computations (for example, 32 × 24) additionally engaged a left parieto-superior frontal network, which may be involved in holding multi-digit numbers in visuospatial working memory, along with bilateral inferior temporal gyri, which is implicated in visual mental imagery. Furthermore, the left intraparietal sulcus and the precentral gyrus were activated, which may reflect the involvement of a finger movement representation network in the calculation process. This is not to say that these skilled adults are counting on their fingers, but it may be that the childhood use of fingers in learning to calculate somehow creates the neural substrate for later acquisition of numerical knowledge[15].

The most interesting finding, however, was that Gamm's brain showed task-dependent activation of four additional areas relative to control subjects. Three of these areas have previously been implicated in episodic memory processes: right medial frontal cortex, right parahippocampal gyri and right upper anterior cingulate gyrus (**Fig. 1**). None of the control subjects showed increased activation relative to baseline in these areas. This supports the proposal that experts develop an ability to use long-term episodic memory to maintain task-relevant materials, rather as computers extend the capacity of RAM by using swap space on the hard drive to create a larger 'virtual memory'.

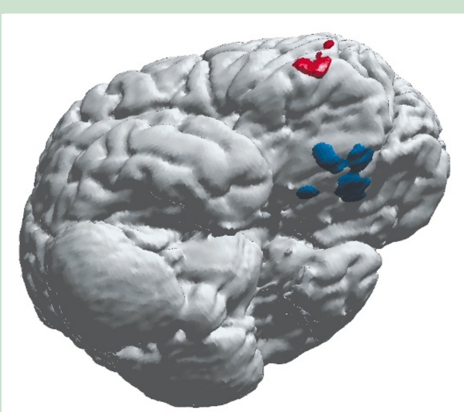
What does this tell us about the making of a prodigy? Frances Galton, in *Hereditary Genius*, proposed three factors, in necessary conjunction: "I do not mean capacity without zeal, nor zeal without capacity, nor even a combination of both of them, without an adequate power of doing a great deal of very laborious work." This probably corresponds to the popular view of genius. Of course, we all know it is ninety percent perspiration, but most of us also subscribe to what might be called 'the Mozart argument'; you cannot become a Mozart just by hard work.

Curiously, though, superior domain-specific innate capacity does not seem to have been relevant in Gamm's case, because he did not seem blessed with any particular gift for mathematics. As a result he lost interest in mathematics until about the age of twenty, when he came across an algorithm for calendrical calculation, working out the day of the week for any date, past or future. He practiced it for fun, and then entered for a TV competition where he could win bets by solving various calculations. In preparation for the program, he started to train up to four hours a day, learning number facts and calculation procedures; he now performs professionally. It would be interesting to compare his abilities and their neural substrate with those of a calculator or gifted mathematician who has shown prodigious abilities from an early age. Is the use of LTWM and episodic memory structures the principal factor differentiating prodigies from normal people, and if so, at what age or stage does this occur? Gamm said that at school he was "very bad at arithmetic" because the teachers never explained the concepts in ways he could understand[10]. Being able to grasp the meaning, structure and relationship of objects in the expert domain seems to be critical in setting up easily retrievable structures in long-term episodic memory, just as it is in our mastery of language. This study, though focused on a remarkable individual, illuminates the unremarkable as well as the extraordinary skills we all possess.

1. Pesenti, M. *et al. Nat. Neurosci.* **4**, 103–107 (2001).
2. Ericsson, K. A. & Kintsch, W. *Psychol. Rev.* **102**, 211–245 (1995).
3. Baddeley, A. *Working Memory* (Clarendon, Oxford, 1986).
4. Paulesu, E., Frith, C. D. & Frackowiak, R. S. J. *Nature* **362**, 342–345 (1993).
5. Smith, S. B. *The Great Mental Calculators* (Columbia Univ. Press, New York, 1983).
6. Ashcraft, M. *Math. Cognit.* **1**, 3–34 (1995).
7. Pesenti, M., Seron, X., Samson, D. & Duroux, B. *Math. Cognit.* **5**, 97–148 (1999).
8. Butterworth, B., Shallice, T. & Watson, F. in *Neuropsychological Impairments of Short-Term Memory* (eds. Vallar, G. & Shallice, T.) 187–213 (Cambridge Univ. Press, Cambridge, 1990).
9. Schlaug, G., Jancke, L., Huang, Y. X., Staiger, J. F. & Steinmetz, H. *Neuropsychologia* **33**, 1047–1055 (1995).
10. Pascual-Leone, A. & Torres, F. *Brain* **116**, 39–52 (1993).
11. Krings, T. *et al.* A fMRI study. *Neurosci. Lett.* **278**, 189–193 (2000).
12. Logie, R. H., Gilhooly, K. J. & Wynn, V. *Mem. Cognit.* **22**, 395–410 (1994).
13. Butterworth, B., Cipolotti, L. & Warrington, E. K. *Q. J. Exp. Psychol.* **49A**, 251–262 (1996).
14. Zago, L. *et al. Neuroimage* (in press).
15. Butterworth, B. *The Mathematical Brain* (Macmillan, London, 1999).

Reward and punishment in orbitofrontal cortex

Although skill at gambling is usually thought to concern people frequenting casinos in Las Vegas, it has real-world consequences as well. Patients with orbitofrontal cortex (OFC) lesions show pronounced deficits in 'gambling' tasks, in which they are required to make choices based on the previous likelihood of monetary gain or loss—and it is widely thought that such deficits underlie their inability to use knowledge of more abstract reward or punishment to guide real-life behavior; such patients are frequently disinhibited, socially inappropriate and irresponsible. Now, O'Doherty and colleagues (page 95) extend the idea that the OFC is critical in forming associations between stimuli and their rewarding or punishing outcomes. Normal human subjects participated in a gambling task while they were in an fMRI scanner. Using a sophisticated event-related design, the authors were able to measure an increase in the activity of the lateral OFC related to the subjects' receipt of punishment (after selecting a stimulus that caused them to lose money; red) and deactivation following reward. The authors recorded the converse pattern in the medial OFC (activation following reward, blue; deactivation following punishment). Therefore, reward and punishment may be processed in distinct subregions of the OFC. Furthermore, the magnitude of activation correlated with the magnitude of the reward or punishment. These results may help to explain why patients with OFC damage seem to be unable to represent the magnitudes of gain or loss, and thus have difficulty judging whether particular decisions are advantageous based on previous experience.



John E. Spiro