhere in the image. Finally, all these effects – as well as the earlier ones – were accounted for by the proposal that attention is necessary to see change. This work therefore showed that this CB is a general and robust phenomenon that can last for several seconds, and can be connected to known perceptual mechanisms. As such, it supported the idea that change perception is an important part of perception, and that studying its failure can cast light on mechanisms central to our experience of the world.

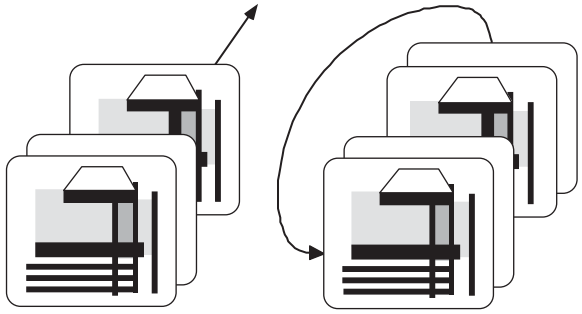


Figure 1 Example of a technique to induce CB. Here the change is made during a brief gap between the original and the modified stimulus. (a) One-shot paradigm. A single alternation of the stimuli is used, and the observer must respond to it. Performance is measured by accuracy of detection (or identification or localization). (b) Flicker paradigm. Stimuli are continually cycled until the observer responds. Performance is measured by the time taken until the change is detected (or identified or localized). Both types of measurement paradigm can also be applied to other techniques, such as changes made during saccades or splats.

Conceptual Distinctions

A clear understanding of CB – and its inverse, change perception – has been slow to emerge. This is partly due to the nature of change itself. Although this concept appears simple, attempts to formalize it over the years – from the earliest Greek thinkers to modern philosophers – have

Author's personal copy

generally encountered difficulties. However, a number of important distinctions have become clear, which have helped our understanding of CB.

Change versus motion

The human perception of temporal variation is handled by two separate systems: a motion-detection system for variation in regards to a particular location and a change-detection system for variation in regards to structure. Temporal variations in the world activate both systems to some extent. For example, a moving automobile will activate motion detectors over the relevant part of the visual field, although these will not be able to determine whether there is an enduring spatiotemporal structure that remains constant. Conversely, a whirling dust devil will be seen as a coherent moving structure, even though there is nothing beyond the flow of dusty air in space. The key challenge in perceiving motion and change is to separate out the contributions of these two systems, so that temporal variation is assigned to the correct substrate.

Change versus difference

Another important distinction is that between change and difference. In both cases, reference is to a particular structure – an object or event of some kind. However, while change refers to transformation of a single structure, difference refers to the comparison of two or more separate structures.

More precisely, change is based on the properties of the same structure at separate points in time, and can be perceived as a single dynamic visual event. For example, when a person is seen walking, their legs are seen at various positions over time. This kind of perception suggests – although does not prove – that the underlying representation has a spatiotemporal continuity of some kind. In contrast, difference is based on an atemporal comparison of structures that may or may not exist simultaneously, for example, comparing the height of two people. This kind of perception allows for the possible involvement of long-term memory elements that are only intermittently engaged.

This distinction is important. Change detection and difference detection can be distinguished, at least conceptually; it is important to consider the type of experiment used when discussing either one. Spotting the difference between two side-by-side stimuli may not engage the same perceptual mechanisms as detecting a change in successively presented stimuli. Failure to make this distinction can lead to erroneous conclusions being drawn about the mechanisms involved.

Experimental Approaches and Results

All studies to date have been based on much the same design: an initial stimulus is first presented (e.g., a picture), an altered version is then shown (e.g., some object in it is removed), and the ability of the observer to perceive the change is then measured (see **Figure 1**). Various aspects of perception have been explored in this manner based on particular selections among a relatively small set of design parameters.

Type of task

CB is the failure to perceive a change. Since there are several different aspects to perception, there can be – at least in principle – several different kinds (or levels) of blindness. These can be investigated by giving the observer the appropriate kind of task:

- Detection. This is the most basic and the most widely studied aspect, concerned with the simple noticing of a change. No properties of the change itself are necessarily perceived: the observer is simply asked to report whether it occurs.
- Identification. This concerns reporting the properties of the change, that is, seeing what type it is (e.g., a change in color, a change in orientation). This can in principle be separated from detection: the observer could be asked to guess the type of change even if the change itself was not detected. Identification of change appears to be more difficult than detection, indicating that somewhat different mechanisms are involved.
- Localization. This is concerned with reporting the location of the change. This can be decoupled from detection and from identification, at least in principle. Relatively little work to date has been done on this aspect of perception. Some results suggest that a separate memory for location may exist, although this has not yet been fully established.

