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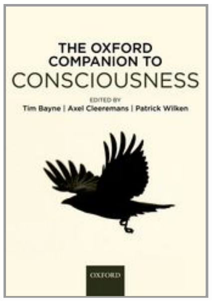

The Oxford Companion to Consciousness

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attention psychophysical approaches

Attention is the mechanism that allows us to selectively process the vast amount of information that we receive and to guide our behaviour. Visual spatial attention can be deployed overtly, accompanied by eye movements to the relevant location, or covertly, without eye movements (Helmholtz 1910/1925, Posner 1980). There are two types of covert attention: *sustained attention* refers to the voluntary, endogenous directing of attention to a location in the visual field, and *transient attention* refers to the automatic, exogenous capture of attention to a location, brought about by a sudden change in the environment (Nakayama and Mackeben 1989, Posner 1980).

Following a procedure devised by Posner (1980), whereby observers are cued to attend to specific locations while keeping their gaze at a central fixation point, many studies have characterized the effects of covert attention on perception. Attention improves performance (higher accuracy and shorter reaction times) on many tasks, involving several dimensions of early vision (contrast sensitivity and spatial resolution), such as detection, discrimination, localization, and visual search. Moreover, attention increases the haemodynamic response, an index of neural activity, in visual areas (for reviews see Reynolds and Chelazzi 2004, Carrasco 2006).

1. Attention and appearance

Psychologists, physiologists, and philosophers have debated the phenomenology of attention since the late 19th century. Does attention alter our subjective experience of the visual world? Which aspects of our visual experience does attention affect? Can attention make a visual pattern seem more detailed, or a colour more vivid? Studies on the phenomenological correlates of attention, which are relevant to the topic of subjective experience and awareness, show that attention alters appearance of basic spatial (contrast, spatial resolution, colour saturation, object size) and temporal (flicker rate, motion coherence, speed) visual dimensions.

Whether and how attention affects appearance has been systematically investigated only recently. This may be due to the difficulty in objectively testing and quantifying the subjective experience of perceived stimuli and changes in such experience with attention. The phenomenology of selective attention has been a subject of debate among pioneers in experimental psychology such as Mach, Fechner, von Helmholtz, Wundt, and James (see James 1890/1950, Wundt 1902). Much of this early work was *introspective, and conflicting conclusions were often drawn from such subjective methods of investigation. On the disagreement among investigators about whether attention increases the perceived intensity of a stimulus, James concluded: ‘The subject is one which would well repay exact experiment, if methods could be devised’ (James 1890/1950:426).

A psychophysical paradigm that assesses the phenomenological correlate of attention, by manipulating transient attention via uninformative spatial cues, makes it possible to study subjective experience and visual awareness more objectively and rigorously (Luck 2004, Treue 2004). This paradigm quantifies the observer's subjective perception using a task contingent upon a comparative judgement between two stimuli on a particular feature (Carrasco et al. 2004; Fig. A22). Observers are shown two stimuli and asked to ‘report property *x* of the stimulus that is greater/lesser in property *y*’. That is, the perceived relative values of property *y*—the primary interest of the experiment (e.g. contrast)—is an indicator of which stimulus to report on property *x* (e.g. orientation). The critical manipulation is that observers are not asked to directly rate their subjective experience on property *y*, but to make a decision about stimulus property *x*. This paradigm allows us to simultaneously measuring the effect of attention on appearance and performance. This paradigm coupled with control experiments for cue bias (see below) rule out response bias (Luck 2004, Treue 2004).

