Part VI

Major Topics in the Science of Consciousness

Topics in the Cognitive Psychology of Consciousness

38

Studying Consciousness Through Inattentional Blindness, Change Blindness, and the Attentional Blink

Michael A. Cohen and Marvin M. Chun

A central topic in consciousness studies concerns the role of attention. However, in order to discuss the relationship between attention and consciousness, it is important to first establish what we mean by the terms "consciousness" and "attention." Unfortunately, both of these terms have proven to be exceptionally difficult to define in a concise manner. Indeed, there is substantial debate concerning which cognitive and neural processes should be associated with conscious awareness and which processes should be associated with unconscious processing (Block 2011; Cohen & Dennett 2011). For the purposes of this chapter, when discussing consciousness, we refer to information that results in a subjective experience (e.g., consciously perceiving a particular color or objects) (Dehaene & Changeux 2011) and that can be consciously and overtly reported. When discussing "attention," we refer to the cognitive process that selects certain bits of information for further processing at the expense of others. Of course, attention itself is not a singular process. For example, attention can be directed outwardly to external stimuli (e.g., the voice of a speaker, the road ahead when driving a car, etc.), but it can also be directed inwardly to internal information (e.g., recalling a bit of trivia, retrieving a specific memory, etc.) (Chun, Golomb, & Turk-Browne, 2011). In the visual modality alone, attention can operate upon basic features such as color and motion, objects, multiple spatial locations, and points in time. Therefore, when considering the relationship between attention and consciousness, it is important to recognize the multifaceted nature of attention and the various ways in which it can be deployed.

Over the last few decades, three prominent behavioral techniques have been developed that can manipulate or divert observers' attention to prevent stimuli from reaching conscious awareness: inattentional blindness, change blindness, and the attentional blink. Each of these paradigms has been instrumental in revealing the limits of conscious processing, addressing a variety of foundational questions in consciousness studies: Is attention necessary for consciousness? What are the depths of unconscious processing? Which neural signatures are associated with consciousness? In this chapter, we first briefly describe each of these methods and highlight some of the critical findings. We then discuss how these techniques have informed these questions.

The Blackwell Companion to Consciousness, Second Edition. Edited by Susan Schneider and Max Velmans.

Inattentional Blindness, Change Blindness, and the Attentional Blink

Inattentional blindness – When attention is directly focused on a particular task, event, or object, other aspects of the scene will often go unnoticed. This phenomenon is known as inattentional blindness. Inattentional blindness is caused by the limitations of attention. Since attention has a finite capacity, unattended items will fail to reach consciousness. Initially, inattentional blindness was found with very simple stimuli. Mack and Rock (1998) discovered that participants did not consciously perceive an unexpected item flashed in the periphery when attention was focused on a cross in the middle of the display. However, this phenomenon is by no means limited to relatively simple stimuli. For example, in one famous experiment, participants were asked to count the number of times a group of players in white shirts passed a basketball back and forth while ignoring the number of times a group of players in black shirts passed a basketball. Halfway through the experiment, a man in a gorilla suit unexpectedly walked into the frame, stopped midway, pounded his chest, and then walked off (Figure 38.1). After the trial, a significant number of participants reported that they did not perceive a man in a gorilla suit (Simons & Chabris 1999). Moreover, beyond laboratory settings, inattentional blindness can also be experimentally induced in the real world. In one study, a participant and an experimenter jogged around the campus of a university. During this run, another group of experimenters staged a mock fight in plain view of the participant. Remarkably, a significant fraction of participants failed to notice the fight occurring just a few feet away from them (Chabris et al. 2011).

In addition to demonstrating the important role that attention plays in allowing stimuli to be consciously perceived, the study of inattentional blindness is also important because it reveals the potential of fatal consequences outside of the lab. Perhaps most commonly, inattentional blindness is thought to cause many automobile accidents every

Figure 38.1 Inattentional blindness.

