

The dark side of visual attention

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The limited capacity of neural processing restricts the number of objects and locations that can be attended to. Selected events are readily enhanced: the bright side of attention. However, such focal processing comes at a cost, namely, functional blindness for unattended events: the dark side of visual attention. Recent work has advanced our understanding of the neural mechanisms that facilitate visual processing, as well as the neural correlates of unattended, unconscious visual events. Also, new results have revealed how attentional deployment is optimized by non-visual factors such as behavioral set, past experience, and emotional salience.

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Abbreviations

FEF frontal eye field
V4 visual area 4

Introduction

In 1999 alone, 41,611 people were killed and over 3,200,000 people were injured in motor vehicle accidents across the US [1]. The majority of these accidents were due to human error, with inattention and fatigue cited as causal factors in a substantial proportion of these incidents [2]. These tragic statistics illustrate the real-world consequences of what we call the ‘dark side’ of attention. In the lab, one of the most striking demonstrations of such functional blindness is the failure of 58% of observers to see a gorilla in clear view thumping its chest, while subjects concurrently performed a challenging visual tracking task (Figures 1,3) [3]. In clinical settings, such functional blindness is commonly observed in neglect patients with damage to the frontal and parietal cortices. In many respects, functional blindness in normal observers appears to mirror the inability of neglect patients to attend to, and consciously perceive, events in their contralesional field. This suggests a link between specific brain areas and conscious, attentive vision [4*,5*].

Understanding the costs of inattention is complementary to the study of how attention facilitates perception. Here, we survey both aspects: the bright and dark side of attention. In addition, because visual selection is limited to such a thin sliver of incoming perceptual information, it is important to understand how attention can be optimally and quickly deployed to task-relevant objects. The final

Figure 1



A striking example of inattention blindness. When attending to the players passing a ball amongst themselves, over half of the viewers failed to notice the man in the gorilla suit appearing in the middle of their game. Reproduced with permission from [3].

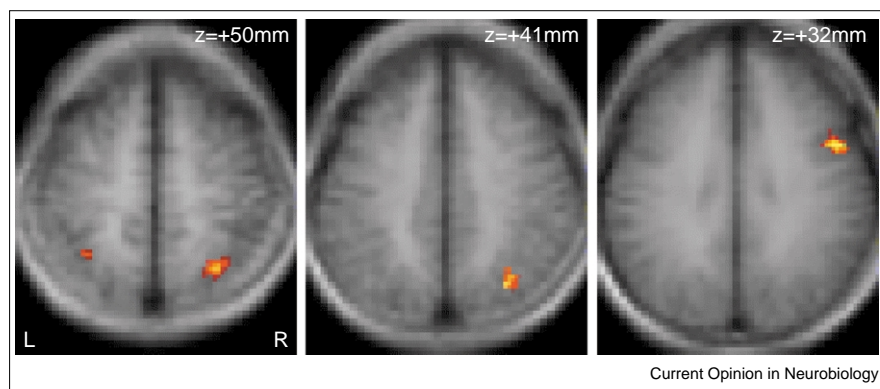
section of this review examines some factors that determine what people attend to.

The bright side of visual attention

Attending to a location or object modulates neural processing in an entire network of cortical areas [6*], facilitating perceptual processing [7,8], permitting tracking of an object’s dynamic features and positions over time [9–11], and enabling perceptual awareness of attended events [4*,12]. Many recent findings have helped characterize the neural mechanisms for such attentional facilitation.

Consider how attention may enhance the detectability of relatively isolated target stimuli. This is particularly important when the sensory signal is weak. The ability to register a sensory input is determined by the strength of the neuronal response and the variability of this response. It turns out that the main effect of attention is to increase neural responses to attended stimuli [13–16]; the variability of neuronal responses (relative to response rate) does not change with attention [17]. In other words, attention serves to increase the signal, not to reduce the noise of neural responses. Attentional facilitation of neural signals appears to mimic the effects of increasing the sensory signal itself, for example by increasing contrast. Attention does not appear to change the tuning of cells, however. For example, the selectivity of visual area 4 (V4) neurons for orientation remained unchanged across increasing levels of attention [18]. Also note that attention only affects neural responses within a range of signal strengths. Attention has little effect to further improve the response to an oriented stimulus presented at maximum contrast [19].