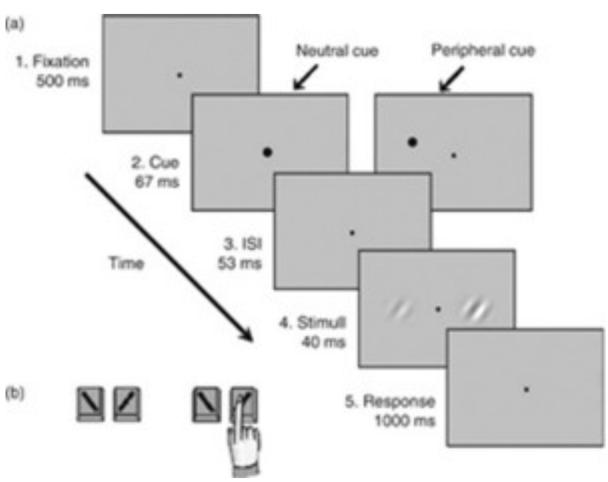

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Fig. A22. Sequence of events in a single trial. (a) Each trial began with a fixation point followed by a brief neutral or peripheral cue. The peripheral cue had equal probability of appearing on the left- or right-hand side, and was not predictive of the stimulus contrast or orientation. The timing of this sequence maximized the effect of transient attention and precluded eye movements. (b) Observers performed a two-by-two forced-choice (2 b 2 AFC) task: they were asked to indicate the orientation (left vs right) of the higher-contrast stimulus. After Carrasco et al. 2004; Figure 1.

2. Attention alters spatial vision: perceived contrast, spatial frequency, gap size and object size, and saturation (but not hue)

Attention increases perceived contrast. Contrast, a fundamental dimension of vision, is a natural candidate for understanding the relation between attention and appearance. Psychophysical and neurophysiological studies indicate that attention increases contrast sensitivity, and suggest that attention may also increase perceived contrast (for reviews see Reynolds and Chelazzi 2004, Carrasco 2006).

To investigate the effects of attention on perceived contrast, observers are presented with two Gabor patches, one to the left and one to the right of fixation, and asked to report the orientation of the higher-contrast stimulus. These instructions emphasize the orientation judgement, when in fact the main interest is in the contrast judgements. On each trial, the 'standard' Gabor had a fixed contrast, whereas the contrast of the 'test' Gabor was randomly chosen from a range of contrasts sampled around the standard contrast. The orientation of each Gabor was chosen randomly. By assessing observers' responses, the psychometric function describing the probability of choosing the test patch relative to the standard, as a function of their contrast, was obtained. The test contrast at which this function reaches 50% is the *point of subjective equality* (PSE). These functions were measured when transient covert attention was automatically captured to the cued location, via a peripheral cue, and when it was distributed across the display, via a neutral cue. The peripheral cue was uninformative in terms of both stimulus orientation and contrast. Observers were told that the peripheral cue had equal probability of appearing either to the left or right of fixation and over the higher or lower contrast stimulus. This eliminated the possibility of observers giving more weight to the information at the cued location and hence a decisional explanation for an attentional effect.

Transient attention significantly increased perceived contrast (Fig. A23a). In the neutral condition the PSE occurred at physical equality. When the test patch was cued the PSE shifted to lower test contrasts; conversely, when the standard patch was cued the PSE shifted to higher test contrasts. The effects are similar for low− and high−contrast stimuli. Because observers perform an orientation discrimination task contingent upon appearance, an objective index shows that the cue improved performance in the discrimination task. The results further argue against response bias, as it should not produce a change in discrimination performance. In sum, when observers' attention was drawn to a stimulus location, observers reported that stimulus as being higher in contrast than it actually was, thus indicating that attention changes appearance.

Schneider (2006) reported that peripheral cues increase perceived brightness only at levels near detection threshold, more so for white than black cues, and he predicted that reversing the cue's luminance polarity should lead to differential cueing effects. However, when this prediction was tested, both black and white cues increased the apparent contrast to the same degree, thus confirming that the cue effect is due to attention, not to sensory factors (Ling and Carrasco 2007).

Tsal et al. (1994) reported that attention reduces perceived brightness contrast, whereas Prinzmetal et al. (1997), using a dual task, reported that attention does not change stimulus appearance in a number of perceptual domains (e.g. frequency, hue); rather, it only reduces response variance, rendering a more veridical percept. However, methodological concerns limit both findings: in Tsal's study, observers were asked to make a comparison judgement between the target and one of four test patterns held in memory, thus forcing observers to rely on a possibly biased categorical memory representation to make their responses.

