approach, then, offers hope that answers to these central questions of cognitive science are tractable, and provides a way forward for those who seek developmental theories that are both explicit and explanatory.

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References

1 Piaget, J. (1952) *The Origins of Intelligence in Children*, International Universities Press
2 Cohen, L.B. *et al.* (2002) A constructivist model of infant cognition. *Cogn. Dev.* 17, 1323–1343
3 Cohen, L.B. *et al.* (1998) The development of infant causal perception. In *Perceptual Development: Visual, Auditory, and Speech Perception in Infancy* (Slater, A. *et al.*, eds), Psychology Press
4 Leslie, A.M. and Keeble, S. (1987) Do six-month-olds perceive causality? *Cognition* 25, 265–288
5 Kellman, P.J. (2001) Separating processes in object perception. *J. Exp. Child Psychol.* 78, 84–97
6 Nakayama, K. *et al.* (1995) Visual surface representation: A critical link between lower-level and higher-level vision. *Visual Cognition: Vol. 2. An Invitation to Cognitive Science* (Kosslyn, S.M. and Osherson, D.N., *et al.* eds), pp. 1–70, MIT Press
7 Michotte, A. (1963) *The Perception of Causality*, Basic Books
8 Mareschal, D. (2000) Object knowledge in infancy: current controversies and approaches. *Trends Cogn. Sci.* 4, 408–416
9 Johnson, S.P. (in press) Building knowledge from perception in infancy. In *Building Object Categories in Developmental Time*. (Gershkoff–Stowe, L. and Rakison, D., eds), Erlbaum
10 Bower, T.G.R. (1974) *Development in Infancy*, W.H. Freeman
11 Bower, T.G.R. *et al.* (1971) Development of the object concept as manifested in changes in the tracking behavior of infants between 7 and 20 weeks of age. *J. Exp. Child Psychol.* 11, 182–193
12 Muller, A.A. and Aslin, R.N. (1978) Visual tracking as an index of the object concept. *Inf. Behav. Dev.* 1, 309–319
13 Spelke, E.S. (1990) Principles of object perception. *Cogn. Sci.* 14, 29–56
14 Baillargeon, R. and Wang, S. (2002) Event categorization in infancy. *Trends Cogn. Sci.* 6, 85–93
15 Fodor, J. (1980) Fixation of belief and concept acquisition. In *Language and Learning: The Debate Between Jean Piaget and Noam Chomsky* (Piatelli-Palmarini, M., ed.), pp. 143–149, Routledge and Kegan Paul
16 Slater, A. *et al.* (1990) Newborn and older infants' perception of partly occluded objects. *Inf. Behav. Dev.* 13, 33–49
17 Johnson, S.P. (2001) Visual development in human infants: Binding features, surfaces, and objects. *Visual Cogn.* 8, 565–578

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Out-of-body experiences: from Penfield to present

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Can the brain, when stimulated, yield entirely novel experiences? Blanke *et al.* (2002) describe a patient who reported spontaneous out-of-body experiences during electrical stimulation of her angular gyrus. These findings, although apparently extraordinary, agree with much earlier reports from a patient tested by Wilder Penfield. Such studies can provide clues about the nature of conscious experience.

Blanke *et al.* recently described a preoperative epilepsy patient who reported spontaneous out-of-body experiences during electrical stimulation of her right angular gyrus [1]. This study is both interesting and important because it addresses the problem of whether brain activity induced by local stimulation can elicit familiar experiences only, novel combinations of familiar experiences, or experiences that are entirely novel.