Figure 2



Increased distractor interference on a target engaged the intraparietal sulcus and the lateral frontal cortex. During letter target identification, distractors that appear close in time, as backward masks, or close in space, as flanking masks, cause perceptual interference [28[•]]. Such distractor interference (relative to a low interference condition) is associated with increased activity in the intraparietal sulcus and the lateral frontal cortex, as shown by the red areas of fMRI activation. Reproduced with permission from [28[•]].

In addition to facilitation, attention serves to filter irrelevant distractors that compete for limited neural resources, especially when these appear close to a target stimulus [20]. Behaviorally, this situation causes lateral interference, reducing the visibility of the ‘crowded’ target [21,22[•]]. Neurophysiologically, the presence of both a distractor and a target within a neuron’s receptive field introduces interference and ambiguity that is suppressed by attention [23–25]. In addition to these suppressive effects, recent findings also suggest that attention may amplify target signals appearing amongst distractors, by modulating the synchronization of neuronal firing to the target [26[•],27].

Although flanker interference typically produces suppression of neural activity in early visual areas such as V4 [23–25], opposite effects are typically observed in frontal and parietal areas. When distractor interference on a target is increased, the right intraparietal sulcus and lateral frontal cortex (at the junction of the inferior frontal, middle frontal, and precentral gyri) show greater activation, as measured by functional magnetic resonance imaging (fMRI), shown in Figure 2 [28[•]]. This pattern of activity suggests that frontal and parietal regions serve to bias competitive interactions between targets and flanking distractors [29]. If so, tying up frontal control processes with a dual task should lead to larger distractor interference effects. Indeed, a recent study showed that increasing working memory load led to larger frontal activation and larger ventral (fusiform, lingual and inferior occipital cortex) activation in response to distractors that were to be ignored [30[•]]. Further evidence for this effect comes from the finding that damage to the dorsolateral prefrontal cortex was correlated with reduced neural activity in ipsilesional extrastriate cortex and impaired detection of contralesional visual targets [31]. These findings reinforce the hypothesis that frontal cortex regulates visual processing in posterior visual areas.

Another frontal area that plays an important role in attentional selection is the frontal eye field (FEF). Not only do FEF neurons reveal attentional discrimination of

targets versus distractors with high reliability [32,33], but also microstimulation of FEF neurons facilitates target detection even when eye movements are not elicited [34]. Future research should reveal how frontal, parietal, and ventral areas coordinate their activity to enhance perception and reduce distractor interference [35,36].

The dark side of visual attention

The bright side of visual attention, facilitation of task-relevant information, comes at a cost and researchers have developed a lively array of paradigms to study perceptual deficits caused by inattention. Three of the most popular tasks are inattention blindness, change blindness, and the attentional blink. Although not reviewed here, other new paradigms continually emerge to reveal the dark side of attention [37[•],38].

Inattention blindness occurs when subjects fail to see a secondary event, such as a dot flashed on the computer screen, while performing another visual task [39]. Observers tend to miss the unexpected event (even when it is a gorilla!), but such errors are limited to the first trial of testing. Once subjects start expecting unusual events, they become readily detectable.

Change blindness, a failure to detect changes in the presence, identity or location of objects in scenes, is also strongest when subjects do not expect changes to occur. For example, over half of real-world observers failed to note a change in the identity of a person that they were conversing with, when the change was made during a brief occlusion (such as workers carrying a door between the conversing people) [40]. Unlike inattention blindness paradigms, however, visually salient changes can be difficult to detect even when the observer expects and actively searches for such changes. For example in lab tasks, subjects may take several seconds to note a jet engine appearing and disappearing from the wing of a Boeing 747 jetliner [41].

Finally, the attentional blink paradigm reliably blinds observers by taxing their attention to the limit [42,43].

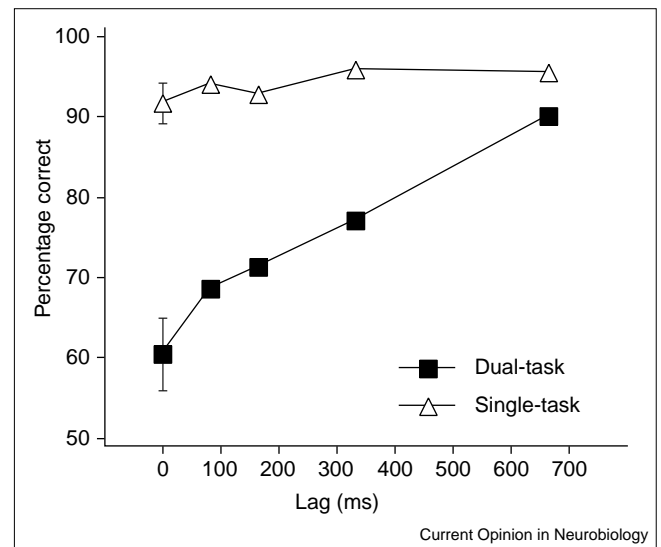
When subjects try to detect two visual targets presented in rapid succession, they typically fail to 'see' the second target appearing within 500 ms of the first. Attention to the first target prevents awareness of the second. This deficit is so powerful that subjects cannot even report a very salient target stimulus, such as a uniquely oriented item, that would otherwise support a rapid and efficient 'feature pop-out' search (Figure 3) [44,45].