A snapshot of the study in which participants failed to notice a man in a gorilla suit when attending closely to the people wearing white shirts. Simons, D.J. and Chabris, C.F. (1999). Reproduced with the permission of Sage Publications.

day because drivers are paying more attention to other items (e.g., their cell phones, the radio, etc.) than they are to the road (Horrey & Wickens 2006). In addition, inattentional blindness may also impair medical screenings. In one study, trained radiologists looking at familiar medical images failed to notice a small picture of a gorilla placed within patients' lungs (Drew, Võ, & Wolfe 2013). While it is unlikely that a radiologist will ever find a gorilla picture in one of their scans, it is imminently possible that they will fail to miss a target mass (e.g., a tumor) if they are distracted by something else (e.g., a conversation or music in the room). Thus, inattentional blindness is not a phenomenon that is strictly confined to the laboratory; indeed, it is likely that we all commonly experience inattentional blindness in our daily lives, but simply fail to realize it.

While inattentional blindness is a powerful way to prevent stimuli from reaching conscious awareness and yields some of the most interesting results in consciousness studies, it can be a difficult experimental paradigm with which to work. In the majority of cases, after participants have been alerted to the conditions of inattention, they will no longer be susceptible to the same types of inattentional blindness. For example, once alerted to having missed the man in a gorilla suit that walked across the display, participants will subsequently perceive that man in future trials (though they may still fail to notice other novel aspects of the scene, such as a background item changing color (Simons 2010)). Thus, in most situations, experimenters only get one critical trial per subject. For this reason, researchers have relied heavily on other psychophysical techniques that render stimuli invisible to consciousness. Below we discuss two such paradigms: change blindness and the attentional blink.

Change blindness – Change blindness is the failure to notice changes between two images. Similar to inattentional blindness, change blindness appears to be caused by an inability to simultaneously attend to multiple items in the world. When an item is not properly attended to, it is easy to miss changes to that item. Many different types of changes can go unnoticed in this context: objects can appear or disappear, change color, change location, and so forth. The critical factor in causing change blindness is that the change occurs during a brief interruption of perceptual continuity. This interruption can take many forms. In a commonly used paradigm, two pictures with one difference between them alternate back and forth with a blank screen in between them (Rensink, O'Regan, & Clark 1997) (Figure 38.2). However, change blindness can also be caused by eye blinks, film cuts in a video, and even distracting "mudsplashes" if they are presented at the same time as the change (O'Regan, Rensick, & Clark 1999). If, however, attention is directed towards the changing item, participants have no trouble noticing the change.

Change blindness is a useful lab task because you can test multiple trials, as long as each change is novel. However, it still contains an element of uncertainty, since the subject does not know what is changing or where the change is occurring. The final paradigm we discuss below does not involve any of these constraints. Subjects are fully instructed what to look for, and even then, attentional limitations will prevent them from seeing the target. Hundreds of trials can be tested, which is useful for neural investigations of conscious perception.

The attentional blink – The attentional blink is a phenomenon in which the second of two rapidly presented targets is missed when the first target is perceived and correctly identified (Raymond, Shapiro, & Arnell 1992; Chun & Potter 1995). In a typical attentional blink experiment, a participant will see several stimuli (e.g., letters and numbers) presented in rapid succession at the same location in space (i.e., rapid serial visual presentation). On each trial, there will be two items within the stream that are designated as

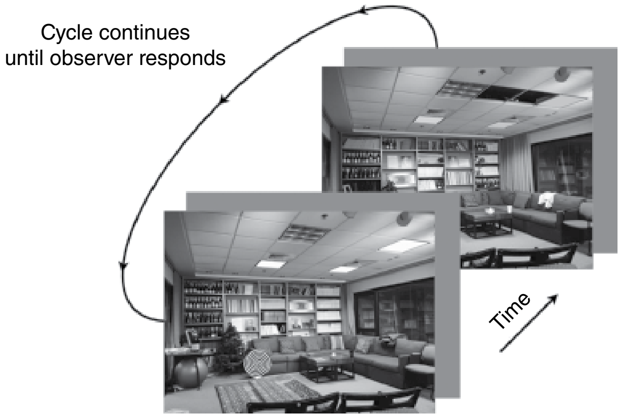

Figure 38.2 Change blindness.
In a standard change blindness paradigm, two images are alternately shown in the same location with a blank gap in the middle until the observer notices the change between the two images. In this particular example, there are several differences between the two displays: ceiling tiles are removed, items on the bookshelf are re-arranged, etc.
Source: Renisnk, R.A., O'Regan, J.K., and Clark, J.J. (1997). Reproduced with the permission of Sage Publications.