The 43-year-old woman in the study suffered complex partial seizures and had temporarily implanted subdural electrodes to identify the epileptic focus. Stimulation at two specific electrode sites over the angular gyrus at the parietal-temporal junction elicited novel vestibular illusions of falling or floating (Fig. 1a). Initial stimulation led to sensations of 'falling from a height' or 'sinking into the bed'. Higher amplitude stimulation led to the report of an apparent out-of-body experience. She reported that 'I see myself lying in bed, from above, but I only see my legs and lower trunk'. In actuality, the patient was lying in bed with her upper body supported at a 45-degree incline. It is worth noting that despite the patient's shift in perceived vantage point, her description of the items in view remained veridical – that is, she did not report seeing her entire body and face from above. Subsequent stimulation led to vestibular illusions of lightness and floating above the bed close to the ceiling. Moreover, when the patient was instructed to watch her legs, stimulation of the same site led to the patient to report that her legs had become shorter or that they appeared to be moving towards her face. Similar effects occurred when she attended to her arms.

The findings suggest that distortion of vestibular and somatosensory processing in the angular gyrus can lead to out-of-body experiences. However, given the extraordinary nature of these reported experiences and possible variability in cortical organization among epileptic patients, one might wonder how to consider such a single, albeit remarkable, clinical report.

Pioneering investigations of electrical brain stimulation

Wilder Penfield, a pioneer at investigating the effects of electrical stimulation in conscious humans under local

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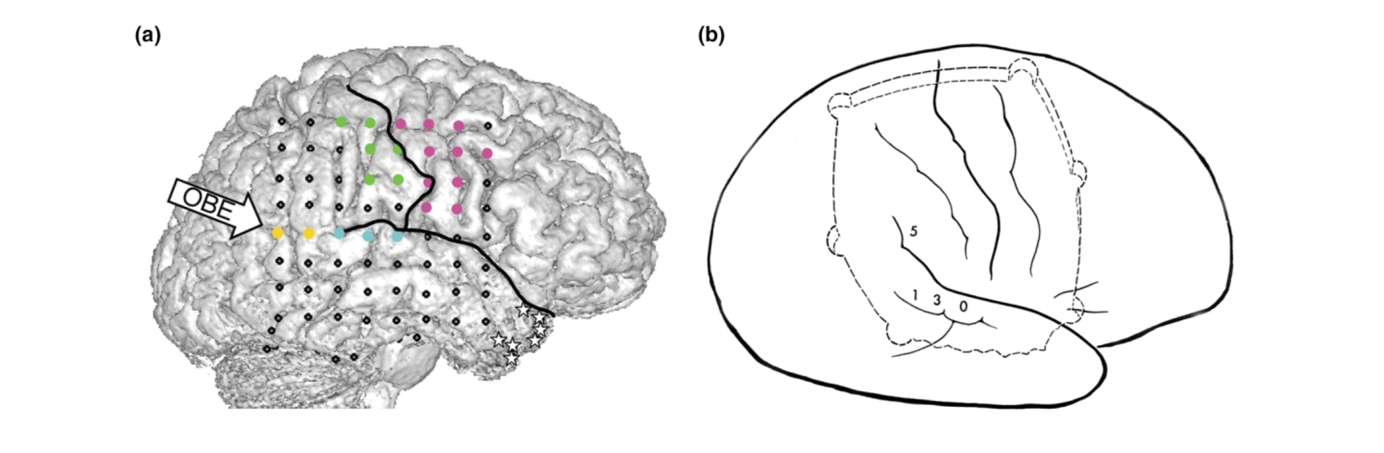

Fig. 1. (a) Electrical stimulation of cortical sites over the angular gyrus, marked in yellow, elicited vestibular illusions, body schema distortions, and an apparent out-of-body experience (OBE). Stimulation at other sites elicited other behavioral responses: magenta, motor responses; green, somatosensory; blue, auditory. Stars indicate the epileptic focus in the medial temporal lobe. Reproduced with permission from Ref. [1]. (b) Schematic diagram showing sites (points 0, 1,3, 5) that elicited out-of-body experiences in patient G.A. Reproduced with permission from Ref. [11].