These paradigms offer insights into basic questions about the role of attention in conscious perception. What is the fate of unreported visual events? This issue addresses the classic debate of early versus late selection [46]. In other words, is the unreported visual event identified at some level beneath awareness (late selection) or is it filtered out during an early stage of processing (early selection)? Clever experiments affirm the late selection view. In change blindness, changes that went undetected still activated some category-sensitive areas in ventral cortex, although the effects were not very consistent [47]. In attentional blink experiments, unreported target words produced semantic priming for subsequent targets [48], and they also triggered event-related potential components sensitive to semantic mismatch, thus providing evidence that brain areas related to word meaning were activated for these unconscious percepts [49].

Another issue concerns the patterns of neural activity associated with visual awareness. Across studies and tasks, a frontal–parietal network appears to be activated during conscious visual states, as compared to unconscious visual states [4*]. This frontal–parietal network is commonly observed in tasks that require attention [50], consistent with the central role that attention plays in conscious perception. For example, Marois *et al.* [28*] manipulated the difficulty of target processing and showed that this modulated the severity of the attentional blink. Importantly, activity in the intraparietal sulcus correlated tightly with this manipulation, suggesting that this structure plays a role in bringing visual information into awareness and in doing so, creates an attentional bottleneck that causes functional blindness for other 'unattended' stimuli.

Together, the findings discussed above support a two-stage model of visual processing, originally proposed to explain the attentional blink [43]. The basic idea is that most unattended visual stimuli are initially processed to the level of identification [51], but limited-capacity attentional processes are needed to bring these visual representations into a state that can be consciously reported. In neurobiological terms, this model suggests that most visual events may activate category-specific and even item-specific representations in ventral cortex, but dorsal and frontal mechanisms are required for the explicit perception of these events. This does not imply that conscious perception takes place in this frontal–parietal network *per se* [28*]. Rather, the parietal and frontal cortices form a limited-capacity processing stage that visual information must pass

Figure 3



Orientation pop-out is impaired in the attentional blink paradigm [44]. On each trial, a colored letter appeared amidst a rapid serial visual presentation sequence of other black letters. After a variable lag, a search array appeared in which a uniquely oriented target was embedded with 50% probability. When subjects ignored the letter task and tried to detect the orientation pop-out target only, performance was very high across all lags. However, in the dual-task condition, using the same display sequences, attention to the letter task severely impaired detection of the orientation pop-out targets. Note how performance systematically improved as the temporal lag between the letter task and pop-out detection task increased. This lag manipulation allows one to parametrically control the magnitude of functional blindness to visual events. Reproduced with permission from Nature [44], © 1997, Macmillan Publishers Ltd.

through in order to be consciously reported [28*]. Accordingly, neurological damage to the areas involved in the network may lead to deficits in conscious perception [4*,5*].

Deploying visual attention

Because of the clear benefits for selected events and the drastic costs resulting from inattention, it is critically important to deploy attention as efficiently as possible, when confronted with a multitude of potential objects that compete for selection. There are a number of mechanisms and strategies that guide attentional deployment. For example, salient visual events, such as abrupt onsets or moving stimuli, tend to attract attention [52]. However, attentional deployment cannot be understood in terms of bottom-up features alone. One of the most interesting aspects of attentional control and deployment is that these processes rely not only on visual cues, but also on close interactions with 'other' neural systems in the brain, such as those involved in working memory, long-term memory, and emotional processing.

Top-down attentional set and attentional shifting

Observers spend a lot of time scanning the environment. This involves shifting one's attention from one location to

another and from one time point to the next. Early studies of the neurophysiology of attentional shifting revealed the involvement of a network of parietal and frontal areas [53]. Exogenous attention can be deployed to visual locations on the basis of external cues, such as a bright light, sound, or even touch [54]. Endogenous attention can be wilfully commanded from one object to the next on the basis of instruction or volition. Interestingly, these two modes of attentional shifting differ greatly in their efficiency and time course [55–57]. Enforcing a scan path through a visual array with deliberate, volitional shifts of attention is much slower than letting attention run freely in an anarchic, uncontrolled manner [58*].

