PONTIFICIA ACADEMIA SCIENTIARUM

THE AWARD
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The aim of the Pontifical Academy of Sciences, which was founded on 28 October 1936 by the Holy Father Pius XI, is to honour pure science, wherever this may be found, to ensure its freedom, and to support the research essential for the progress of applied science.

On 28 October 1961, on the occasion of the XXVth anniversary of the foundation of the Pontifical Academy of Sciences, the Holy Father John XXIII established the Pius XI Gold Medal in honour of the founder of the Academy. The medal should be awarded to a young scientist who has already gained an international reputation.

The Council of the Academy unanimously decided to award the "Pius XI Gold Medal" for the year 2000 to

Prof. STANISLAS DEHAENE

in recognition of his great merits as a scholar and the important contribution of his research to scientific progress.


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STANISLAS
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Educational Background:

Ecole Normale Supérieure in Mathematics, Paris, France (1984).

Masters in Applied Mathematics, University of Paris VI, Paris, France (1985).

PhD in Cognitive Science, Ecole des Hautes Etudes en Sciences Sociales, Paris, France (1989).

Professional Experience:

Research Scientist, Institut National de la Santé et de la Recherche Médicale (INSERM), Laboratoire de Sciences Cognitives et Psycholinguistique, Paris, France (1989-1999).

Post-doctoral Fellow, Institute of Cognitive and Decision Sciences, University of Oregon (USA), director Michael Posner (1992-1994).

Research Director at INSERM Unit 334, Service Hospitalier Frédéric Joliot, Commissariat à l'Energie Atomique (CEA), Orsay, France (1999-2001).

Member Scientific Advisory Board, Fyssen Foundation, Paris (1998-present).

Member Scientific Advisory Board, Trieste Encounters in Cognitive Science (1999-present).

Advisory Council, International Association For The Study Of Attention And Performance (1998-present).

Member Administration Council, French Society for Neuroscience (2001-present).

Director, INSERM Unit 562, Service Hospitalier Frédéric Joliot, Commissariat à l'Energie Atomique (CEA), Orsay, France (2002-present).

Academic Awards and Honors:

Fanny Emden Prize, French Academy of Sciences (1996).

Jean Rostand Award for the book *La Bosse des Maths* (1997).

James S. McDonnell Centennial Fellowship (1999).

Villemot Prize, French Academy of Sciences (1999).

Jean-Louis Signoret Prize, IPSEN Foundation (2001).

Boehringer-Ingelheim Prize, Federation of European Neuroscience Societies (2002).

SUMMARY OF SCIENTIFIC ACTIVITY

When I was a student in mathematics, I was always intrigued by the peculiar mental activity that characterizes mathematical thought, with moments of quick insight followed by periods of tedious, almost mechanical computation. Intuition and computation both seemed essential, but in strikingly different, indeed complementary ways. Following this lead, my scientific research has attempted to shed some light on the mental and cerebral bases of mathematical thought.

Joining Jacques Mehler's Laboratory for Cognitive Science and Psycholinguistics in 1985, I learned that the methods of cognitive science could be applied to study mathematical thought. I focused on what is perhaps its most elementary constituent, the comprehension and manipulation of numbers. My first experiments concerned number comparison. How do we know that 63 is larger than 55? Using chronometric tests, I showed that the time that our brain takes to compare two numbers is a highly regular psychophysical function of the distance between them, as well as of their size. This indicated that numbers were represented internally, not by discrete symbols, but by analogical quantities on an internal continuum that could be likened to a mental 'number line'.

Of course, there were also many indications in my experiments that humans could manipulate numerical symbols mentally if the task required it. In 1991, I discovered that the intuition of quantity and the manipulation of symbols rely on separable brain systems. With Laurent Cohen, at the Hôpital de la Salpêtrière in Paris, I studied a patient who had suffered a large left-hemispheric lesion and experienced devastating impairments in language, calculation, and memory. Remarkably, in all of these domains, he showed a spared ability to approximate the correct quantity. For instance, he could not perform an operation as simple as 2+2 – he sometimes stated that this made 3, or 4, or 5 –, but he knew that 2+2=9 was false because the quantities involved were too distant.

Based on this and many other cases, I proposed a formal model of the mental representations that contribute to number processing, the 'triple code model'. This model helped to predict and to understand the many experimental observations that followed.

When brain imaging techniques became available in the late 1980s, it was clear that they provided a whole set of new tools to test the model. I therefore engaged into a large number of studies that used brain-imaging techniques to probe the functional anatomy of calculation networks with positron emission tomography (PET) and later functional functional magnetic resonance imaging (fMRI). I also attempted to specify the temporal sequence of number processing stages by recording event-related potentials (ERPs). In particular, by combining fMRI and ERPs, I was able to confirm that approximation and exact calculation tap two distinct cerebral circuits.

My studies pointed to the crucial role of a small region in the horizontal segment of the intraparietal sulcus (HIPS), in the left and right hemispheres. This region can be systematically identified in all subjects. It occupies a fixed location relative to other functional areas in the parietal lobe that are engaged in various sensorimotor tasks. My research suggests that this region is systematically activated whenever a person manipulates numerical quantities mentally. During number comparison, the activity of this region is a direct function of the semantic distance between the numbers to be compared; and during calculation, its activity increases in proportion of the size of the numbers involved. This region is therefore a good candidate for a cerebral map of numerical quantity.

In 1993, with Jean-Pierre Changeux, I proposed a formal theoretical model that specified how number could be encoded by a population of neurons. The model proposed the existence of "numerosity detectors", neurons that were coarsely tuned to a specific quantity of items. In 2002, this prediction was verified when electrophysiologists identified a population of number-sensitive neurons in the monkey parietal lobe, at a location homologous to the human HIPS area. Together with other observations that preverbal infants, in their first year of life, already possess elementary quantity manipulation abilities, those data indicate that 'number sense' is a basic ability which has been laid down in our brains in the course of evolution.

Intuitions are often unconscious. Would it be possible to show that the human sense of number can be triggered automatically and unconsciously? Intrigued by this idea, I designed a paradigm where we could flash subliminal words or digits that were masked by other shapes and therefore could not be consciously seen. Behavioral and brain imaging methods revealed an unsuspected depth of processing of those masked symbols. I discovered that masked stimuli could activate a case-independent fusiform representation of visual words, but also the parietal representation of number, and even the motor cortex when subjects were engaged in a fast chronometric task.

This research lead me to ask what was special about the conscious state. What aspects of human cerebral organization make it possible to slowly but flexibly perform a large variety of mental operations, and give rise to the feeling of conscious access and conscious direction? For many years, I had been working with molecular neurobiologist Jean-Pierre Changeux on the development of neuro-realistic models of cognitive functions. Those models accounted for neuropsychological tests associated with the prefrontal cortex, and their impairments reproduced the deficits exhibited by frontal patients. Recently, we realized that their architecture could be synthesized into a broader proposal, the "neuronal workspace hypothesis". Inspired by Bernard Baars' workspace view of consciousness, our model proposes that the neural basis of conscious thought is the sudden and coordinated activation of a highly interconnected network of neurons with long-distance axons. This model serves as a theoretical framework for new imaging studies of conscious and subliminal processing. Most recently, my studies have confirmed that conscious processing is associated with a brain-scale state of coordinated activity at distributed sites in parietal, prefrontal and cingulate cortex.

In the future, I plan to continue to search for the cerebral bases of high-level mental activity in humans. Brain-imaging techniques are providing us with remarkable insights into the organization of the brain and how it supports abstract thought. Mathematical thought remains my central theme, but I also apply the methods of cognitive neuroscience to other fields. With Jacques Mehler and other colleagues, I study the organization of language comprehension and, in particular, how bilinguals manage to fit two languages in the same brain. With Laurent Cohen, I study how written words are decoded and how this changes when the brain learns to read in a given culture. Finally with my wife Ghislaine Dehaene-Lambertz, I attempt to specify how the brain systems that we can visualize in human adults are laid down in the course of child development.

LIST OF MAIN PUBLICATIONS

Research articles

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Nadal, J.P., Toulouse, G., Changeux, J.P., & Dehaene, S. Networks of formal neurons and memory palimpsests. *Europhysics Letters*, 1, 535-542, 1986.

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