anaesthesia, reported very similar findings in 1941 [2]. Patient G.A. suffered habitual epileptic attacks that never evoked hallucinations. Yet upon electrical stimulation of her right superior temporal gyrus at point 0 (see Fig 1b), she spontaneously exclaimed: 'I have a queer sensation as if I am not here… As though I were half here and half not here.' She reported that she had never felt this way before. Stimulation of point 1 elicited the response that she felt queer again, as if she were floating away. Similar responses occurred for point 3 and for point 5 in the neighboring parietal lobe. Penfield noted that these out-of-body experiences appeared to be linked to vestibular illusions rather than to visual or auditory hallucinations. Also, the patient seemed to have 'mental diplopia' – an understanding of her current surroundings superimposed on illusory impressions of being elsewhere. Penfield proposed that such resulting conflict in sensory impressions might account for her sense of remoteness and unreality.

From Penfield to present

The similarities between the two patient reports, which occurred over 60 years apart, are striking. In both cases, vestibular illusions are tightly linked to out-of-body experiences, and the sites of stimulation are in quite close proximity. Both sets of stimulation sites encompassed the right temporal-parietal region posterior to the post-central gyrus, close to multisensory areas implicated in vestibular processing [3,4] and also spatial neglect [5,6], although Penfield's schematically drawn sites appear to be more anterior than Blanke *et al.*'s. (It is not known whether Penfield tested more posterior regions in patient G.A.) Whereas Blank *et al.*'s patient reported body distortions when she viewed her own body, Penfield's patient, who was lying on the operating table, was unlikely to have had the opportunity to view her own body during stimulation.

Accounting for body distortions

In addition to the dramatic vestibular illusions, Blanke *et al.*'s patient perceived distortions in the length and position of her limbs when she watched them closely. Why might this be the case? The patient only noticed these body distortions after she was instructed to watch specific parts of her body, suggesting that these illusions included a strong visual component.

It is known that conflicting somatosensory and visual information can lead to perceived distortions of body size in normal subjects. If a subject views an afterimage of his or her own hand in the dark (generated by a brief bright flash), subsequent movement of the hand towards the face will lead to a perceived shrinkage of the hand afterimage [7,8]. This is because the retinal afterimage remains constant in size but somatosensory information dictates that the hand is now closer and should therefore subtend a larger retinal angle. The integration of false information about retinal size and veridical somatosensory information about the distance of the hand can account for the resulting hand-size illusion.

Likewise, if electrical stimulation leads to perceived shifts in the somatosensory position of a limb that remains physically stationary, then the integration of false somatosensory information with veridical visual information could also result in a corresponding change in perceived limb size. Consistent with this proposal, Blanke *et al.*'s patient reported that her limbs appeared to be approaching her face and also that they were decreasing in perceived size, just as in the hand-afterimage experiment. The integration of conflicting somatosensory and visual information provides a plausible account for the perceived changes in body length. The dissociation between veridical visual information and distorted somatosensory/vestibular information might also account for the sense of remoteness, unreality or 'mental diplopia' that has been identified with out-of-body experiences. Consistent with this proposal, stimulation applied while the patient's eyes were closed elicited reports of shifts in perceived body position but failed to elicit out-of-body experiences (O. Blanke, personal communication).

Implications for the nature of conscious experience

Can entirely novel experiences be elicited by focal cortical stimulation, implying that such experiences lie dormant but ready to be expressed in the brain? Both patients discussed above had never had out-of-body illusions before, yet direct stimulation of their brain somehow generated experiences quite different from those of everyday life. Is this difference a matter of quality or degree? Many people have had dreams of intense, prolonged falling, even though they have never fallen from such heights before. Perhaps vestibular-somatosensory responses, at the extreme, can lead to the qualitatively novel impression of being outside of one's own body. Analogous studies in proprioception have shown that peripheral stimulation of muscle spindles can lead to illusions of impossible limb positions, such as experiencing one's own arm bent backwards against the joint [9,10].