Naturally, it helps if the goal of an attentional search is explicit. Neural processing may be restricted to objects that match templates in mind, such as searching for a blue-colored journal amongst a pile of other books and papers [59]. Representations in working memory may serve to bias neural activity towards objects that share features with the target [60,61]. Interestingly, such selective tuning makes attention obligatory for any event that matches the template. When holding a target in mind, subjects have difficulty ignoring task-irrelevant stimuli that match the working memory representation [62,63*]. One possible mechanism for this involves feature-based selection. Neurons in V4 show enhanced activity when attention is directed to a location or to a feature. Interestingly, when attention is directed to a feature such as orientation, oriented neurons throughout the entire visual field exhibited increased activity [64] (see also [65]).

Even when visual stimulation is absent, neural mechanisms prepare for upcoming visual events. When cued to expect a target in a certain location, significant preparatory activity is observed in frontal and parietal cortices [66,67*,68*]. Attention can be cued to points in time as well [69]. Preparatory activity can be distinguished from neural activity associated with target detection.

Effects of experience

In addition to top-down attentional tuning, the past history of the observer also affects how attention is deployed. Both short-term and long-term perceptual experiences influence attention. Across short time durations, attention and eye movements are deployed more efficiently towards features that were viewed within the previous 30 s [70,71]. Within an ongoing context of repeated stimuli, attention becomes biased towards, indeed even captured by, novel events. The inferior parietal cortex/temporoparietal junction appears to play a particularly important role in the detection of novel targets, or in the appearance of targets in previously unattended locations [68*,72,73*].

The effects of long-term experience are not fully characterized yet, but learning appears to influence visual activity and attention in a number of visual areas. In anterior inferior temporal cortex, training increases neural responses to stimuli that are

behaviorally relevant [74]. Some intriguing findings, important for saccadic control, have also been observed in FEF. Neurons in FEF are not typically selective for visual features, but they can become selective with extensive training [75]. FEF is also biased towards features that defined targets in previous testing sessions [76]. These findings illustrate the existences of neural correlates of long-term visual priming.

More complex forms of visual experience may be encoded in the form of visual context. The visual context of a scene helps define which objects and locations should be attended to [77,78*]. For instance, vehicle drivers are more likely to detect and fixate a stop sign at a street intersection than a sign appearing along a street mid-block [79]. Contextual information is a form of top-down knowledge that must be acquired through learning [78*]. Hence, memory systems within the brain play an important role in attentional processing. In fact, amnesic patients with medial temporal lobe damage do not exhibit contextual benefits in visual search tasks [80,81]. Such contextual knowledge encoded by medial temporal lobe areas appears to interface rapidly with posterior visual areas to guide perception [82].

Emotional salience

Emotionally salient events attract attention, serving to enhance responses to potentially threatening stimuli [83]. For example, aversive words, such as ‘rape’, are detected more readily than common neutral words controlled for word frequency. If presented during an attentional blink interval, smaller deficits are observed for the emotional words [84*]. What is the neural mechanism that summons attention to motivationally significant stimuli? The amygdala plays a critical role in the affective modulation of attention and perception [85]. Accordingly, patients with bilateral or left amygdala damage do not show enhanced perception of aversive events, even though they clearly comprehend the meaning of the stimuli presented [84*].

Conclusions

We have divided the study of attention into three domains. The first concerns how neural mechanisms select and enhance processing of attended information. The second examines the behavioral costs and neural representations of unattended information. The third addresses how the brain quickly deploys attention to the information most relevant to behavior. In our view, the most remarkable aspect of attentional processing is that it works in concert with other memory, emotion, and executive mechanisms throughout the brain, to optimize deployment and to minimize the costs of functional blindness to unattended information. This makes attention a rich topic of study in cognitive neuroscience.

