turning 9 + 6 into 10 + 5) (*10*). The authors note that problems with larger numbers are more likely to be transformed in this way using, what they call, "quantity-based strategies" that "cause activation in the bilateral intraparietal circuits in regions identical to those active during approximation" (*6*).

Even the simplest arithmetic is more than just fact retrieval. Indeed, there is evidence that children learning multiplication tables are not simply passive recorders of the verbal form, but reorganize the facts to make them easier to retrieve—for example, by using a single preferred form for commuted pairs such as 6×2 and 2×6 (*11*).

Dehaene *et al.* identify the key role of the parietal lobes as representing approximate magnitude, but this region may serve other mathematical functions as well. It has long been known that brain lesions in the left parietal lobe severely impair many kinds of exact number tasks (*12*). However, the Dehaene results are unable to provide evidence for the involvement of the parietal lobes in exact calculations because this would require the comparison of both approximation and exact calculations with a common baseline condition.

The parietal lobes have been implicated in conceptualizing space, and hence make a plausible locus for a "mental number line" along which approximate magnitudes are arrayed. However, it is worth noting that the parietal lobes, and particularly the intraparietal sulci (*13*)—identified by Dehaene and colleagues as the crucial region for approximate calculations—are part of the neural circuit that controls handshapes and finger movements. This raises the possibility that these brain regions contribute to finger counting and finger calculation—an almost universal stage in the learning of exact arithmetic. This connection between fingers and arithmetic prompts the suspicion that the parietal lobes, in the course of development and learning, come to support the digital representation of numbers (*5*).

References

1. J. Piaget, *The Child's Conception of Number* (Routledge & Kegan Paul, London, 1952).
2. P. Starkey and R. G. Cooper Jr. *Science* **210**, 1033 (1980).
3. K. Wynn, *Nature* **358**, 749 (1992).
4. ______ *Math. Cognit.* **1**, 35 (1995).
5. B. Butterworth, *The Mathematical Brain* (Macmillan, London, 1999).
6. S. Dehaene, E. Spelke, P. Pinel, R. Stanescu, S. Tsivkin, *Science* **284**, 970 (1999).
7. S. Dehaene and L. Cohen, *Cortex* **33**, 219 (1997).
8. M. Delazer and T. Benke, *ibid.*, p. 697.
9. E. Warrington, *Q. J. Exp. Psychol.* **34A**, 31 (1982).
10. J.-A. LeFevre, G. S. Sadesky, J. Bisanz, *J. Exp. Psychol. Learn. Mem. Cognit.* **22**, 216 (1996).
11. B. Butterworth, N. Marchesini, L. Girelli, in *The Development of Arithmetical Concepts and Skills*, A. Baroody and A. Dowker, Eds. (Erlbaum, Mahwah, NJ, in press).
12. M. Jackson and E. K. Warrington, *Cortex* **22**, 611 (1986).
13. M. Jeannerod, M. A. Arbib, G. Rizzolatti, H. Sakata, *Trends Neurosci.* **18**, 314 (1995).

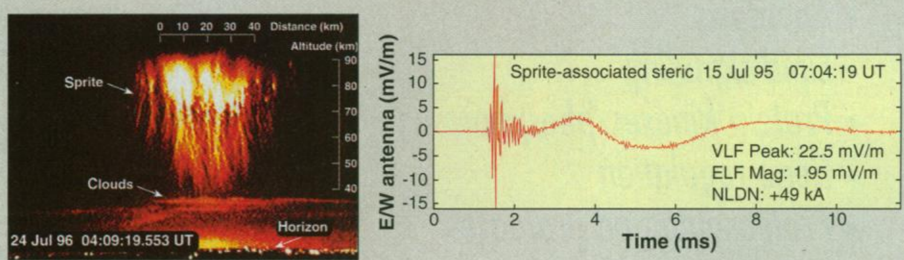
NOTA BENE: ATMOSPHERIC PHYSICS

Catching Sprites by Radio

Sprites are upper atmospheric optical phenomena associated with lightning (*1*, *2*). They have been implicated in electrochemical processes in the upper atmosphere (*3*) and transfer large amounts of charge between different atmospheric regions (*4*). Further interest comes from a growing body of evidence for perturbation of natural lightning by pollutants, with a recent study showing that smoke advected from southern Mexico into the United States led to large amounts of lightning with positive polarity, as well as an unusually high number of sprites (*5*).

The first images of sprites were serendipitously recorded only in 1990 (*2*), although anecdotal reports preceded this discovery. Sprites are barely detectable by the human eye because they are short-lived, faint compared with cloud-to-ground and intracloud lightning, and often obstructed by clouds. Associated with about one in every 100 lightning strikes—usually strong strikes with positive polarity—sprites occur at altitudes of about 40 to 90 kilometers above thunderstorms and reveal complex structures when viewed with an intensified television camera (see the figure).

Many aspects of sprite formation and their effect on the global atmospheric environment remain poorly understood. Purely visual observations of sprites are now complemented by other techniques, such as detailed optical spectra (*6*). A recent paper (*7*) shows that radio atmospherics or sferics, which are impulsive electromagnetic signals produced by lightning discharges, may enable determination of the global rate of sprite occurrence and the characteristics of sprite-producing storms by remote sensing. Sferics recorded for lightning associated with sprites have a long-lived tail (see the figure, right panel), whereas a normal lightning strike does not (*8*). Reising *et al.* (*7*) now demonstrate that a longer lasting current exists in lightning strikes that lead to sprites and that sprites themselves radiate low-frequency waves of similar strength to those emitted by the lightning. These features can be used over distances of up to 12,000 kilometers for sprite detection and characterization independently from optical measurements. The method potentially allows low-cost global detection and monitoring of sprites from just a few monitoring stations, and may help to quantify the amount of global ionization and heating in the middle and upper atmosphere due to sprites.



Now you see it.... Sprites above thunderstorms reach Earth's ionosphere. This false-color low–light-level television image was taken from a ground observatory near Fort Collins, CO, in the course of a Stanford University/Lockheed-Martin joint experiment aimed at studying sprites and related phenomena. **(Right)** A sprite-associated sferic shows a characteristic slow tail after the initial excitation.

CREDIT: S. REISING; SOURCE: STANFORD/LOCKHEED-MARTIN

References and Notes

1. Information on sprites and other upper atmospheric processes associated with lightning can be found at http://sprite.gi.alaska.edu/html/sprites.htm. See also S. B. Mende, D. D. Sentman, E. M. Wescott, *Sci. Am.* **277**, 56 (August 1997) (available at http://www.sciam.com/0897issue/0897mende.html).
2. R. D. Franz, R. J. Nemzek, J. R. Winckler, *Science* **249**, 48 (1990).
3. B. D. Green *et al.*, *Geophys. Rev. Lett.* **23**, 2161 (1996).
4. V. P. Pasko, U. S. Inan, T. F. Bell, S. C. Reising, *ibid.* **25**, 3493 (1998).
5. W. A. Lyons *et al.*, *Science* **282**, 77 (1998).
6. D. L. Hampton, M. J. Heavner, E. M. Wescott, D. D. Sentman, *Geophys. Res. Lett.* **23**, 82 (1996); S. B. Mende, R. L. Rairden, G. R. Swenson, W. A. Lyons, *ibid.* **22**, 2633 (1995)
7. S. C. Reising, U. S. Inan, T. F. Bell, *ibid.* **26**, 987 (1999).
8. ______, W. A. Lyons, *ibid.* **23**, 3639 (1996).

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