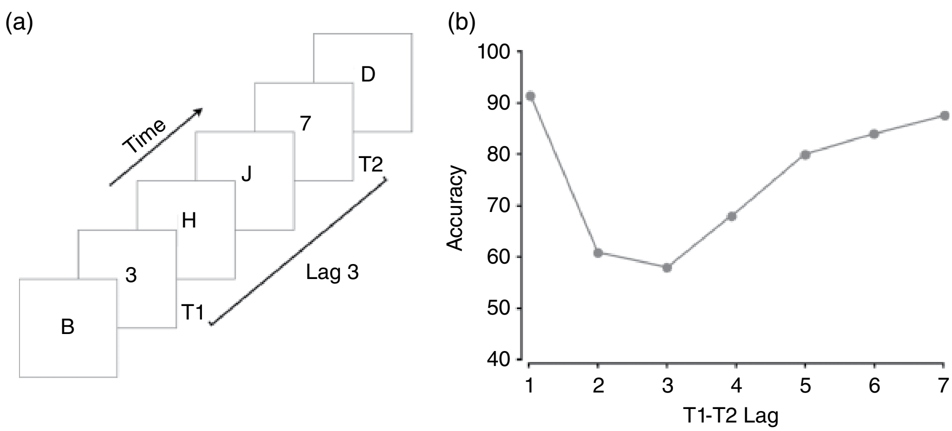

Figure 38.3 (a) Attentional blink.
Depiction of a standard attentional blink trial where the two numbers (i.e., 3 and 7) are the targets with letters as distractors. In this case, since the second target is shown three spaces after the first target, this is a "Lag-3" trial. (**b**) Representation of data commonly obtained with the attentional blink. Accuracy for the second target is presented on the y-axis, while the distance between the two targets is shown on the x-axis.
Source: Chun, M.M. and Potter, M.C. (1995). Reproduced with the permission of American Psychological Association.

the targets. An example trial is depicted in Figure 38.3a where the target items are numbers presented amongst letters. At the end of the trial, participants will report the identity of those two targets. On trials in which the first target is correctly reported, participants will often fail to correctly report the identity of the second target. Performance with the second target is often measured in terms of the number of distracting items that are presented between the first and second targets (i.e., the lag between the two targets). A common depiction of attentional blink data is shown in Figure 38.3b, with accuracy for the second target plotted against the lag between target one (T1) and target two (T2). This graph shows that detection of the second target improves as it appears further away from the first target in time, a signature result of the attentional blink. Another hallmark of attentional blink data is the fact that if the second target is presented immediately after the first target, performance on the second target is largely unaffected by detection of the first target. This phenomenon is referred to as "Lag-1-sparing". Lag-1 sparing occurs because the temporally adjacent items are processed together.

The attentional blink is caused by an attentional limitation rather than a visual limitation. This can be revealed in a task where the first target and second target are cued differently (e.g., the first target is red and the second target is green). In the dual-target condition, subjects have to report both colored targets. In a single target control condition, subjects only have to report the second of the two colored targets (e.g., only report the green target). Thus, the displays are identical in both conditions. Attentional blink is not observed when the first target is ignored, showing that it is an attentional limitation (Raymond et al. 1992; Chun & Potter 1995). While the attentional blink is often studied with simple items, such as letters and numbers, it should be noted that this phenomenon is not limited to a small subset of basic visual stimuli. The same basic findings have been observed with words (Luck, Vogel, & Shapiro 1996), pictures of complex scene (Evans & Treisman 2005), and basic visual features (Joseph, Chun, & Nakayama 1997).