References and recommended reading

Papers of particular interest, published within the annual period of review, have been highlighted as:

- of special interest
- of outstanding interest

1. **1999 Annual report to Congress on the World Wide Web.** URL: <http://www.nts.gov/Publicatn/2000/SPC0003.pdf>

2. **Transportation statistics annual report 1998: long-distance travel and freight, chapter 3.** URL: <http://www.bts.gov/programs/transst/tstar/tstar98/chap3.pdf>
3. Simons DJ, Chabris CF: **Gorillas in our midst: sustained inattentional blindness for dynamic events.** *Perception* 1999, **28**:1059-1074.
4. Rees G: **Neuroimaging of visual awareness in patients and normal subjects.** *Curr Opin Neurobiol* 2001, **11**:150-156.
This review article combines insights from normal subjects and patients with neglect to explore the neural correlates of visual awareness. The reviewed findings indicate that frontoparietal areas and the ventral visual cortex interact to produce conscious visual experience.
5. Driver J, Vuilleumier P: **Perceptual awareness and its loss in unilateral neglect and extinction.** *Cognition* 2001, **79**:39-88.
Here, Driver and Vuilleumier survey the dark side of attention from a neuropsychological perspective, an important domain that is beyond the scope of the present review.
6. Kanwisher N, Wojciulik E: **Visual attention: Insights from brain imaging.** *Nat Rev Neurosci* 2000, **1**:91-100.
A comprehensive review into how neuroimaging experiments have yielded new insights into the neural mechanisms of attention. A key theme is that attention actively shapes perceptual experience. Neuroimaging has improved our knowledge of the locus of selection, the targets of selection (objects versus spatial locations), the neural correlates of attentional facilitation, and the source of top-down attentional control signals.
7. Olson CR: **Object-based vision and attention in primates.** *Curr Opin Neurobiol* 2001, **11**:171-179.
8. Carrasco M, McEree B: **Covert attention accelerates the rate of visual information processing.** *Proc Natl Acad Sci USA* 2001, **98**:5363-5367.
9. Blaser E, Pylyshyn ZW, Holcombe AO: **Tracking an object through feature space.** *Nature* 2000, **408**:196-199.
10. Culham JC, Brandt SA, Cavanagh P, Kanwisher NG, Dale AM, Tootell RB: **Cortical fMRI activation produced by attentive tracking of moving targets.** *J Neurophysiol* 1998, **80**:2657-2670.
11. Diwadkar VA, Carpenter PA, Just MA: **Collaborative activity between parietal and dorso-lateral prefrontal cortex in dynamic spatial working memory revealed by fMRI.** *Neuroimage* 2000, **12**:85-99.
12. Treisman AM, Kanwisher NG: **Perceiving visually presented objects: recognition, awareness, and modularity.** *Curr Opin Neurobiol* 1998, **8**:218-226.
13. Mountcastle VB, Andersen RA, Motter BC: **The influence of attentive fixation upon the excitability of the light-sensitive neurons of the posterior parietal cortex.** *J Neurosci* 1981, **1**:1218-1225.
14. Haenny PE, Schiller PH: **State dependent activity in monkey visual cortex. I. Single cell activity in V1 and V4 on visual tasks.** *Exp Brain Res* 1988, **69**:225-244.
15. Bushnell MC, Goldberg ME, Robinson DL: **Behavioral enhancement of visual responses in monkey cerebral cortex. I. Modulation in posterior parietal cortex related to selective visual attention.** *J Neurophysiol* 1981, **46**:755-772.
16. Spitzer H, Desimone R, Moran J: **Increased attention enhances both behavioral and neuronal performance.** *Science* 1988, **240**:338-340.
17. McAdams CJ, Maunsell JHR: **Effects of attention on the reliability of individual neurons in monkey visual cortex.** *Neuron* 1999, **23**:765-773.
18. McAdams CJ, Maunsell JH: **Effects of attention on orientation-tuning functions of single neurons in macaque cortical area V4.** *J Neurosci* 1999, **19**:431-441.
19. Reynolds JH, Pasternak T, Desimone R: **Attention increases sensitivity of V4 neurons.** *Neuron* 2000, **26**:703-714.
20. Desimone R, Duncan J: **Neural mechanisms of selective visual attention.** *Annu Rev Neurosci* 1995, **18**:193-222.
21. Bouma H: **Interaction effects in parafoveal letter recognition.** *Nature* 1970, **226**:177-178.
22. Intriligator J, Cavanagh P: **The spatial resolution of visual attention.** *Cognit Psychol* 2001, **43**:171-216.