In Prinzmetal's studies, a concurrent task paradigm was used in which attention allocation is not properly controlled, making it difficult to isolate the source of possible processing differences. Moreover, because observers were given an unlimited response time, eye movements between the simultaneously presented target and the response palette were possible, thus confounding results attributed to covert attention with overt eye movements, which could underlie the veridicality of their judgements. The conclusions of these studies are further limited because observers were asked to make appearance judgements directly, and there was no objective index of the effectiveness of the attention manipulation (e.g. Carrasco et al. 2004, Treue 2004).

It is likely that the appearance enhancement (Carrasco et al. 2004, Ling and Carrasco 2007) accompanies the increased contrast sensitivity observed in previous psychophysical studies. The conclusion that attention increases apparent contrast supports a linking hypothesis, which states that the attentional enhancement of neural firing is interpreted as if the stimulus has a higher contrast. Converging evidence from neurophysiological, psychophysical, and neuroimaging studies support this proposal (Luck 2004, Reynolds and Chelazzi 2004, Treue 2004, Carrasco 2006).

Attention increases perceived spatial frequency, gap size, and object size. Using the appearance paradigm described above, it has been shown that attention increases apparent spatial frequency and apparent gap size, which are both related to spatial resolution (Gobell and Carrasco 2005). This result is consistent with the finding that in a gap−localization task, attention increases the perceived distance between the ends of the two line stimuli, making the gap bigger and easier to localize (Shalev and Tsal 2002). Both studies lend support to the proposal that attention increases spatial resolution by contracting a neuron's effective receptive field around the attended stimulus. Furthermore, because spatial tuning of visual neurons provides the basis for perceiving spatial relations, attention might distort perceived spatial relation and object sizes by shifting receptive fields. The appearance paradigm was used to test this hypothesis. Consistent with the finding that attention is mediated by dynamic shifts of visual receptive fields, attention increased the perceived size of moving visual patterns (Anton−Erxleben et al. 2007).

Attention increases perceived saturation, but does not alter perceived hue. The appearance paradigm also revealed that attention increases perceived saturation consistently for three separated equiluminant regions of colour space (red, blue, and green). The same paradigm, however, revealed no effect on apparent hue (Fig. A24a). The existence of the effect for saturation, but not for hue, is notable in light of the fact that attention improves orientation discrimination for both hue and saturation stimuli, which validates cue effectiveness. This dissociation shows that the presence of an attentional enhancement of behavioural performance does not lead to, or require, a corresponding change or enhancement in appearance. Thus, the cueing effect on saturation appearance cannot be explained by response bias or cue bias—response bias towards the cued item. This finding is strong evidence that it is a genuine phenomenal effect and not a cognitive effect that is not driven by phenomenology (Fuller and Carrasco 2006).

A useful distinction in this context is that of metathetic vs prothetic perceptual dimensions. Saturation, contrast, spatial frequency, and flicker rate are prothetic dimensions having meaningful zero values and inherent directionality. Hue is metathetic; our percepts of red and blue are qualitatively different. Attention may increase the appearance of prothetic dimensions because increased contrast and saturation make it easier to discriminate the signal from the background, and facilitate the discrimination of the features of the signal. However, there is no a priori reason why attention should affect apparent hue in one direction or another.

3. Attention alters temporal vision: perceived flicker rate, motion coherence, and speed

The appearance paradigm was used to assess a phenomenological correlate of attention for temporal vision, asking whether and how transient attention affects perceived flicker rate. In each trial, two suprathreshold Gabor stimuli were counter−phase modulated at either the same or different temporal frequencies. Observers were asked to report the orientation of the stimulus