Alternatively, these novel body illusions might reflect the fact that neurons representing vestibular impressions and body position are in direct conflict with veridical sensory information from vision. This latter explanation would imply that novel experiences instead reflect the novel combination of two or more familiar sensory experiences. Exactly how the brain gives rise to such extraordinary experiences will be an exciting topic for future investigations, perhaps for another sixty years.

References

1 Blanke, O. *et al.* (2002) Stimulating illusory own-body perceptions. *Nature* 419, 269–270
2 Penfield, W. and Erickson, T.C. (1941) *Epilepsy and Cerebral Localization*, Charles C. Thomas
3 Brandt, T. and Dieterich, M. (1999) The vestibular cortex: its locations, functions, and disorders. *Ann. New York Acad. Sci.* 871, 293–312
4 Penfield, W. and Jasper, H. (1954) *Epilepsy and the Functional Anatomy of the Human Brain*, Little, Brown & Co
5 Vallar, G. and Perani, D. (1986) The anatomy of unilateral neglect after right-hemisphere stroke lesions. A clinical/CT-scan correlation study in man. *Neuropsychologia* 24, 609–622
6 Karnath, H.O. *et al.* (2001) Spatial awareness is a function of the temporal not the posterior parietal lobe. *Nature* 411, 950–953
7 Taylor, F.V. (1941) Change in size of the after-image induced in total darkness. *J. Exp. Psychol.* 29, 75–80
8 Gregory, R.L. *et al.* (1959) Changes in the size and shape of visual afterimages observed in complete darkness during changes in position in space. *Q. J. Exp. Psychol.* 11, 54–55
9 Craske, B. (1977) Perception of impossible limb positions induced by tendon vibration. *Science* 196, 71–73
10 Goodwin, G.M. *et al.* (1972) Proprioceptive illusions induced by muscle vibration: contribution by muscle spindles to perception? *Science* 175, 1382–1384
11 Penfield, W. and Rasmussen, T. (1950) *The Cerebral Cortex of Man*, Macmillan

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Letters

Show us the model

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Pinker and Ullman's [1] accounting of the facts about the past tense cannot be taken at face value and needs to be dissected more closely than possible here. Because of space limitations, we will focus on inaccuracies in their rendering of the Joanisse and Seidenberg model (J&S) [2].

(1) Pinker and Ullman claim that our model failed to produce the advantage for irregulars over regulars seen in some patients with left frontal damage. On the contrary, the model did produce this pattern; it occurred relatively rarely in multiple runs of the model (corresponding to multiple 'patients'), and it occurs infrequently in patients [3]. The advantage for irregulars is eliminated in the model and patients if the regular and irregular stimuli are closely controlled with respect to frequency, phonological complexity and concreteness [2,3].

(2) Pinker and Ullman's claim that the J&S model is a 'crude' instantiation of their theory rests on equating a highly structured, hierarchical lexical system containing all the apparatus illustrated in their Fig. 1 (p. 457, and elaborated in Pinker's books), with the semantic representations in our model, which consisted of exactly one bit per verb concept. Here Pinker and Ullman stretch to find a point of contact between our model and their theory, and ignore the differences. Their theory rests on a distinction between rule-governed forms and exceptions, which are said to be processed by independent modules governed by different principles [4]. This distinction plays no role in our model; the production of every past-tense form is determined by the conjunction of phonological and semantic constraints. These constraints (and others that apply under other circumstances, for example, in context) vary in how much they contribute to different forms, but all forms are generated using all weights. This is different from shunting some words to the lexicon and others to the rule. We also know (from submitted research) that the J&S results do not depend on using localist nodes. In sum, these are fundamentally different theories.

(3) Pinker and Ullman's claim that 'each model has been tailored to account for one phenomenon' and that 'few models account for more than one phenomenon or predict new ones' (p. 462), ignores the fact that our model's predictions about morphological deficits were *themselves* derived from work in a different domain – reading words. It was a further, correct prediction that patients with impaired morphology would exhibit corresponding forms of acquired dyslexia (phonological, surface). The same

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