A comprehensive series of experiments demonstrate that the resolution of attentional selection is coarser than the resolution of visual acuity. This was demonstrated by measuring the closest spacing by which individual targets in dense displays could be individuated from each other. Hence, the results are directly relevant for understanding spatial interference effects. The parietal cortex is implicated as the most likely locus for this limited resolution of attentional selection.
23. Moran J, Desimone R: **Selective attention gates visual processing in the extrastriate cortex.** *Science* 1985, **229**:782-784.
24. Luck SJ, Chelazzi L, Hillyard SA, Desimone R: **Neural mechanisms of spatial selective attention in areas V1, V2, and V4 of macaque visual cortex.** *J Neurophysiol* 1997, **77**:24-42.
25. Kastner S, De Weerd P, Pinsk MA, Elizondo MI, Desimone R, Ungerleider LG: **Modulation of sensory suppression: implications for receptive field sizes in the human visual cortex.** *J Neurophysiol* 2001, **86**:1398-1411.
26. Fries P, Reynolds JH, Rorie AE, Desimone R: **Modulation of oscillatory neuronal synchronization by selective visual attention.** *Science* 2001, **291**:1560-1563.
The authors of this study show how localized γ -frequency synchronization may serve to amplify neural signal transmission for attended events. The discovery of such synchronization in visual cortex (area V4) is important because synchronization provides a mechanism to amplify neural signals, in a manner that is distinct from simply increasing firing rates to an attended stimulus. The latter mechanism is not always available and is potentially ambiguous under certain stimulus conditions.
27. Steinmetz PN, Roy A, Fitzgerald PJ, Hsiao SS, Johnson KO, Niebur E: **Attention modulates synchronized neuronal firing in primate somatosensory cortex.** *Nature* 2000, **404**:187-190.
28. Marois R, Chun MM, Gore JC: **Neural correlates of the attentional blink.** *Neuron* 2000, **28**:299-308.
Here, the authors demonstrate the effects both of temporal and spatial distractor interference on target processing in parietal and frontal cortex. Resolving such interference appears to create a processing bottleneck that is responsible for inattentional blindness deficits, such as the attentional blink.
29. Behrmann M, Haimson C: **The cognitive neuroscience of visual attention.** *Curr Opin Neurobiol* 1999, **9**:158-163.
30. de Fockert JW, Rees G, Frith CD, Lavie N: **The role of working memory in visual selective attention.** *Science* 2001, **291**:1803-1806.
Using a dual-task paradigm, the authors show the importance of prefrontal working memory mechanisms in reducing perceptual distraction.
31. Barcelo F, Suwazono S, Knight RT: **Prefrontal modulation of visual processing in humans.** *Nat Neurosci* 2000, **3**:399-403.
32. Schall JD, Hanes DP: **Neural basis of saccade target selection in frontal eye field during visual search.** *Nature* 1993, **366**:467-469.
33. Bichot NP, Thompson KG, Chenchal Rao S, Schall JD: **Reliability of macaque frontal eye field neurons signaling saccade targets during visual search.** *J Neurosci* 2001, **21**:713-725.
34. Moore T, Fallah M: **Control of eye movements and spatial attention.** *Proc Natl Acad Sci USA* 2001, **98**:1273-1276.
35. Friston KJ, Buchel C: **Attentional modulation of effective connectivity from V2 to V5/MT in humans.** *Proc Natl Acad Sci USA* 2000, **97**:7591-7596.
36. Culham JC, Kanwisher NG: **Neuroimaging of cognitive functions in human parietal cortex.** *Curr Opin Neurobiol* 2001, **11**:157-163.
37. Di Lollo V, Enns JT, Rensink RA: **Competition for consciousness among visual events: the psychophysics of reentrant visual processes.** *J Exp Psychol Gen* 2000, **129**:481-507.
A systematic series of psychophysical experiments characterize a new masking effect that limits the visibility of visual targets under conditions of inattention. The authors offer an account for this masking effect on the basis of reentrant processing, namely, feedback activity from higher-level stages in the visual system.
38. Bonneh YS, Cooperman A, Sagi D: **Motion-induced blindness in normal observers.** *Nature* 2001, **411**:798-801.
39. Mack A, Rock I: *Inattentional Blindness.* Cambridge, MA: MIT Press; 1998.
40. Simons DJ, Levin DT: **Failure to detect changes to people in a real-world interaction.** *Psychon Bull Rev* 1998, **5**:644-649.
41. Rensink RA, O'Regan JK, Clark JJ: **To see or not to see: the need for attention to perceive changes in scenes.** *Psychol Sci* 1997, **8**:368-373.
42. Raymond JE, Shapiro KL, Arnell KM: **Temporary suppression of visual processing in an RSVP task: an attentional blink?** *J Exp Psychol Hum Percept Perform* 1992, **18**:849-860.

