

Conscious vs neural time

SIR — Conscious subjective experience and neural processes are phenomenologically independent; the first is accessible only to the subject individual, the latter to an external observer. The relationship between these phenomena can, however, be investigated. Our experimental analyses of the time-factors in this inter-relationship have provided evidence for at least two remarkable features; first, a substantial duration of continual cerebral neural activity, up to about 0.5 s, is required before a conscious experience appears (whether a sensation or intention to move)^{1,2}, and second, the subjective timing of the sensory experience appears

Optimal circular packing

SIR — In his News and Views article¹, Ian Stewart recounts the amusing story of how the clathrin cages of coated vesicles beat the mathematicians at solving the problem of finding optimal coverings of spheres by circles. I would like to draw attention to another class of structures, the inorganic clathrate hydrates, that may have the same mathematical ability.

The structures of the clathrate hydrates² are based on a space-filling packing of polyhedra with pentagonal and hexagonal faces. An example is provided by the structure of the hydrate of chloroform (sometimes called the type II clathrate hydrate structure), which has been known for some time³. As well as the pentagonal dodecahedra which solve the 12-circle problem, the structure contains the hexakaidecahedra with 12 pentagonal and 4 hexagonal faces (*b* in Stewart's article), that have now been shown⁴ to correspond to the best-known solution to the problem of the optimal sphere covering by 16 circles.

The dual of the hexakaidecahedron, where now the vertices represent the 16 circle centres, has an even longer history⁵ in crystal chemistry, where it is called the Friauf polyhedron. It may be derived by capping the hexagonal faces of a truncated tetrahedron and is a conspicuous feature of many alloy structures². However, in this context it probably arises as an attempt to solve the complementary circle packing (rather than covering) problem.

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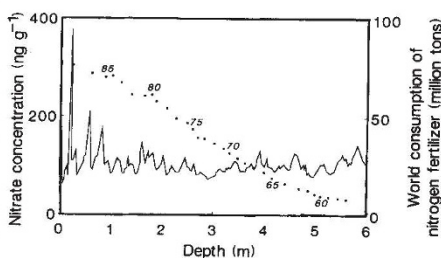
1. Stewart, I. *Nature* **351**, 103 (1991).
2. Wells, A. F. *Structural Inorganic Chemistry* 5th edn (Clarendon, Oxford, 1984).
3. Clausen, W. F. *J. chem. Phys.* **19**, 259–260 (1951).
4. Tarnai, T. *J. molec. Biol.* **103**, 485–488 (1991).
5. Friauf, J. B. *J. Am. chem. Soc.* **49**, 3107–3114 (1927).

to have no significant delay. This timing appears to be subjectively referred back to an early signal arriving at the cortex within about 10–20 ms (ref. 3). Glynn argues⁴ that our proposal of subjective antedating is flawed, and that even if the proposal is sound, it does not violate any physical or physiological rules.

We had shown that the sensation of a skin stimulus pulse, applied well after the onset of a train of pulses to somatosensory cortex, was reported by subjects to appear before the sensation elicited by the cortical stimulus. It was empirically established that the cortical stimulus could not have elicited its sensation until at least 0.5 s after its onset; other evidence^{1,3} indicated that 'neuronal adequacy' for production of the skin-induced sensation also should have involved a similar delay.

Fertilizer and snowfall nitrate

SIR — Turner compares¹ global consumption of nitrogen fertilizer from 1950 to 1987 with measurements of the nitrate concentration in snowfall at the South Pole (station T) taken from Mayewski *et al.*². Unfortunately, the data from Mayewski's original paper (Fig. 3 of ref. 2) have been misunderstood. The data reproduced by Turner as nitrate in snowfall



Nitrate concentration (solid line) in 6 metres of snowfall at South Pole station T (ref. 1) compared to world consumption of nitrogen fertilizer (dotted line) (from ref. 2).

are in fact the October total ozone concentration from Halley station, Antarctica. A diagram showing the correct comparison is produced above. Turner states that the apparent rise in nitrate is a linear trend with a 60 per cent increase between 1975 and 1985, and compares this to a 62 per cent increase in global consumption of nitrogen fertilizer over the same period. The snowfall-nitrate data, however, appear essentially flat, apart from unusually large peaks in the 1987 and 1988 snowfall. It seems unlikely on this evidence that a correlation exists between world consumption of nitrogen fertilizer and nitrate deposition at the South Pole.

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1. Turner, R. E. *Nature* **349**, 469–470 (1991).
2. Mayewski, P. A. & Legrand, M. R. *Nature* **346**, 258–260 (1990).

The reported timing order for the skin versus cortically induced sensations therefore suggested a subjective antedating for the skin sensation but not for the cortically induced one; this proposal has been tested and confirmed³.

Glynn proposed⁴ an alternative explanation: to produce the conscious sensory experience, an extra latency of about 0.5 s would follow the adequate 0.5-s cortical stimulus but not the 0.5-s time for neuronal adequacy after the skin stimulus. But there is no experimental evidence that further cortical activity must follow the minimally adequate stimulus train applied to the cortex; indeed, electrophysiological recordings are negative¹. Consequently, adding an additional 0.5-s latency for the experience to appear only after the adequate cerebral stimulus is simply speculation. Glynn further proposes that no extra latency follows the empirically required minimum stimulus train applied to the medial lemniscus (ascending sensory pathway in midbrain). The striking absence of delay for subjective timing of lemniscus-induced sensation, in contrast to the cortically induced sensation³, is explained by our hypothesis without *ad hoc* assumptions of differences in latency.

The existence of a neural time-marker¹ does provide a neuronal event to act as a clock-time reference for subjective antedating, but it does not explain how that event is translated into an altered content of subjective timing. Everyone would agree that subjective experiences are intimately related to neuronal processes, but the relationships of subjective time (and other experiences) to neural activities are not definable, *a priori*, by physical observations or by the known physical laws; the relationships must be discovered^{1,2}. Glynn's views seem to rest on the unstated premise that a "neural-identity theory"⁵ explains the mind-brain relationship. But identity theory is a philosophical position, not a scientifically established one. In view of the special yet fundamentally important relation between the phenomenologies of conscious experience and the physical world, we need to keep an open mind about the possibilities for explaining it.

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GLYNN REPLIES — By calling the period between the completion of a cortical stimulus and the evoked sensation an "extra latency" — as if there had already been a latent period — and the period between the completion of a skin stimulus and the evoked sensation a "time for neuronal adequacy", Libet makes my suggestion that the two latent periods are similar⁴ look like a suggestion that they are very different. His letter also misrepresents my suggestion about the latent period that follows stimulation of the medial lemniscus.