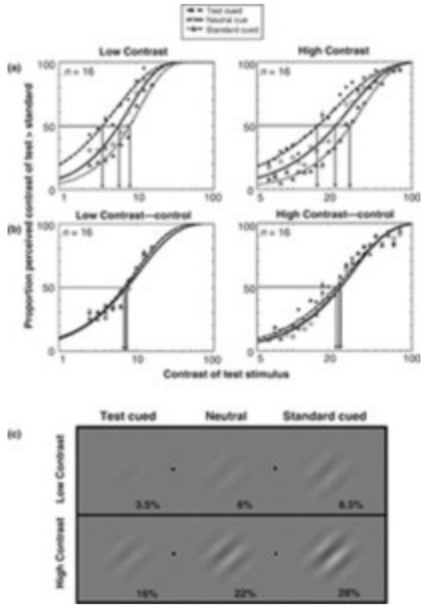

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Fig. A23. Contrast appearance. (a) Psychometric functions (proportion of responses in which observers reported the contrast of the test patch as higher than the standard patch as a function of the test patch's physical contrast) for the neutral and peripheral conditions (test cued and standard cued). The standard was 6% contrast (left panel) for the low-contrast condition and 22% contrast (right panel) for the high-contrast condition. The horizontal line intersecting both fits indicates the contrasts necessary for the test and standard stimuli to attain subjective equality (50%; see (c). (b) Control experiment: lengthened interval between cue and target. When transient attention is extinguished via a longer timing interval, results are the same when the test is peripherally or neutrally cued. Error bars correspond to the average ± 1 s. e. for each condition. (c) Effect of covert attention on apparent contrast. If you were looking at one of the four fixation points (black dot), and the grating to the left of that fixation point that was cued, the stimuli at both sides of fixation would appear to have the same contrast. Top: With attention, a 3.5% contrast stimulus appears as if it were 6% contrast. Similarly, a cued 6% contrast stimulus appears as if it were a more clearly discriminable 8.5% contrast stimulus. Bottom: Likewise, with high-contrast stimuli when a 16% contrast grating is cued it appears as if it were 22% contrast, and a cued 22% contrast grating appears as if it were 28%. After Carrasco et al. 2004; figures 2, 4, and 5.

that flickered faster. Directing attention to a stimulus location increased its perceived flicker rate. Attention could affect the activation pattern across temporal frequency channels by increasing the contribution or weight of the highest temporal frequency channel to the total output. This would result in an overestimation of perceived flicker rate in the attended compared with the neutral condition (Montagna and Carrasco 2006).

To assess the effect of attention on the appearance of motion, observers viewed pairs of moving dot patterns and were asked to report the motion direction of the pattern with higher coherence. Directing attention to a stimulus location increased its perceived coherence level and improved performance on a direction discrimination task. These results are consistent with neurophysiological studies showing that attention modulates motion−sensitive areas MT/hMT+ in monkeys and humans respectively, and provide evidence of a subjective perceptual correlate of attention with a concomitant effect on performance (Liu et al. 2006).

The appearance paradigm has also revealed that directing attention to a stimulus location increased its perceived speed, although, according to the author, this may occur despite a lack of change in visual awareness (Turatto et al. 2007).

4. Ruling out alternative explanations of the cueing effect

Several control experiments rule out alternative explanations of the appearance results, namely cue or response bias.

Reversing the direction of the question. When observers were asked to report the orientation of the stimulus of lower, rather than higher, apparent contrast, they chose the cued test stimulus less frequently. Had results been due to cue bias, observers would have chosen the cued stimulus more often than the other stimulus regardless of the direction of the question. Reversing the instructions has been a successful control in appearance studies of colour saturation (Fuller and Carrasco 2006; see Fig. A19b), contrast (Carrasco et al. 2004, Ling and Carrasco 2007), spatial frequency (Gobell and Carrasco 2005), flicker rate (Montagna and Carrasco 2006), size of a moving object (Anton−Erxleben et al. 2007), and speed (Turatto et al. 2007).

Lengthening the interval between the cue and target. Because of the ephemeral nature of transient attention (*c*.120 ms), a lengthened interval between the cue and target should eliminate any effect that it may have on perception, and any residual effect would be attributed to a cue bias. When the cue preceded the stimuli by 500 ms, neutral and peripheral conditions did not differ. Appearance studies of contrast appearance (Carrasco et al. 2004, Ling and Carrasco 2007; see Fig. A18b), motion coherence (Liu et al. 2006), and speed (Turatto et al. 2007) show that when transient attention was no longer active, stimulus appearance is not altered.

