

The asynchrony of consciousness

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We present below a simple hypothesis on what we believe is a characteristic of visual consciousness. It is derived from facts about the visual brain revealed in the past quarter of a century, but it relies most especially on psychophysical evidence which shows that different attributes of the visual scene are consciously perceived at different times. This temporal asynchrony in visual perception reveals, we believe, a plurality of visual consciousnesses that are asynchronous with respect to each other, reflecting the modular organisation of the visual brain. We further hypothesise that when two attributes (e.g. colour and motion) are presented simultaneously, the activity of cells in a given processing system is sufficient to create a conscious experience of the corresponding attribute (e.g. colour), without the necessity for interaction with activities of cells in other processing systems (e.g. motion). Thus any binding of the activity of cells in different systems should be more properly thought of as a binding of the conscious experiences generated in each system.

Our hypothesis about visual consciousness is derived from the following facts:

1. The primate visual brain consists of multiple areas (Zeki 1978, Felleman and Van Essen 1991, Zeki *et al.* 1991, Haxby *et al.* 1994, Tootell *et al.* 1996)
2. The consensus of evidence is that the different areas are functionally specialised to process different attributes of the visual scene, e.g. colour, form and motion, a conclusion derived from anatomical, physiological and clinical evidence (Zeki 1978, DeYoe and Van Essen 1988, Livingstone and Hubel 1988, Zeki and Shipp 1988, Zeki 1993). This statement is correct even if there are differing views about the extent of functional specialisation within each system and across the different visual systems (Maunsell 1993, Cowey 1994, Schiller 1997).
3. The specialised processing systems can act fairly autonomously of one another. Clinical evidence shows that damage restricted to one system leads to an imperception in the attribute for which that system is specialised, and not to a global blindness (see Zeki 1993 for a review). Conversely, a system that is spared while all others are damaged can function more or less adequately. For example, damage that is severe enough to render patients blind - as in the case of carbon monoxide poisoning or cardiac arrest - can nevertheless spare their colour vision selectively (Wechsler 1933, Campion and Latt 1985, Humphrey *et al.* 1995). Moreover, even when one system, such as the motion one based on area V5, is largely disconnected from the primary visual cortex (V1) it can still function crudely, presumably through the alternative pathway that reaches V5 without passing through V1 (Cragg 1969, Standage and Benevento 1983, Beckers and Zeki 1995, ffytche *et al.* 1995). Under these conditions activity in V5 can result in a conscious visual experience without the participation of V1 or of areas specialised for other visual attributes (Riddoch 1917, Ceccaldi *et al.* 1992, Barbur *et al.* 1993, Weiskrantz 1995).
4. Although in our daily experience we perceive different modalities coherently (*i.e.*, with spatio-temporal registration), there is a large body of evidence which shows that different modalities (e.g. audition and vision) are perceived with different delays from the time of stimulus onset in the subsecond range (Woodworth and Schlosberg 1965). This is also true of attributes within a modality. An example in vision is when subjects are asked to pair two rapidly alternating states of two attributes, for example a bar having one of two colours and one of two orientations. They are then found to consistently mis-bind attributes which occur at the same time, because the two attributes are perceived at different times. For example colour is perceived before orientation, which is perceived before motion, with about 30 ms and 40 ms lag times, respectively (Moutoussis and Zeki 1997). What subjects perceive consciously in these experiments is the change in the two states while they are pairing one with the other; they are not however aware of what we measure, namely the difference in relative perceptual times. Given that subjects have to pay equal attention to both attributes in order to pair them, the controversial phenomenon of 'prior entry' (Cairney 1975) is not relevant here. Collectively, this evidence supports the notion of a general asynchrony in perception, including visual perception.

Thus two characteristics of the visual brain are: (a) it consists of multiple, spatially distributed and functionally specialised processing systems and (b) there is a temporal asynchrony in the perception of different visual attributes.

The interpretation that we give to the above facts leads us to formulate a testable hypothesis about visual consciousness.

- (a) We interpret this asynchrony in the perception of different attributes to mean that different processing systems create their corresponding percepts independently and with different delays. We therefore speak of processing-perceptual systems; neural activity in each of these can have a conscious correlate (micro-consciousness) (Zeki and ffytche 1998; Moutoussis and Zeki 1997), without the

need for a central conscious observer (Dennett and Kinsbourne 1992). Since the different processing systems generate their percepts with different delays with respect to stimulus onset, it follows that there are multiple visual micro-consciousnesses which are asynchronous with respect to each other. More simply, our hypothesis states that the neural correlates of consciousness for two attributes (e.g. colour and motion) differ in space and time. An experiment to test this would be one in which two attributes, presented simultaneously but perceived at different times, can be manipulated in such a way that one attribute is perceived without the other. This would show that when two systems are simultaneously stimulated, activity in one need not be bound to activity in the other to result in a conscious visual experience.

- (b) We hypothesise that when two attributes (e.g. colour and orientation) are presented simultaneously, they will be perceived at different times if the percepts are created by the activity of cells at different sites; conversely, they will be perceived at the same time if the percepts are created by activity of cells at the same site (Bartels and Zeki, A Theory of Perceptual Sites in the Cortex, in preparation). Over short time-spans, different attributes will therefore be perceived asynchronously unless they are processed at the same site. We remain deliberately vague about the definition of 'site' - it could refer to cells or to areas within a specialised system. Interestingly we are not aware of this perceptual asynchrony in our daily experience; it is only revealed by relatively sophisticated psychophysical experiments.

The above leads us to put forward the view that consciousness is not the consequence of binding the activities of cells at different sites; it is rather the micro-consciousnesses that are generated at different sites that require binding. We think that our theory of the asynchronicity of consciousnesses might be important to future theorising about the nature of consciousness and the general problem of binding and coherence.

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