Is Attention Necessary for Consciousness?

While these three paradigms demonstrate the ways in which information can go unnoticed because of attentional manipulations, they have also been incredibly useful in addressing many foundational issues concerning the broader relationship between attention and consciousness. More specifically, are attention and consciousness inextricably linked or can they be dissociated from one another in certain cases (i.e., attention without consciousness or consciousness without attention)? In recent years, it has become generally accepted that attention and consciousness are indeed distinct processes. For example, attention can operate upon or be drawn towards stimuli even though those stimuli are never consciously perceived, which should not be possible if they were one and the same. When attention is directed towards an unconscious stimulus, larger priming effects are associated with that stimulus even though it fails to reach consciousness (Naccache, Blandin, & Dehaene 2002). In addition, stimuli that are rendered invisible by continuous flash suppression can still automatically attract attention (Jiang et al. 2007). Together, these studies show that attention and consciousness are distinct processes and that attention can operate upon stimuli without elevating those items to conscious awareness. While attention can operate on a stimulus without that stimulus reaching consciousness (i.e., attention without consciousness), this does not mean that consciousness does not require attention. We believe that there is no convincing empirical evidence of stimuli reaching consciousness without attention. Thus, while attention and consciousness can be dissociated from one another, it is a one-way dissociation, not a double dissociation (Cohen et al. 2012). To make this argument, we rely on a variety of results using the three paradigms described above.

Those who claim that attention is not necessary for consciousness generally cite three primary results (Koch & Tsuchiya 2007). First, certain stimuli "pop-out" in displays independent of set size (e.g., a red target amongst green distractors, a vertically oriented bar amongst horizontally oriented bars, etc.), suggesting that no attention is required to detect and perceive these items (Treisman & Gelade 1980). Second, images that contain animals and vehicles are thought to reach conscious awareness with little or not attention (Li et al. 2002). Finally, the gist of a scene (i.e., the representation of the broad category of a scene such as beach or highway) is also thought to require no attention to be consciously perceived (Mack & Rock 1998). If it is indeed true that no attention is required for these stimuli, these particular items should be impervious to attentional manipulations. In other words, if a stimulus can reach consciousness without attention, that stimulus should never be missed because of inattentional blindness, change blindness, or the attentional blink.

The challenge for claims of conscious perception without attention is that they rely on null effects. When a target is perceived in the "absence" of attention, it is difficult to conclude that attention is not necessary because it is logically possible that researchers simply failed to remove all attention available to the target. Accordingly, if someone demonstrates that the same target stimuli can go undetected when attention is manipulated in a different way, then one can scientifically conclude that attention is required for conscious perception, at least for the stimulus category at question, such as feature pop-out, animals or vehicles, or the gist of a scene. Indeed, a systematic review shows that all of these stimuli can go unnoticed when tested properly using inattentional blindness, change blindness, or attentional blink. Below, we briefly review the most relevant results.

While basic feature singletons do indeed appear to "pop-out," requiring minimal attention, there is good reason to believe that some attention is necessary to perceive these items. For starters, basic features that traditionally "pop-out" in search tasks are still susceptible to inattentional blindness (Mack & Rock 1998; Most et al. 2005). That is, when attention is focused on another primary task, an observer will fail to notice even the most basic features in a visual display, such as a bright red square amongst black items. In addition, these basic features can also fail to reach consciousness due to the attentional blink. On trials when participants successfully identify the first target, they will fail to detect a second target that is comprised of a "pop-out" display (Joseph et al. 1997). A similar pattern of results has been found with images that contain animals or vehicles; such images can be rendered invisible by both inattentional blindness (Cohen, Alvarez, & Nakayama 2011) and the attentional blink (Evans & Treisman 2005). Finally, while it is not susceptible to change blindness, the gist of a scene (e.g., indoor vs. outdoor) can fail to reach conscious awareness because of inattention (Cohen et al. 2011) and the attentional blink (Marois, Yi, & Chun 2004). Taken together, these results indicate that these supposedly "pre-attentive" stimuli require some amount of attention in order to be consciously perceived. Once again, were it the case that they truly required no attention to reach consciousness, they should be unaffected by inattentional blindness, change blindness, or the attentional blink.