Post−cue vs pre−cue. When observers were asked to report the stimulus followed by a post−cue rather than preceded by a pre−cue, the pre−cue increased perceived spatial frequency (Gobell and Carrasco 2005) or object size (Anton−Erxleben et al. 2007), but the post−cue did not alter appearance, although the spatial and temporal contiguity between cue and stimulus were the same. These results are consistent with an fMRI study investigating the neural basis of transient attention, in which pre−cueing, but not post−cueing, the target location increased stimulus−evoked response in corresponding retinotopic striate and extrastriate areas (Liu et al. 2005).

Performance. Appearance and orientation discrimination performance have been concurrently assessed (Carrasco et al. 2004, Fuller and Carrasco 2006, Liu et al. 2006, Anton−Erxleben et al. 2007, Ling and Carrasco 2007). Improvements in such performance−based tasks indicate that exogenous attention has been engaged to a peripheral location. Because cue location and stimulus orientation are uncorrelated, concurrent improvements at the cued locations and impairments at the uncued locations further show that the appearance results are not due to response bias.

5. Conclusion

Using this appearance paradigm, it has been found that attention alters our subjective impression of many dimensions of spatial and temporal vision, mediated by the ventral and dorsal streams, respectively: contrast (Carrasco et al. 2004, Ling and Carrasco 2007), spatial frequency and gap size, both related to spatial resolution (Gobell and Carrasco 2005), colour saturation (but not hue; Fuller and Carrasco 2006) and perceived size of moving visual patterns (Anton−Erxleben et al. 2007), as well as flicker rate (Montagna and Carrasco 2006), motion coherence (Liu et al. 2006), and perceived speed (Turatto et al. 2007).

By showing that the spatial deployment of attention leads to a change in phenomenological experience, these studies confirm the intuition of William James that attention and awareness are intertwined. We conclude that covert attention can intensify the sensory impression of a stimulus. Attention not only affects how we perform in a visual task—it also affects what we see and experience.

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Bibliography

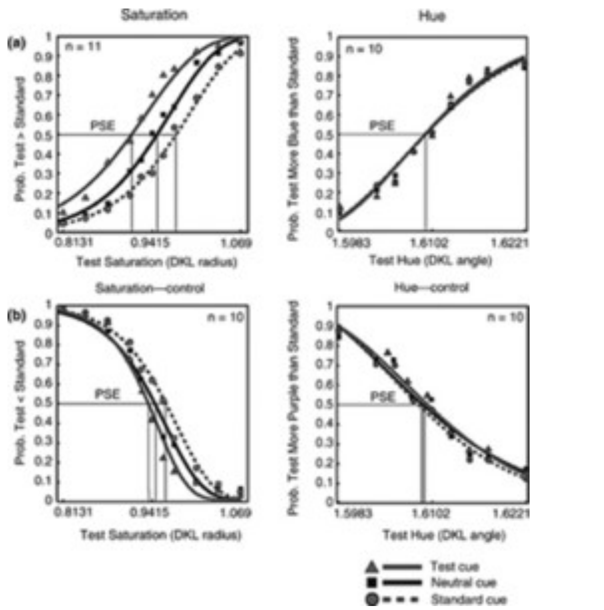

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Fig. A24. Colour appearance psychometric functions. (a) Left panel: saturation functions (proportion of responses when observers were asked to report the orientation of the 'redder' stimulus in which observers reported the saturation of the test patch as higher than the standard as a function of the test patch's physical saturation) for the neutral and peripheral conditions (test cued and standard cued). The intersection of the horizontal and vertical lines indicates the saturation necessary for the test and standard stimuli to attain subjective equality (50%). Right panel: hue functions (proportion of responses in which observers reported the 'bluer' stimulus of each pair as higher than the standard as a function of the test patch's physical hue) for the neutral and peripheral conditions (test cued and standard cued). The intersection of the horizontal and vertical lines indicates the hue necessary for the test and standard stimuli to attain subjective equality (50%). (b) Control experiments: reversed instructions functions when observers were asked to report the orientation of the 'less red' stimulus (saturation; left panel) or the 'purpler' stimulus (hue; right panel). Attention altered the appearance of saturation (left panels) but not of hue (right panels). After Fuller and Carrasco 2006, figures 5 and 7.