Author's personal copy

Type of response

Another way to engage different mechanisms is to use different aspects of the response of an observer to a change in the external world. These effectively test different perceptual subsystems:

- Explicit percept. This is the approach used in most perceptual experiments, involving the conscious visual experience of the observer. A high degree of blindness can usually be induced. The proposal that attention is needed to see change is concerned with this type of experience.
- Semiexplicit percept. Some observers can have a 'gut feeling' for several seconds that change is occurring, even though they do not yet see it (i.e., do not have a picture of it). The basis of this is controversial, but it may involve nonattentional or subattentional systems.
- Implicit percept. Change that is not experienced consciously may still be perceived implicitly. If so, this must be measured by its effect on other processes. For example, some studies indicate that an unseen change can influence forced-choice guessing about its possible location. The existence of this form of perception is controversial, although evidence for it appears to be increasing.
- Visuomotor response. This involves the response of a visually guided motor system to a change that is not consciously experienced. Systems used are almost always manual pointing or eye fixation. Both kinds of visuomotor response are faster than consciously mediated ones. They also appear to be more accurate, suggesting the existence of representations with higher-capacity memory.

Attentional manipulation

A central tenet in change perception is that attention is needed to consciously experience change. In normal viewing, the local motion signals accompanying a change attract attention to its location, allowing the change to be seen immediately; this is why it helps to wave at a friend from across the room. If these local signals can be neutralized so that the automatic drawing of attention cannot help, a time-consuming attentional scan of the display will be needed. The observer will consequently be blind to the change until attention is directed to the appropriate item. A variety of techniques have explored this:

- Gap-contingent techniques. The change is made during a blank field or mask briefly displayed between the original and altered stimulus, which swamps the local motion signal (see **Figure 1**). Observers are very poor at detecting change if more than a few items are present; results suggest only 3–4 items can be seen to change at a time.
- Saccade-contingent techniques. The change is made during a saccade of the eyes. Observers are generally poor at detecting change if more than a few items are present; again, a limit of 3–4 items is found. CB can also be induced for position change with even one item present, provided no global frame of reference exists.
- Blink-contingent technique. The change is made during an eyeblink. Again, observers are generally poor at detecting such changes. Interestingly, blindness can be induced even if the observer is fixating the changing item.
- Splat-contingent techniques. These make the change at the same moment as the appearance of brief distractors (or splats) elsewhere in the image. The blindness induced in this manner is relatively weak, but still exists, showing that it can be induced even when the change is completely visible.
- Gradual-change techniques. Here, the transition between original and altered display is made slowly (e.g., over the course of several seconds). Observers generally have difficulty detecting such changes, even though no disruptions are used.

The results from all these approaches are consistent with the proposal that attention is needed to see change. The finding that at most 3–4 items can be seen to change at a time is consistent with the capacity of attention obtained via other techniques such as attentional tracking.

Perceptual set

An important part of perception is the perceptual set of the observer, which strongly affects the mechanisms engaged for a given task. The issue of set is important for the question of which

Author's personal copy

mechanisms are involved in everyday vision, and how these are related to performance as measured in the laboratory:

- Intentional set. Observers are instructed to expect a change of some kind. They are assumed to devote all their resources to detecting the change, which provides a way to determine perceptual capacities. A further refinement is controlling expectation for particular types of change. Changes for presence and location are not affected by expectation of type, whereas changes for color are.
- Incidental set. Observers are given some other task as their primary responsibility (e.g., count the number of sheep in an image); there is no mention of a possible change until after the task is over. The engagement of perceptual mechanisms is believed to be more representative of their use in everyday life. The degree of blindness found under these conditions is higher than under intentional conditions, indicating that relatively little is attended – or at least remembered – in many real-life tasks.

Implications for Perceptual Mechanisms

At one level, CB is an important phenomenon in its own right: among other things, it illustrates the extent to which we can potentially miss important changes in everyday life. Indeed, most people are unable to believe the extent to which they are unable to see change – in essence, they suffer from 'CB blindness.'

However, CB itself can also be harnessed as a powerful tool to investigate the mechanisms by which we see. The exact conclusions obtained from such studies are still the subject of debate, but their general outlines are becoming clear.

Visual attention and short-term memory

All experiments on CB are consistent with the proposal that attention is needed to see change. Experiments on carefully controlled stimuli suggest that 3–4 items can be seen to change at a time, consistent with the limit on attention obtained via other techniques, such as attentional tracking.

However, while a limit of some sort is involved, the nature of this limit is still somewhat unclear. Contrary to subjective impression, change perception is not an elementary process. Instead, it involves – at least in principle – a sequence of several steps: enter the information into a memory store, consolidate it into a form usable by subsequent processes, hold onto this for at least a few hundred milliseconds, compare it to the current stimulus at the appropriate location, clear the memory store, and then shift to the next item. A limit on any of these steps would limit the entire process, making it difficult to determine the relevant step in a given situation.

Most proposals for mechanisms have been couched in terms of either visual attention or vSTM. Both are similar in the results they cite and the mechanisms they propose. Part of this is caused by the extensive overlap that appears to exist between the mechanisms associated with attention and vSTM. Indeed, the difference may be largely one of terminology, caused by the vagueness in the definition of attention. As used in CB studies, attention is defined by the formation of representations coherent over space and time; such representations are not that different from those posited as the basis of vSTM.

In any event, interesting new issues are emerging. One is whether the limiting factor applies to the construction of the coherent representation, or to its maintenance once it is formed, or perhaps both. Another issue is the nature of the elements that are attended and held in vSTM. Much evidence suggests that these are proto-objects that already have a considerable local binding of features; if so, the function of attention and vSTM would be to create a representation with extended spatial and temporal coherence. Results also suggest that the 3–4 items are not independent, but, rather, may have a higher level of interaction such that their contents are pooled into a single collection point (or nexus) that supports the perception of an individual object.

Scene perception

Given that only a few items may have a coherent representation at any time, our subjective impression of seeing everything that happens in front of us cannot be correct. But care must be taken in the particular inferences drawn. Since it deals only with dynamic quantities, CB cannot say anything

Author's personal copy

about the static information that may or may not be accumulated. On the other hand, it does show the existence of severe limits on the extent to which changes are represented in those subsystems accessible to conscious perception.

To account for the impression that we see all the changes that occur in front of us – not to mention that we can actually react to many of these – it has been proposed that scene perception is handled by a virtual representation. Here, coherent representations of objects – needed for change perception – are created on a 'just in time' basis, that is, formed whenever they are needed for a task and then dissolved afterward. Coordination of this process can be achieved via a sparse schematic representation of the scene – perhaps a dozen or so items, each with some properties – formed independently of the coherent representations. Guidance could be done on the basis of both high-level factors (e.g., schemas that enable testing of expected objects) and low-level factors (e.g., motion signals that draw attention to unexpected events). All results on CB are consistent with this proposal, and results from other areas (e.g., research on eye movements) appear consistent with this as well.

The status of static scene information is still unclear. In principle, it could be accumulated to create a dense description that would match our subjective impression. However, such accumulation is unnecessary: a virtual representation could handle most if not all aspects of scene perception. Furthermore, no results to date have clearly shown storage of information beyond the relatively sparse information used for guidance and the contents of attention and vSTM. Some information about the prior state of a changed item appears to be stored in a longer-term memory not used for the perception of change; the amount of this is information not known. More generally, many scenes might be stored in long-term memories of various kinds, but the information density of each could still be quite low – perhaps a relatively limited amount of information from each of a dozen or so locations.

Whether the dynamic element is total or partial, it nevertheless plays an important role in each individual's perception of a given scene. CB has therefore been useful as a tool to investigate individual differences in perception: the faster a change is detected, the more important it is deemed to be. Studies have shown an effect of training – including culture – on the encoding of objects and the importance attached to them, along with an influence of the particular task undertaken. There is also an emerging connection here with the design of interactive visual interfaces: these owe much of their success to the engagement of these dynamic mechanisms, and are therefore subject to many of the same considerations regarding operator and task.

Inattentional Blindness

Background

It has been known for thousands of years that people engaged in deep thought can fail to see something directly in front of their eyes. Such blindness can be easily induced when an observer intensely attends to some event, for example, waiting to see if an oncoming automobile will stop in time. Under such conditions, much of the visual field can effectively disappear from consciousness, even if it contains objects that are highly visible. It was long believed that such blindness might be due to the image of an unseen object falling onto the periphery of the eye, which is relatively poor at perceiving form. But decades of research have shown that location is unimportant – the key factor is attention.

One of the earliest lines of research that encountered this IB was the study of head-up displays for aircraft pilots, which superimpose instructions and information over a view of the external world. Simulator studies in the early 1960s discovered that when pilots carried out difficult maneuvers requiring attention to outside cues, they did not see the unexpected appearance of instructions to alter course. Later studies showed the converse effect: if pilots focused on the displayed instructions, they often failed to see highly visible aircraft unexpectedly rolled out onto the runway in front of them.

