

How does conscious experience arise? The neural time factor

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How does the brain “produce” conscious subjective experience, an awareness of something? This question has been regarded as perhaps the most challenging one facing science. Penfield et al. [9] had produced maps of *where* responses to electrical stimulation of cerebral cortex could be obtained in human neurosurgical patients. Mapping of cerebral activations in various subjective paradigms has been greatly extended more recently by utilizing PET scan and fMRI techniques. But there were virtually no studies of what the appropriate neurons do in order to elicit a conscious experience. The opportunity for me to attempt such studies arose when my friend and neurosurgeon colleague, Bertram Feinstein, invited me to utilize the opportunity presented by access to stimulating and recording electrodes placed for therapeutic purposes intracranially in awake and responsive patients. With the availability of an excellent facility and team of co-workers, I decided to study neuronal activity requirements for eliciting a simple *conscious* somatosensory experience, and compare that to activity requirements for *unconscious* detection of sensory signals.

We discovered that a surprising duration of appropriate neuronal activations, up to about 500 msec, was required in order to elicit a conscious sensory experience [5]. This was true not only when the initiating stimulus was in any of the cerebral somatosensory pathways; several lines of evidence indicated that even a single stimulus pulse to the skin required similar durations of activities at the cortical level. That discovery led to further studies of such a delay factor for awareness generally, and to profound inferences for the nature of conscious subjective experience. It formed the basis of that highlight in my work [1,3].

For example, a neuronal requirement of about 500 msec to produce awareness meant that we do not experience our sensory world immediately, in real time. But that would contradict our intuitive feeling of the experience in real time. We solved this paradox with a hypothesis for “backward referral” of subjective experience to the time of the first cortical response, the primary evoked potential. This was tested and confirmed experimentally [8], a thrilling result. We could now add subjective referral *in time* to the already known subjective referral *in space*. Subjective referrals have no known neural basis and appear to be purely mental phenomena!

Another experimental study supported my “time-on” theory for

eliciting conscious sensations as opposed to unconscious detection [7].

The time-factor appeared also in an endogenous experience, the conscious intention or will to produce a purely voluntary act [4,6]. In this, we found that cerebral activity *initiates* this volitional process at least 350 msec before the conscious wish (W) to act appears. However, W appears about 200 msec before the muscles are activated. That retained the possibility that the conscious will could *control* the outcome of the volitional process; it could veto it and block the performance of the act. These discoveries have profound implications for the nature of free will, for individual responsibility and guilt.

Discovery of these time factors led to unexpected ways of viewing conscious experience and unconscious mental functions. Experience of the sensory world is delayed. It raised the possibility that all conscious mental functions are *initiated unconsciously* and become conscious only if neuronal activities persist for a sufficiently long time. Conscious experiences must be *discontinuous* if there is a delay for each; the “stream of consciousness” must be modified. Quick actions or responses, whether in reaction times, sports activities, etc., would all be initially unconscious. Unconscious mental operations, as in creative thinking, artistic impulses, production of speech, performing in music, etc., can all proceed rapidly, since only brief neural actions are sufficient. Rapid unconscious events would allow faster processing in thinking, etc. The delay for awareness provides a physiological opportunity for modulatory influences to affect the content of an experience that finally appears, as in Freudian repression of certain sensory images or thoughts [2,3].

The discovery of the neural time factor (except in conscious will) could not have been made without intracranial access to the neural pathways. They provided an experimentally based entry into how new hypotheses, of how the brain deals with conscious experience, could be directly tested. That was in contrast to the many philosophical approaches which were speculative and mostly untestable. Evidence based views could now be accepted with some confidence.

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