Anton−Erxleben, K., Henrich, C., and Treue, S. (2007). '*Attention changes perceived size of moving visual patterns*'. *Journal of Vision*, 7.
Find this resource:

Carrasco, M. (2006). '*Covert attention increases contrast sensitivity: psychophysical, neurophysiological and neuroimaging studies*'. *Progress in Brain Research*, 154.
Find this resource:

——, Ling, S., and Read, S. (2004). '*Attention alters appearance*'. *Nature Neuroscience*, 7.
Find this resource:

Fuller, S. and Carrasco, M. (2006). '*Exogenous attention and color perception: performance and appearance of saturation and hue*'. *Vision Research*, 46.
Find this resource:

Gobell, J. and Carrasco, M. (2005). '*Attention alters the appearance of spatial frequency and gap size*'. *Psychological Science*, 16.
Find this resource:

Helmholtz, H. L. F. von (1910/1925). *Helmholtz's Treatise on Physiological Optics*, Vol. 3, ed. and trans. J. P. C. Southhall.
Find this resource:

James, W. (1890/1950) *The Principles of Psychology*.
Find this resource:

Ling, S. and Carrasco, M. (2007) '*Transient covert attention does alter appearance: a reply to Schneider (2006)*'. *Perception and Psychophysics*, 69.
Find this resource:

Liu, T., Fuller, S., and Carrasco, M. (2006). '*Attention alters the appearance of motion coherence*'. *Psychonomic Bulletin and Review*, 13.
Find this resource:

——, Pestilli, F., and Carrasco, M. (2005). '*Transient attention enhances perceptual performance and FMRI response in human visual cortex*'. *Neuron*, 45.
Find this resource:

Luck, S. J. (2004). '*Understanding awareness: one step closer*'. *Nature Neuroscience*, 7.
Find this resource:

Montagna, B. and Carrasco, M. (2006). '*Transient covert attention and the perceived rate of flicker*'. *Journal of Vision*, 6.

Find this resource:

Nakayama, K. and Mackeben, M. (1989). '*Sustained and transient components of focal visual attention*'. *Vision Research*, 29.
Find this resource:

Posner, M. I. (1980). '*Orienting of attention*'. *Quarterly Journal of Experimental Psychology*, 32.
Find this resource:

Prinzmetal, W., Nwachuku, I., Bodanski, L., Blumenfeld, L., and Shimizu, N. (1997). '*The phenomenology of attention. 2. Brightness and contrast*'. *Consciousness and Cognition*, 6.
Find this resource:

Reynolds, J. H. and Chelazzi, L. (2004). '*Attentional modulation of visual processing*'. *Annual Review of Neuroscience*, 27.
Find this resource:

Schneider, K. (2006). '*Does attention alter appearance?*' *Perception and Psychophysics*, 68.
Find this resource:

Shalev, L. and Tsal, Y. (2002). '*Detecting gaps with and without attention: further evidence for attentional receptive fields*'. *European Journal of Cognitive Psychology*, 14.
Find this resource:

Treue, S. (2004). '*Perceptual enhancement of contrast by attention*'. *Trends in Cognitive Science*, 8.
Find this resource:

Tsal, Y., Shalev, L., Zakay, D., and Lubow, R. E. (1994). '*Attention reduces perceived brightness contrast*'. *Quarterly Journal of Experimental Psychology A*, 47.
Find this resource:

Turatto, M., Viscovi, M., and Valsecchi, M. (2007). '*Attention makes moving objects be perceived to move faster*'. *Vision Research*, 47.
Find this resource:

Wundt, W. (1902). *Outlines of Psychology*, trans. C. H. Judd.
Find this resource: