

acquired during a given task or perceptual activity (while the subject is listening to Bach's *Prelude in C Major*, for example). The temporally static image can account only for a static cerebral response. But the brain's response is actually dynamic and self-organizing over time. So the perception of music and its neural code must be reflected in the neural dynamics — in both space and time. It is not only important to identify the neurons, neuronal assemblies or brain regions that respond to a given input. We must also develop techniques that allow the systematic classification of the temporal dynamics underlying elements of information processing. But adding time as the fourth dimension to three-dimensional space is not easy.

Patel and Balaban<sup>3</sup> study brain dynamics using stimulus-related magnetoencephalographic responses. Subjects hear different sequences of tones that are switched on and off in rapid, 40-Hz sequences. Examination of the stimulus-related brain response that cycles at 40 Hz, the so-called steady-state response, allowed Patel and Balaban to determine how the timing of neural responses varied with different tone sequences. They found a relationship between the phase (but not the signal power) of the steady-state response and the frequency of the acoustic stimulus. That is, the timing of the neuronal response depended on the properties of the stimulus.

Intriguingly, these phase fluctuations vary with the structures of the tone sequences. Between-site phase coherence, which indicates synchronized activity between brain areas, was most pronounced for tone sequences that resembled melodies. Generalizing this outcome, the *Prelude in C Major* should produce higher inter-channel phase coherence than the same tones shuffled in random sequence (Fig. 1). Would Bach do better than the Beatles? We do not know, but now we can study how limited brain regions track the changes in pitch of auditory sequences as a piece of music is played.

Steady-state responses are a valuable tool for monitoring activity in different sensory modalities. To exploit this approach fully, we will need to understand how such brain responses are produced. In general, if the interval between successive stimuli is short enough, the transient evoked response to one stimulus will not have died away before the next stimulus is delivered. The compound response that appears is the steady-state response. There are various ways in which transient responses can sum over time to produce a steady-state response, and these fall into two groups. For a linear system, transient and steady-state descriptions of the system's behaviour are equivalent, and a simple superposition of transient evoked responses with the appropriate time lags

should fully predict the steady-state responses<sup>4</sup>. However, neural assemblies are nonlinear elements. If a nonlinear system is stimulated periodically, harmonics, combination frequencies and subharmonic components may evolve<sup>5</sup>.

Neither of these simple principles of organization accounts for the observation by Balaban and Patel that the phase of the steady-state response follows the pitch of the auditory stimulus more strongly for scales than for melodies. Obviously, higher areas of brain influence the auditory cortex and related structures by 'top-down' processes, tuning their responses according to contextual cues and previous learning. So coupled oscillations between higher-order and sensory cortices may explain why what sounds like noise to an adult is music to the ears of a teenager.

Attempts to segregate brain function into distinct modules are limited because the nervous system tends to operate through the intercommunication of task-relevant subsystems. So the simplistic modular approach needs to be complemented by modelling, in space and time, the network that incorporates the different modules. In the visual system, several different types of discrimination can be processed in the same small

area of cortex. A similar phenomenon has been seen in the motor system<sup>6</sup>. Likewise, a single type of stimulation of two digits can produce two opposite, use-dependent effects on the spatial relationship of the cortical representations of the digits, depending on the nature of the discrimination condition used<sup>7</sup>. In other words, multiple maps, specific to different modes of discrimination or tasks, share the same region of cortex. So the three-dimensional modular approach provides us with seemingly conflicting results: there are many three-dimensional shadows in a four-dimensional world. It is time to add time!

Thomas Elbert and Andreas Keil are in the Department of Psychology, University of Konstanz, D-78457 Konstanz, Germany.  
e-mails: thomas.elbert@uni-konstanz.de  
andreas.keil@uni-konstanz.de

1. Frith, C. D. & Friston, K. J. in *Cognitive Neuroscience* (ed. Rugg, M. D.) 169–195 (MIT Press, Cambridge, Massachusetts, 1997).
2. Elbert, T. in *Magnetism in Medicine* (eds Andr , W. & Nowak, H.) 190–262 (Wiley, New York, 1998).
3. Patel, A. & Balaban, E. *Nature* **404**, 80–84 (2000).
4. Gutschalk, A. et al. *Clin. Neurophysiol.* **110**, 856–868 (1999).
5. Pantev, C., Roberts, L. E., Elbert, T., Ross, B. & Wienbruch, C. *Hearing Res.* **101**, 62–74 (1996).
6. Karni, A. et al. *Nature* **377**, 155–158 (1995).
7. Braun, C., Schweizer, R., Elbert, T., Birbaumer, N. & Taub, E. *J. Neurosci.* **20**, 446–450 (2000).

Animal biology

Beauty is ova-rated

Female ducks are choosy when it comes to mating. Some male mallards (*Anas platyrhynchos*) are much more attractive to females than others, and females that mate with these 'preferred' males seem to raise more chicks to adulthood. It has generally been assumed that this bias reflects a genetic advantage conferred by the father.

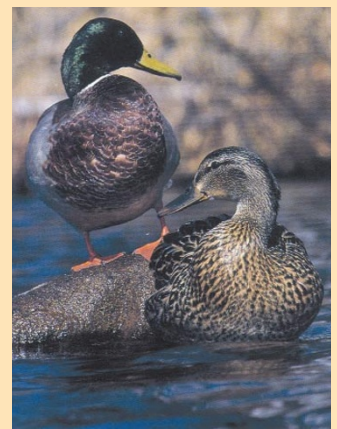
Elsewhere in this issue (*Nature* **404**, 74–77; 2000), Emma Cunningham and Andrew Russell propose a different explanation. They have compared the clutches of eggs produced by females after mating with more attractive males with those produced by females mated with less attractive males. They find that pairings with preferred males result in bigger eggs being laid.

Chicks that hatch from large eggs are more likely to survive the critical first few days after hatching. So the higher viability of the offspring

of attractive males may have nothing to do with the genetic legacy of the father — instead, it may result from increased maternal investment in the eggs. When Cunningham and Russell controlled for egg size, the attractiveness of the father made no difference to the health of the chicks.

So why do female ducks invest more energy in eggs that are fathered by more attractive males? It is likely that male attractiveness is linked to some characteristic that makes their offspring more successful in the long run. Females would then invest more in these eggs to further their own breeding success.

Male mallards are not good fathers — females do all the work of rearing chicks. So males cannot be selected by females for their paternal qualities. But they do defend feeding areas around their mates during the breeding



season, so attractiveness may be linked to the ability of a male to fend off other mallards. This ties in with the fact that females prefer males from early-hatching clutches, who tend to be bigger and stronger.

Cunningham and Russell point out that researchers need to be careful, when studying the influence of male attractiveness or dominance on the viability of offspring, to allow for the effects of differential maternal investment rather than attributing all differences to paternal genetics.

Rachel Smyly

SCOTT NIELSEN