43. Chun MM, Potter MC: **A two-stage model for multiple target detection in rapid serial visual presentation.** *J Exp Psychol Hum Percept Perform* 1995, **21**:109-127.
44. Joseph JS, Chun MM, Nakayama K: **Attentional requirements in a 'preattentive' feature search task.** *Nature* 1997, **387**:805-808.
45. Kawahara J, Di Lollo V, Enns JT: **Attentional requirements in visual detection and identification: evidence from the attentional blink.** *J Exp Psychol Hum Percept Perform* 2001, **27**:969-984.
46. Pashler H: *The Psychology of Attention.* Cambridge, MA: MIT Press; 1998.
47. Beck DM, Rees G, Frith CD, Lavie N: **Neural correlates of change detection and change blindness.** *Nat Neurosci* 2001, **4**:645-650.
48. Shapiro K, Driver J, Ward R, Sorensen RE: **Priming from the attentional blink: a failure to extract visual tokens but not visual types.** *Psychol Sci* 1997, **8**:95-100.
49. Luck SJ, Vogel EK, Shapiro KL: **Word meanings can be accessed but not reported during the attentional blink.** *Nature* 1996, **383**:616-618.
50. Wojculik E, Kanwisher N: **The generality of parietal involvement in visual attention.** *Neuron* 1999, **23**:747-764.
51. Potter MC: **Very short-term conceptual memory.** *Mem Cognit* 1993, **21**:156-161.
52. Yantis S, Jonides J: **Abrupt visual onsets and selective attention: evidence from visual search.** *J Exp Psy Hum Percept Perform* 1984, **10**:601-621.
53. Corbetta M, Miezin FM, Shulman GL, Petersen SE: **A PET study of visuospatial attention.** *J Neurosci* 1993, **13**:1202-1226.
54. Macaluso E, Driver J: **Spatial attention and crossmodal interactions between vision and touch.** *Neuropsychologia* 2001, **39**:1304-1316.
55. Nakayama K, Mackeben M: **Sustained and transient components of focal visual attention.** *Vision Res* 1989, **29**:1631-1647.
56. Jonides J: **Voluntary versus automatic control over the mind's eye.** In *Attention and Performance IX*, Edited by Long J, Baddeley A. Mahwah, NJ: Lawrence Erlbaum Associates; 1981:187-203.
57. Posner MI: **Orienting of attention.** *Q J Exp Psychol* 1980, **32**:3-25.
58. Wolfe JM, Alvarez GA, Horowitz TS: **Attention is fast but volition is slow.** *Nature* 2000, **406**:691.
- In visual search tasks, randomly scanning a display is considerably faster than deliberately moving attention from one area to the next. The results presented here highlight an internal limit on the speed of volitional commands.
59. Egeth HE, Virzi RA, Garbart H: **Searching for conjunctively defined targets.** *J Exp Psychol Hum Percept Perform* 1984, **10**:32-39.
60. Chelazzi L, Miller EK, Duncan J, Desimone R: **A neural basis for visual search in inferior temporal cortex.** *Nature* 1993, **363**:345-347.
61. Chelazzi L, Miller EK, Duncan J, Desimone R: **Responses of neurons in macaque area V4 during memory-guided visual search.** *Cereb Cortex* 2001, **11**:761-772.
62. Pashler H, Shiu LP: **Do images involuntarily trigger search? A test of Pillsbury's hypothesis.** *Psychon Bull Rev* 1999, **6**:445-448.
63. Folk CL, Leber A, Egeth H: **Made you blink! Contingent attentional capture produces a spatial blink.** *Percept Psychophys* 2002, in press.
- This study shows a new, robust way to demonstrate people's inability to suppress distractor events that they are instructed to ignore, but that fit an attentional search template held in mind. For example, searching for a colored letter appearing in a rapid sequence at fixation is disrupted by the appearance of a colored distractor appearing at a different, to-be-ignored location.
64. McAdams CJ, Maunsell JH: **Attention to both space and feature modulates neuronal responses in macaque area V4.** *J Neurophysiol* 2000, **83**:1751-1755.
65. Treue S, Martinez Trujillo JC: **Feature-based attention influences motion processing gain in macaque visual cortex.** *Nature* 1999, **399**:575-579.
66. Kastner S, Pinsk MA, De Weerd P, Desimone R, Ungerleider LG: **Increased activity in human visual cortex during directed attention in the absence of visual stimulation.** *Neuron* 1999, **22**:751-761.
67. Hopfinger JB, Buonocore MH, Mangun GR: **The neural mechanisms of top-down attentional control.** *Nat Neurosci* 2000, **3**:284-291.