These results indicate that attention is necessary, though not sufficient, for conscious processing. Only items that are attended may reach consciousness (Figure 38.4). Of course, this is not to say that all attended items will reach consciousness – as shown repeatedly above, visual events may be attended without reaching consciousness. In these cases, even though these items failed to reach consciousness, the fact that they have been attended will increase the extent to which they are unconsciously processed and contribute to subsequent priming effects (Naccache et al. 2002).

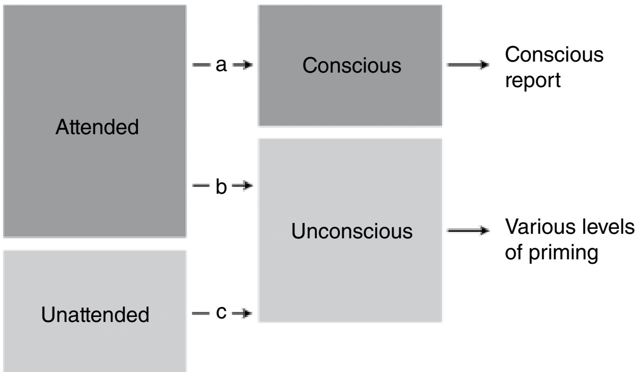

Figure 38.4 Consciousness requires attention.
Graphical illustration of the proposed relationship between attention and conscious awareness. **(a)** Information can only become conscious if it is attended to. **(b)** However, some information that is attended to will still fail to reach conscious awareness. **(c)** Meanwhile, information that is not attended to will always fail to be consciously perceived.
Source: Cohen, M.A., Cavanagh, P., Chun, M.M., and Nakayama, K. (2012). Reproduced with the permission of Elsevier.

To What Extent is Information Processed Unconsciously?

In addition to shedding light on whether or not attention is necessary for conscious processing, inattentional blindness, change blindness, and the attentional blink tasks reveal the extent to which information can be processed unconsciously. Classic models of attention claimed that selection occurs early and unattended stimuli are not processed deeply by the visual system (Broadbent 1958). However, later models stated that attentional selection occurs later and unattended information can nevertheless be thoroughly processed across the visual hierarchy. Lavie's Load Theory (Lavie 2005) has addressed this debate by suggesting that the depths to which unattended information is processed depend on the cognitive load of the system at a given moment. Under this view, when the perceptual load is high, unattended information will be filtered out early on. Meanwhile, when perceptual load decreases, and more cognitive resources are freely available, stimuli will be selected later after having received more perceptual and conceptual processing.

With this long-standing debate in mind, researchers sought to examine the depths of unconscious processing using the three attentional paradigms described earlier, converging on the idea that information that fails to reach conscious awareness can nevertheless be processed to surprising depths that can affect behavior. For example, with inattentional blindness, even though participants fail to notice the target item, there is ample evidence of both perceptual and semantic priming (Mack & Rock 1998). The fact that priming effects are seen at a semantic level suggests that stimuli are not simply processed to a lower level of analysis, but instead are processed to higher levels of conceptual analysis. A similar pattern of results is also found with change blindness. When participants are unable to identify the changing item between displays, some information about the objects before the change is still preserved (Mitroff, Simons, & Levin 2004). Furthermore, asking participants a leading question (i.e., "Did you notice that there used to be something different on the shelves?") helps them "re-discover" changes that they initially failed to notice (Simons et al. 2002). The fact that participants are able to retroactively retrieve this information provides strong evidence that it is processed quite deeply even if it fails to reach consciousness. Together, these results strongly suggest that information that is not consciously perceived is nevertheless processed in the brain to a surprising degree.

While there is ample behavioral evidence of unconscious processing with inattentional and change blindness, there is also neural evidence of unconscious processing, most notably from the attentional blink. Multiple studies have shown that targets that are missed during the attentional blink still activate high-level neural regions and processes. For example, in one study, participants had to first identify a target face and then identify a target scene in rapid succession (Marois, Yi, & Chun 2004). The authors then asked to what extent high-level visual regions, most notably the scene-selective parahippocampal place area (PPA), would respond to images of scenes that were not consciously perceived. Interestingly, even on trials when the scene went unnoticed, it nevertheless elicited significant activation in the PPA. An earlier study used the N400, an electrical event-related potential (ERP) signal associated with detection of semantic incongruities, to ask if semantic information was processed for words that were missed during the attentional blink. In this experiment, participants were first shown a context word at the beginning of each trial (e.g., "razor" or "wheel"). Then, they had to detect a set of numbers as the first target (e.g., "333333" or "444444") and a word as the second target (e.g., "shave" or "jewel"). When participants see words that are incongruent with the context ("jewel" as opposed to "shave" for the context "razor") this will elicit an N400 signal. Remarkably, target words that were missed because of the attentional blink still evoked a significant N400 signal, which suggests that undetected words are still evaluated for the semantic meaning even when they fail to reach conscious awareness. Together, these results demonstrate that information that fails to reach consciousness can still activate high-level neural processes associated with complex visual and semantic analysis.

A Neural Signature of Conscious Processing

In recent years, these paradigms, as well as many others, have identified differences between information that is consciously perceived and information that fails to reach consciousness. These different paradigms afford researchers the unique opportunity to directly contrast what happens on trials when a participant notices a target compared to trials where they fail to see the target in any of the three paradigms we have discussed. Together, a consensus has emerged that conscious processing is associated with activation in the prefrontal and parietal cortices (see Dehaene & Changeux 2011 for a review). These two regions appear critical for conscious processing since they are highly connected with the rest of the brain and are processing hubs within which information from a variety of sensory modalities and neural networks can be integrated together (van den Heuvel & Sporns 2013). Meanwhile, information that does not reach consciousness will still be processed deeply by sensory cortices (e.g., high-level visual cortex), but will not extend into the prefrontal/parietal network.

Two paradigms that have been especially useful in identifying this potential signature of conscious processing are change blindness and the attentional blink. These tasks allow researchers to keep the parameters of the experiment constant (e.g., the stimulus categories, the presentation time, etc.) but still have some trials where the target is noticed and some trials where the target is not consciously perceived. This makes for an ideal situation for studying consciousness in the brain. When the stimulus input is held constant, whatever differences there are in neural processing between the two types of trials can confidently be attributed to the difference between conscious and unconscious processing.

Taking advantage of this fact, change blindness studies have shown that when a change between displays was successfully identified, there was an increase in activation fronto-parietal network compared to when participants failed to notice the change (Beck et al. 2001). Similarly, the attentional blink has also shown that missed targets will still elicit strong activation in sensory cortices, but that activation does not extend into the prefrontal or parietal cortices. However, a second target that is consciously perceived will activate these higher-level fronto-parietal regions (Marois, Yi, & Chun 2004). Together, these results suggest that the transition of information processing from sensory cortices into these higher-level regions is a strong neural marker of conscious processing.

Beyond the activation of fronto-parietal networks, higher-level neural regions become increasingly coupled or synchronized with other brain areas during conscious processing. This coupling and synchronization is referred to as functional connectivity. In the attentional blink task, conscious perception is associated with changes in long-range synchronization between the frontal, parietal, and temporal lobes, as measured with magnetoencephalography (Gross et al. 2004). Similar evidence for long-range synchronization during conscious perception has been demonstrated with electroencephalography (Melloni et al. 2007). To examine functional connectivity at the whole-brain level, global integration of neural processing can be revealed using sophisticated computational methods such as graph theoretical techniques. These methods reveal that global patterns in functional connectivity change when participants are aware of a visual stimulus compared to when they are not (Godwin et al. 2015). Together, these types of findings support the global models of awareness discussed earlier.