The first perceptual studies to investigate this effect took place in the 1970s. These used selective looking tasks, where observers were presented with two superimposed visual events (e.g., a sports game and the face of someone talking) and asked to attend to just one of these. Results showed that observers could easily report what happened in the attended event, but did not do well in the other:

Author's personal copy

they often missed large unexpected events, such as the appearance of a woman carrying an umbrella. This happened even when the unseen stimulus was in the center of the visual field, showing that the cause of this blindness effect was not optical, but attentional.

Although this effect was surprising, the use of superimposed stimuli caused it to be considered somewhat artificial, and interest in it never really developed. But in the 1990s a new wave of studies did manage to kindle interest. These differed from the earlier studies in several ways. First, they used opaque rather than superimposed (or transparent) stimuli, greatly reducing concerns about artificiality. Indeed, it was found that even large unexpected events – such as the appearance of a human in a gorilla suit – were still not noticed by most observers under these conditions. Second, in addition to videos of events, techniques were also developed based on brief-presented static images (**Figure 2**), which showed that IB could apply to both static and dynamic stimuli. Third, simple stimuli were often used in both the static and dynamic case, allowing more experimental control. And finally, there was greater examination of the effects caused by the stimuli that were not seen consciously. Together, these developments showed that IB could indeed occur in everyday life, and that the mechanisms involved play a major role in everyday perception.

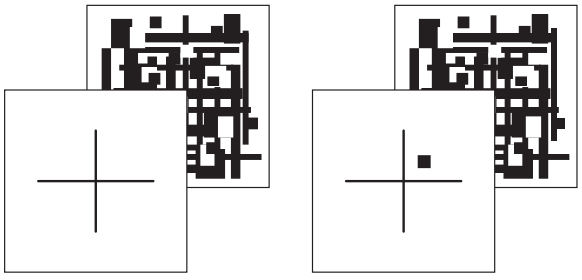


Figure 2 Example of a technique to induce IB. A static test stimulus is presented while visual attention is focused on a primary task; here, the task is to report which of the two lines is longer. (a) Noncritical trial. The primary lines alone are presented for 200 ms, followed by a mask to prevent further processing. The observer must report which is the longer line. Two or three such trials are usually given to allow the observer to get into the appropriate mental state. (b) Critical trial. Along with the primary lines, an unexpected test stimulus is presented nearby. Blindness is measured by detection (or identification or localization) of the test stimulus. An additional round of trials is often presented, in which the test stimulus is now expected; this is believed to correspond to a condition of divided attention.

Conceptual Distinctions

Work on the theoretical and experimental aspects of IB have emphasized several conceptual distinctions. Some apply not only to IB but are also relevant to more general issues of awareness.

Expression versus suppression

Given that attention is needed to see something (i.e., consciously experience it), two general possibilities exist as to how it acts. First, attention might cause selected stimuli to be expressed consciously, for example, they enter awareness by being activated so as to exceed some threshold. In this view, attention does not just facilitate the conscious perception of a stimulus – it also enables it. On the other hand, attention might act to selectively suppress some of the stimuli, so that they vanish from the conscious mind. (In both cases, the status of unattended items is open: they might be weakly expressed in some way, or available implicitly.) It is worth noting that the two possibilities are not exclusive: it could be that both are used, with attention acting to express – or at least emphasize – some items while suppressing others.

Restricted versus unrestricted effects

A related issue is the extent of any expression or suppression. It was once believed that everything registered in the visual system was experienced consciously. However, given that implicit perception of various kinds has been found, an important issue is whether the selective effects underlying IB are restricted to conscious experience, or whether they spill over to other aspects of perception.

For example, results show that attentional inhibition of a given location will increase the amount of blindness there. But does such inhibition attenuate the input strongly enough to also affect implicit processes at that location? Virtually all studies to date have assumed that selective effects are restricted to conscious experience, but this assumption has not been tested.

Author's personal copy

Experimental Approaches and Results

At the most general level, all studies of IB use the same basic approach. An observer is given a primary task that engages their visual attention, an unexpected test object (or event) then appears in the display, and the response of the observer to that appearance is then tested. Because expectation is an important factor, several trials without a test stimulus are generally presented first. Results are taken from the trial in which the test stimulus first appears (the critical trial). After this, the object is no longer entirely unexpected, and the blindness levels in subsequent trials are usually much lower, consistent with the idea that attention is now divided among the expected stimuli.

Type of task

As in the case of CB, several different aspects of perception can be distinguished, each of which can be tested by appropriate selection of task:

- Detection. This is the most basic aspect of perception, concerned with the simple noticing of something present; no properties of the stimulus itself need be involved. For isolated static items that are small, that is, have an extent of less than about 1° of visual angle, observers often fail to see anything at all in conditions that induce IB. For larger items, however, detection remains generally good. For dynamic events, informal observations suggest that the unattended event does not necessarily disappear entirely – observers often notice 'something else' going on, but cannot say what it is.
- Identification. This is concerned with determining various properties of the stimulus. For example, observers can be asked to report the color or location of an item; in principle – although not often in practice – this can be done whether or not it was detected. Observers can usually report the color of a small item that is detected; identification of shape appears to be more difficult. Detection without identification has been reported, but it has been suggested that these are simply false positives.
- Localization. Here, the task is to locate the test stimulus that appears in the critical trial. In principle, this can be tested independently of detection and identification, although this is rarely done. Observers are able to report the location of a small item that is detected, showing that there may be some interaction between these two aspects of perception.

Type of response

Performance can also be studied in terms of the kind of percept experienced. Operationally, this can be done by testing different aspects of the observer's response to the appearance of a stimulus. These different aspects effectively involve different perceptual subsystems:

- Explicit percept. This is the kind of percept used in most IB experiments. The observer is asked to respond to their conscious experience, that is, the picture they have of something. The usual definition of IB is in terms of the failure to have such an experience; the proposal that attention is needed to see is likewise concerned with this aspect.
- Implicit percept. Items that are not experienced consciously may still be perceived implicitly. Given that the observer is blind to the stimulus, responses cannot be measured via direct subjective experience; they must instead be based on indirect effects. For example, relatively little blindness is found for emotionally laden words or pictures. This suggests that such words have been perceived implicitly, with attention drawn to them on the basis of their meaning. Similarly, a length illusion can occur in a set of lines perceived consciously, even if the background lines that induce the illusion are themselves not reported.
- Motor response to primary task. The response to the appearance of a test stimulus can be measured by its effect on the speed or accuracy of the primary task. This is essentially the approach developed to study attention capture, which measures the effect of a new item on motor response times for the main task, regardless of whether the new item is seen. (An interesting variation would be to determine if such effects are conditional on the experiential state of the test stimulus.)
- Visuomotor response. Here, the appearance of an item causes the eye to move toward it. This is another approach developed in the area of attention capture; again, this response is measured

Author's personal copy

regardless of whether the item is seen. This might be useful for studying IB if measurement were made conditional on whether the test stimulus is consciously experienced.

Attentional manipulation

An important factor in inducing IB is to present the test stimulus while the observer has their visual attention engaged on an unrelated task. This has been done in several ways:

- Superimposed stimuli. Two independent dynamic events (e.g., a basketball game and two pairs of hands playing a game) are presented simultaneously. In earlier studies, this was often done via half-silvered mirrors; more recent studies do this electronically. The result is perceived as a set of transparent or ghostly images. Observers can easily attend to one of these, but can often miss events in the other.
- Interspersed stimuli. Here, two different sets of stimuli are presented; all are opaque and appear on the same display (see **Figure 2**). Tests on static stimuli generally use this method. Observers are asked to carry out a primary task on one of the sets (e.g., make a length judgment on a pair of lines); a test stimulus is presented near these lines a few trials later. Dynamic events have also been tested this way. A high degree of blindness can be found, even when the items in the two sets of stimuli are intermingled.
- Dichoptic presentation. Here, two independent events are presented, each to a different eye; the observer is asked to pay attention to one of them. Events in the unattended eye often fail to be reported. In contrast with superimposed stimuli, where observers often have an impression of 'something else' going on, observers here fail to experience anything of the unattended set – it is simply not there. This may be related to the blindness experienced in binocular rivalry suppression.

Perceptual set

An important aspect of IB is the perceptual set of the observer. There are several ways this could influence performance:

- Control of selectivity. This is the extent to which selection – either expression or suppression – is invoked in the primary task. For example, observers can be required to attend only to the white-shirted players in a game, while ignoring the black-shirted players. In such tasks, blindness appears to be due at least in part to observers suppressing the features of the ignored stimuli: the greater the similarity of the test item to the ignored items, the greater the blindness. In non-selective tasks, there is no need to screen out any stimuli, at least up to the critical trial. Blindness is still induced here, but it remains unknown whether this is due to a failure of expression or an invocation of suppression.
- Control of capture. It has been suggested that high-level control may be exerted over the kind of stimuli that can capture attention, and thus be seen. Attention is usually drawn by the appearance of a new item or by the presence of a unique property. However, work on attention capture has shown that this can be overridden by a high-level attentional set. Results on IB are consistent with the proposal that an attentional set governs what is consciously seen, with distinctive stimuli experienced consciously only if they fit into the observer's expectations.

Implications for Perceptual Mechanisms

The finding that observers can often fail to see highly noticeable objects and events touches on several issues concerning the way we cope with our world. For example, it suggests that we might not be aware of the extent to which we fail to see various aspects of our immediate environment, even if these are important and highly visible. (This might be termed IB blindness.) This has obvious implications for tasks such as driving, where the ability to accurately perceive objects and events is literally a matter of life and death, and where knowing about our limitations could well affect how careful we are.

Meanwhile, work on IB can also tell us about the mechanisms involved in visual perception. In particular, it can provide a unique perspective on the mechanisms that underlie our conscious experience of the world.

Author's personal copy

Visual attention

All results to date are consistent with the proposal that attention is needed to see an object or event. For example, the degree of blindness has been found to increase with distance from the center of the attended location, in accord with space-based models of attention. In addition, the greater the attentional load of the primary task, the greater the blindness to the test stimulus, which is consistent with the proposal of a limited attentional capacity. Indeed, the inability of an observer to follow more than one coherent event supports the proposal that only one complex object or event can be attended at a time.

Results also provide tentative support for the proposal that the high-level control of attention is achieved via an attentional set which determines the kinds of information that can capture attention, and perhaps also the kinds of information that can enter conscious awareness. This development potentially connects work on IB to work on attention capture.

Another possible connection is with preattentive vision, usually studied by the rapid detection (or pop-out) of unique items in a display. Work here has pointed toward a considerable amount of processing achieved in the absence of attention. But this assumes that little or no attention is given to most items in a display at any moment. Results on IB suggest that this supposedly inattentional condition may be better viewed as a case of diffuse attention, with the inattentional condition characterized as one where no conscious perception exists.

However, there are several findings that make these connections less than certain. For example, an observer in an IB experiment can usually detect the individual items in a group, although the grouped pattern itself cannot be identified. In addition, the pop-out of a unique item in a group occurs only if the group appears in the critical trial; if this group is shown earlier in noncritical trials (with the unique item the same as the others), pop-out no longer occurs. So what is the effect of the unique item here? If it is to draw attention to the group, why are the individual elements already seen in the earlier, noncritical trials? And why should pop-out occur in one condition, but not the other?

Scene perception

Relatively little work has studied the aspects of natural scenes perceived under conditions of inattention. Studies using briefly presented scenes as test stimuli found that observers could usually report the scene gist (i.e., its overall meaning, such as being an office or a forest), along with several objects of indeterminate description. Some confabulation is also found. This is broadly similar to results on the ability of observers to rapidly perceive the gist of scenes from brief exposures of 100 ms or less, which is also likely done with little or no focused attention.

Individual differences in the coding of scenes and events can be measured in terms of how blindness varies with the primary task. For example, experts in basketball could better detect the appearance of an unexpected object while they were attending to a basketball game. This suggests that they had encoded the scenes and events in a way that allowed them to divert some of their attention to occasionally monitor other items, without seriously affecting performance on the primary task.

The model of scene perception often used to account for results on IB is the perceptual cycle. Here, sustained attention is believed to activate the conscious percept of a stimulus; once this has been done, the stimulus has entered the cycle, and helps select the appropriate schema to determine what information to admit next. In contrast, stimuli that do not become part of the predictive cycle may never be seen at all. Such stimuli – especially low-level signals – can guide the process, but do not enter awareness on their own. Similarly, information assembled at a preattentive level can also guide this process, although it too does not enter awareness automatically. This model has some similarities to the dynamic scene representation often used to account for CB, as well as the reentrant models used to account for conscious experience.

General Issues

Change Blindness versus Inattentional Blindness

CB and IB both involve a failure to perceive things that are easily seen once noticed, and both are

Author's personal copy

believed to be due to a lack of attention. It is therefore likely they are related. But exactly how?

First of all, the difference between CB and IB does not depend on the kind of input. Both can be found using dynamic images, and both can be found using static images. And the particular contents of the input do not matter for either. Instead, the critical difference between the two is the status of the information under consideration. IB is entirely concerned with first-order information – the simple presence of quantities. In contrast, CB involves second-order information – the transitions between these quantities. These can be separated: an alternating sequence of two images, say, could be experienced as a 50% presence of each image over time (same first-order distributions), but with different amounts of change (different second-order distributions) if the alternation rates are not the same. And just as CB can say little about first-order (static) information, IB can say little about second-order (changing) information. The two therefore refer to largely complementary aspects of the visual world.

This distinction has consequences for the perceptual mechanisms involved. For example, the kind of attention required for each aspect of perception may be different – or at least, have different effects. The kind of attention involved in IB is space based: the degree of blindness increases with increasing distance from the center of attention. It is also easily diverted – hence the common use of a test stimulus that is completely unexpected. In contrast, the kind of attention needed to perceive change is object-based and is much less easily diverted (or at least slower), since telling the observer that a change will occur – and even giving them practice at perceiving it – does not affect performance to any great extent. Loosely speaking, IB might be identified with the absence of diffuse attention, and CB with the absence of focused attention. But a final determination of this must await a better understanding of attention itself.

Blindness versus Amnesia

An important issue in regards to the status of these induced failures is whether they are failures of perception or of memory. It might be, for instance, that an observer did experience something under conditions that induced CB or IB, but then forgot it before they could make their report. If so, these effects would not be forms of blindness, but forms of amnesia.

In the case of CB, the resolution of this issue is reasonably straightforward. Perception of change is often measured by asking the observer to respond to the change as soon as they see it; all that is needed to trigger this is a minimal conscious experience. When observers are asked to respond to a single change, only a few hundred milliseconds exist between its presentation and the initiation of the report (e.g., the pressing of a button). Thus, if the experience of change is forgotten in the absence of attention, it would be exceedingly brief and incapable of causing a response to be initiated. To all intents and purposes it would be as if it never existed, at least at the conscious level. (Note that if taken seriously, the possibly of such a fleeting perception would not be restricted to CB – it would apply to any failure of perception.)

The situation for IB is more complex. In one sense, this issue was resolved by the finding that unattended – and thus unseen – items are indeed perceived, in that they can indirectly affect aspects of conscious experience. Entry into conscious experience itself, however, is not addressed by this. The observer is usually asked about a possible item only after the primary task has been completed, which allows several seconds to possibly forget it. And, the observer cannot be asked to prepare to respond to the test stimulus, since this sets up an expectation of the item, which severely diminishes the attentional diversion, and thus the degree of blindness.

This issue has been grappled with in several ways. One is to present a highly surprising or meaningful item, and hope that the observer will spontaneously report it. However, this has not generally been successful: even if a human walks around in a gorilla suit or if an airplane is wheeled out onto the runway where the pilot is about to land, most observers still do not respond. It has been proposed that the observers do see the visual elements, but do not assign meaning to them. In essence, this phenomenon becomes one of inattentional agnosia. (This may explain the reports in some selective looking experiments, where observers see 'something else' going on, but do not know what it is.)

Author's personal copy

Another perspective derives from studies of the neural systems involved. Patients with lesions to particular parts of the cortex can suffer conditions such as neglect and extinction, in which attention cannot be easily allocated to objects. Such patients, however, do not appear to experience forgetting – they simply do not report perceiving such stimuli, even when asked with the object in full view. In addition, functional imaging of the brains of normal observers shows that words are not consciously identified in the absence of attention, even if the observer is looking directly at them. These results make it highly likely that the failure is one of perception, and not memory.

Visual Attention versus Visual Experience

CB and IB can be regarded as two forms of the perceptual failure created by the diversion of attentional resources. They can be distinguished at the functional level by the type of information involved (second- or first-order information, respectively). They also appear to be distinguished by the type of attention involved (focused or diffuse) and the kinds of operations (e.g., comparison) associated with these. This division may correspond to the two modes sometimes proposed for conscious visual experience: an object mode associated with focused attention and a background mode operating as default. Beyond this, however, only partial and tentative conclusions can be drawn regarding the issue of how visual attention relates to conscious visual experience.

In the case where attention of any kind is absent, there does not appear to be any conscious experience of stimuli (second-order quantities for focused attention; first-order quantities for diffuse). However, results still point to a considerable amount of processing being carried out. For example, work on IB indicates that unattended – and therefore unseen – items can influence the perception of attended items. Similarly, some models of CB posit low-level representations with a degree of detail and feature binding (proto-objects) that are formed in the absence of this kind of attention.