- One in a recent series of studies [66,68] that dissociates the neural activity related to top-down attentional control from activity triggered by sensory processing. Mental cueing to a location recruited a network of superior frontal, inferior parietal, and superior temporal areas.
68. Corbetta M, Kincade JM, Ollinger JM, McAvooy MP, Shulman GL: **Voluntary orienting is dissociated from target detection in human posterior parietal cortex.** *Nat Neurosci* 2000, **3**:292-297.
- Another study [66,67] that examines the neural mechanisms of orienting to a particular location, prior to stimulus onset. Activity in the intraparietal sulcus was primarily related to preparatory attention, whereas the right temporoparietal junction was active upon target detection, especially when reorienting was required to an unattended location.
69. Coull JT, Frith CD, Buchel C, Nobre AC: **Orienting attention in time: behavioural and neuroanatomical distinction between exogenous and endogenous shifts.** *Neuropsychologia* 2000, **38**:808-819.
70. McPeck RM, Maljkovic V, Nakayama K: **Saccades require focal attention and are facilitated by a short-term memory system.** *Vision Res* 1999, **39**:1555-1566.
71. Maljkovic V, Nakayama K: **Priming of pop-out. I. Role of features.** *Mem Cognit* 1994, **22**:657-672.
72. Downar J, Crawley AP, Mikulis DJ, Davis KD: **A multimodal cortical network for the detection of changes in the sensory environment.** *Nat Neurosci* 2000, **3**:277-283.
73. Marois R, Leung HC, Gore JC: **A stimulus-driven approach to object identity and location processing in the human brain.** *Neuron* 2000, **25**:717-728.
- The authors of this article demonstrate the importance of the lateral temporal cortex and the temporoparietal junction in the detection of novel events, regardless of whether the oddball targets are defined by unexpected changes in shape identity or spatial location. Thus, the functional segregation between ventral stream processing for shape and dorsal stream processing for location does not fully apply to the perception of novel objects.
74. Jagadeesh B, Chelazzi L, Mishkin M, Desimone R: **Learning increases stimulus salience in anterior inferior temporal cortex of the macaque.** *J Neurophysiol* 2001, **86**:290-303.
75. Bichot NP, Schall JD, Thompson KG: **Visual feature selectivity in frontal eye fields induced by experience in mature macaques.** *Nature* 1996, **381**:697-699.
76. Bichot NP, Schall JD: **Effects of similarity and history on neural mechanisms of visual selection.** *Nat Neurosci* 1999, **2**:549-554.
77. Biederman I, Mezzanotte RJ, Rabinowitz JC: **Scene perception: detecting and judging objects undergoing relational violations.** *Cognit Psychol* 1982, **14**:143-177.
78. Chun MM: **Contextual cueing of visual attention.** *Trends Cognit Sci* 2000, **4**:170-178.
- This article reviews recent work on how visual context information is learned and how it influences attention and eye movements.
79. Shinoda H, Hayhoe MM, Shrivastava A: **What controls attention in natural environments?** *Vision Res* 2001, **41**:3535-3545.
80. Chun MM, Phelps EA: **Memory deficits for implicit contextual information in amnesic subjects with hippocampal damage.** *Nat Neurosci* 1999, **2**:844-847.
81. Manns J, Squire LR: **Perceptual learning, awareness, and the hippocampus.** *Hippocampus* 2001, **11**:776-782.
82. Olson IR, Chun MM, Allison T: **Contextual guidance of attention: ERP evidence for an anatomically early, temporally late mechanism.** *Brain* 2001, **124**:1417-1425.
83. Öhman A, Mineka S: **Fears, phobias, and preparedness: toward an evolved module of fear and fear learning.** *Psychol Rev* 2001, **108**:483-522.
84. Anderson AK, Phelps EA: **Lesions of the human amygdala impair enhanced perception of emotionally salient events.** *Nature* 2001, **411**:305-309.
- Here, the authors present clear evidence for tight interactions between emotional, attentional, and perceptual mechanisms in the human brain. The human amygdala plays a central role in affective modulation of the attentional salience of perceptual events.
85. LeDoux JE: *The Emotional Brain: The Mysterious Underpinnings of Emotional Life.* New York, NY: Simon & Schuster; 1996.