Conclusion

The relationship between attention and consciousness is a foundational issue for anyone interested in consciousness studies. Inattentional blindness, change blindness, and the attentional blink have provided a tremendous amount of information regarding the relationship between attention and consciousness. Specifically, even though it appears as if we are continuously seeing a richly detailed visual world, these three paradigms highlight strict limitations on our perception that we are not always aware of (Levin et al. 2000). Indeed, a long-term goal of consciousness research is to create a unified theory of sensory awareness that accounts for our subjective impression of a detailed visual world, while also acknowledging the objectively measurable limits of perception.

See also 18 The intermediate level theory of consciousness; 39 Conscious and unconscious perception; 42 Methodologies for identifying the neural correlates of consciousness.

Further Readings

Cohen, M. A., Cavanagh, P., Chun, M. M., and Nakayama, K. (2012) The attentional requirements of consciousness. *Trends in Cognitive Sciences* 16, 411–17.

Dehaene, S. and Changeux, J.-P. (2011) Experimental and theoretical approaches to conscious processing. *Neuron*, 70, 200–27.

Koch, C., Massimini, M., Boly, M., and Tononi, G. (2016) Neural correlates of consciousness: progress and problems. *Nature Reviews Neuroscience* 17, 307–21.

Lavie, N., Beck, D. M., and Konstantinou, N. (2014). Blinded by the load: attention, awareness and the role of perceptual load. *Philosophical Transactions of the Royal Society of London* 369, 1–10.

Tsuchiya, N., Frässle, S., Wilke, M., and Lamme, V. (2016) No-report paradigms: extracting the true neural correlates of consciousness. *Trends in Cognitive Sciences* 19, 757–70.

References

Beck, D. M., Rees, G., Frith, C. D., and Lavie, N. (2001) Neural correlates of change detection and change blindness. *Nature Neuroscience* 4, 645–50.

Block, N. (2011) Perceptual consciousness overflows cognitive access. *Trends in Cognitive Sciences* 15, 567–75.

Broadbent, D. (1958) *Perception and Communication*. London: Pergamon Press.

Chabris, C. F., Weinberger, A., Fontaine, M., and Simons, D. J. (2011) You do not talk about Fight Club if you do not notice Fight Club: inattentional blindness for a simulated real-world assault. *iPerception* 2, 150–3.

Chun, M. M. and Potter, M. C. (1995) A two-stage model for multiple target detection in rapid serial visual presentation. *Journal of Experimental Psychology: Human Perception and Performance* 21, 109–27.

Chun, M. M., Golomb, J. D., and Turk-Browne, N. B. (2011) A taxonomy of external and internal attention. *Annual Review of Psychology* 62, 73–101.

Cohen, M. A., and Dennett, D. C. (2011) Consciousness cannot be separated from function. *Trends in Cognitive Sciences* 15, 358–64.

Cohen, M. A., Alvarez, G. A., and Nakayama, K. (2011) Natural-scene perception requires attention. *Psychological Science* 22, 1165–72.

Cohen, M. A., Cavanagh, P., Chun, M. M., and Nakayama, K. (2012) The attentional requirements of consciousness. *Trends in Cognitive Sciences* 16, 411–17.

Dehaene, S. and Changeux, J.-P. (2011) Experimental and theoretical approaches to conscious processing. *Neuron* 70, 200–27.

Drew, T., Võ, M. H., and Wolfe, J. M. (2013) The invisible gorilla strikes again: sustained inattentional blindness in expert observers. *Psychological Science* 24, 1848–53.

Evans, K. K. and Treisman, A. (2005) Perception of objects in natural scenes: is it really attention free? *Journal of Experimental Psychology: Human Perception and Performance* 31, 1476–92.

Godwin, D., Barry, R. L., and Marois, R. (2015) Breakdown of the brain's functional network modularity with awareness. *Proceedings of the National Academy of Sciences* 112, 3799–804.

Gross J., Schmitz, F., Schnitzler, I., Kessler, K., Shapiro, K., Hommel, B., and Schnitzler, A. (2004) Modulation of long-range neural synchrony reflects temporal limitations of visual attention in humans. *Proceedings of the National Academy of Sciences* 101, 13050–5.

Horrey, W. J. and Wickens, C. D. (2006) Examining the impact of cell phone conversations on driving using meta-analytic techniques. *Human Factors* 48, 196–205.

Jiang, Y., Costello, P., Fang, F., Huang, M., and He, S. (2007) A gender- and sexual orientation-dependent spatial attentional effect of invisible images. *Proceedings of the National Academy of Sciences* 103, 17048–52.

Joseph, J. S., Chun, M. M. and Nakayama, K. (1997) Attentional requirements in a "preattentive" feature search task. *Nature* 387, 805–7.

Koch, C. and Tsuchiya, N. (2007) Attention and consciousness: two distinct brain processes. *Trends in Cognitive Sciences* 11, 16–22.

Lavie, N. (2005) Distracted and confused?: selective attention under load. *Trends in Cognitive Sciences* 9, 75–82.

Levin, D. T., Momen, N., Drivdahl, S. G., and Simons, D. J. (2000) Change blindness blindness: the metacognitive error of overestimating change-detection ability. *Visual Cognition* 7, 397–412.

Li, F. F., VanRullen, R., Koch, C. and Perona, P. (2002) Rapid natural scene categorization in the near absence of attention. *Proceedings of the National Academy of Sciences* 99, 9596–601.

Luck, S. J., Vogel, E. K., and Shapiro, K. L. (1996) Word meanings can be accessed but not reported during the attentional blink. *Nature* 383, 616–18.

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

Marois, R., Yi. D.-J., and Chun, M. M. (2004) The neural fate of consciously perceived and missed events in the attentional blink. *Neuron* 41, 465–72.

Melloni, L., Molina, C., Pena, M., Torres, D., Singer, W., and Rodriguez, E. (2007) Synchronization of neural activity across cortical areas correlates with conscious perception. *Journal of Neuroscience* 27, 2858–65.

Mitroff, S. R., Simons, D. J., and Levin, D. T. (2004) Nothing compares 2 views: change blindness can occur despite preserved access to the changed information. *Perception and Psychophysics* 66, 1268–81.

Most, S. B., Scholl, B. J., Clifford, E. R., and Simons, D. J. (2005) What you see is what you set: Sustained inattentional blindness and the capture of awareness. *Psychological Review* 112, 217–42.

Naccache, L., Blandin, E., and Dehaene, S. (2002) Unconscious masking priming depends on temporal attention. *Psychological Science* 13, 416–24.

O'Regan, J. K., Rensink, R. A., and Clark, J. J. (1999) Change-blindness as a result of "mudsplashes." *Nature* 398, 34–7.

Raymond, J. E., Shapiro, K. L., and Arnell, K. M. (1992) Temporary suppression of visual processing in an RSVP task: an attentional blink? *Journal of Experimental Psychology: Human Perception and Performance* 18, 849–60.

Rensink, R. A., O'Regan, J. K., and Clark, J. J. (1997) To see or not to see: the need for attention to perceive changes in scenes. *Psychological Science* 8, 368–73.

Simons, D. J. (2010) Monkeying around with the gorillas in our midst: familiarity with an inattentional-blindness task does not improve the detection of unexpected events. *iPerception* 1, 3–6.

Simons, D. J. and Chabris, C. F. (1999) Gorillas in our midst: sustained inattentional blindness for dynamic events. *Perception* 28, 1059–74.
Simons, D. J., Chabris, C. F., Schnur, T. T., and Levin, D. T. (2002) Evidence for preserved representations in change blindness. *Consciousness and Cognition* 11, 78–97.
Treisman, A. M. and Gelade, G. (1980) A feature integration theory of attention. *Cognitive Psychology* 12, 97–136.
Van den Heuvel, M. P. and Sporns, O. (2013) Network hubs in the human brain. *Trends in Cognitive Sciences* 17, 683–96.