It is worth pointing out that observers in IB experiments often report that they can detect something about the nonselected stimuli, even though they cannot always identify it. Importantly, this kind of experience is found only in those experiments involving superimposed or interspersed stimuli; for dichoptically presented stimuli, there is a complete absence of perception of the nonselected event. This suggests that in the superimposed and interspersed conditions diffuse attention is given to nonselected events, with the main event given focused attention. If so, this would suggest that identification and localization may require more focused attention (or related resource), and that both diffuse and focused attention may be allocated simultaneously to different stimuli.

This proposal would be consistent with work on CB. Focused attention is needed only for the perception of complex quantities such as change; background items not given focused attention might still be seen, but only in regards to detection and perhaps a limited form of identification based on relatively fragmented pieces of static items.

Conclusions

Work on CB suggests that focused attention is needed for the conscious experience of change: without it, observers will be blind to even large changes, at least at the conscious level. Some ability to implicitly perceive change may exist; if so, this does not appear to require focused attention.

Similarly, work on IB suggests that diffuse attention is needed to detect an unexpected object or event, that is, to see it as 'something.' Some results indicate that further (attentional) processing may be needed to more completely identify or locate it. There also appears to be some ability to pick up and process information about static items in the absence of any form of attention, even though such items are not experienced consciously.

Beyond this, our current understanding is poor. More work is needed to expand our empirical knowledge of the basic phenomena. More work is also needed on the basic conceptual issues involved, in particular, on our understanding of terms such as attention and awareness. However, much exciting progress is being made on these fronts. And some of the most powerful sources of these new developments are the phenomena of CB and IB.

Author's personal copy

See also: Attention: Selective Attention and Consciousness; Neglect and Balint's Syndrome; Perception: Unconscious Influences on Perceptual Interpretation.

Suggested Readings

Brockmole JR and Henderson JM (2005) Object appearance, disappearance, and attention prioritization in real-world scenes. *Psychonomic Bulletin & Review* 12: 1061–1067.

Irwin DE (1991) Information integration across saccadic eye movements. *Cognitive Psychology* 23: 420–456.

Levin DT (2002) Change blindness blindness as visual metacognition. *Journal of Consciousness Studies* 9: 111–130.

Luck SJ and Vogel EK (1997) The capacity of visual working memory for features and conjunctions. *Nature* 390: 279–280.

Mack A and Rock I (1998) *Inattentional Blindness*. Cambridge, MA: MIT Press.

Moore CM and Egeth H (1997) Perception without attention: Evidence of grouping under conditions of inattention. *Journal of Experimental Psychology: Human Perception and Performance* 23: 339–352.

Most SB, Scholl BJ, Clifford E, and Simons DJ (2005) What you see is what you set: Sustained inattentional blindness and the capture of awareness. *Psychological Review* 112: 217–242.

Neisser U and Becklen R (1975) Selective looking: Attending to visually significant events. *Cognitive Psychology* 7: 480–494.

Rensink RA (2002) Change detection. *Annual Review of Psychology* 53: 245–277.

Rensink RA, O'Regan JK, and Clark JJ (1997) To see or not to see: The need for attention to perceive changes in scenes. *Psychological Science* 8: 368–373.

Simons DJ (ed.) (2000) *Change Blindness and Visual Memory.* Hove, East Sussex, UK: Psychology Press.

Simons DJ and Chabris CF (1999) Gorillas in our midst: Sustained inattentional blindness for dynamic events. *Perception* 28: 1059–1074.

Simons DJ and Rensink RA (2005) Change blindness: Past, present, and future. *Trends in Cognitive Sciences* 9: 16–20.

Wilken P (ed.) (1999) Mack & Rock: Inattentional blindness. *Psyche* 5–7. http://psyche.cs.monash.edu.au/symposia/mack_rock/.

Wolfe JM (1999) Inattentional amnesia. In: Coltheart V (ed.) *Fleeting Memories*, pp. 71–94. Cambridge, MA: MIT Press.

Biographical Sketch

Ronald A Rensink is an associate professor in the Departments of Computer Science and Psychology at the University of British Columbia (UBC). His interests include human vision (particularly visual attention), computer vision, and human–computer interaction. He has presented work at major conferences and in major journals on visual attention, scene perception, computer graphics, and consciousness. He received his PhD in computer science (in computer vision) from UBC in 1992, and was then a postdoctoral fellow for 2 years in the psychology department at Harvard University. This was followed by a position as a research scientist at Cambridge Basic Research, a laboratory sponsored by Nissan Motor Co., Ltd. He returned to UBC in 2000, and is currently a part of the UBC Cognitive Systems Program, an interdisciplinary program that combines computer science, linguistics, philosophy, and psychology.