An Introduction to the Reference Module in Neuroscience and Biobehavioral Psychology

J Stein, University of Oxford, Oxford, United Kingdom

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Although our brains are only about 1.5 kg in weight (ie, about 2% of the weight of our whole body), the brain consumes one-fifth of the body’s total energy production and its unfolded cortical and cerebellar surfaces extend to over 5 m². It contains a hundred billion ($10^{11}$) nerve cells and $10^{12}$ supporting glial cells. At birth a baby’s neurons make 1000 new connections per second. In an adult a thousand million million ($10^{15}$) of these connections between neurons have survived drastic pruning by 90% of them during infancy, leaving intact only those most useful for representing the world and our interactions with it. The human brain forms more possible combinations of connections than there are particles in the whole universe; hence it is probably the most complex organized system in that universe. So it is little wonder that people are fascinated by it; yet our brains have encountered huge difficulties in trying to understand themselves. In the old adage, “you cannot cut butter with a knife made of butter”—our brain’s limitations undermine its ability to understand itself, and we are only at the threshold of understanding how it works. But the powerful techniques introduced over the last 25 years may be beginning to solve this impasse.

This Reference Module in Neuroscience and Biobehavioral Psychology has therefore been developed to provide a comprehensive source of information about our present understanding of the brain by taking advantage of the power of the Internet and cloud computing. We are creating a “virtual” encyclopedia, a "Neuropedia,” comprising many thousands of articles about neuroscience. These will be continually updated by trustworthy experts, and new ones will be commissioned as needed. This will be a rolling program, so that, unlike a conventional printed encyclopedia, an expensive new edition will not be needed every few years. Instead the contents of the module will always be very up-to-date, and new ideas and discoveries will be introduced within a few months of their nascence.

Likewise no printed encyclopedia could have several thousand chapters, not least because it would take hours to find what you wanted. But with the marvels of computer indexing, any desired article will be available with a few keystrokes, in milliseconds. Much thought has been devoted to how people formulate their “desires” in this context. Most people do so by typing a few keywords perhaps connected by logical operators; in the Reference Module, this will generate a drop-down menu of the titles of all the articles containing them and prompt a more comprehensive advanced search if necessary.

Alternatively a reader can track down the article he/she wants by following successively more detailed levels of the index “hierarchy” in the Module. These subject hierarchies have been designed by the editorial board to be highly intuitive to make it easy to navigate and find essential information. In addition they will be linked to relevant journal articles and book chapters on ScienceDirect, and there will be extensive interlinking between different sections of the module, so that, for example, a description of the “clustered regularly interspaced short palindromic repeats” (CRISPR) system used for editing DNA can be accessed from all the articles that mention its use.

“Biochemists, biologists, geneticists, biotechnologists, immunologists, neuroscientists and psychologists will benefit with access to the most up-to-date essential content that in the past was unavailable during the lengthy publishing process,” said Theresa Hunt, Elsevier Vice President of Marketing. “Librarians, under increasing pressure to stretch budgets further and secure content that contributes to cutting-edge research and learning, find high value in the Reference Modules’ continuous reviews and updates led by expert editorial boards.”

This Reference Module in Neuroscience and Biobehavioral Psychology will have access to nearly 7000 articles in 19 encyclopedias which have already been published by Elsevier covering: Adolescence, Applied Psychology, Behavioral Brain Mapping, Clinical Psychology, Consciousness, Creativity, Epilepsy, Hormones, Human Behavior, Human Brain, Infant and Early Child Development, Mental Health, Movement Disorders, Neurological Science, Neuroscience, Psychotherapy, Sleep, The Eye.

In this module after a section on the “History of Neuroscience,” mainly covering the thinkers and scientists who advanced the subject in the past, it continues with a section on “Techniques for Studying the Brain”; all the subsequent sections will have links back to these initial sections. The three most important recent advances in methodology have been, first, the development of powerful molecular genetic techniques which are beginning to enable us to unravel the genetic basis of normal and abnormal neurodevelopment. The second recent technological advance was the invention of powerful noninvasive functional imaging techniques for use in humans, so that we can now see where and when sensory, cognitive, and motor activities are actually taking place in the live human brain. They comprise functional magnetic resonance imaging (fMRI) which has millimeter spatial precision but low temporal resolution (only c.10 s), magnetoencephalography (MEG) which has millisecond temporal resolution but slightly less good spatial resolution (c.5 mm), and field potential/electroencephalography (EEG) recording which has similarly high temporal resolution but is very noisy and has low spatial resolution; the EEG has only about 20 mm resolution at best. But behind these two inventions lies possibly the most important, namely the third recent advance—Information Technology; none of the genetic and functional imaging techniques could have happened without the 21st century’s advances in computer technology which have made cheap and hugely powerful computational assistance so readily available.
Brain Evolution

The next section is on Brain Evolution, particularly human. Early primates developed a gradually bigger brain relative to their body size since 2 million years ago, leading to Homo sapiens. Human brain size then increased still more, by nearly 3 times, from about 500 cm³ in Homo habilis up to 1500 cm³ in Homo sapiens neanderthalensis, the hominin with the biggest brain of all. Since then, over the past 30,000 years, the hominin average brain size has actually shrunk by 10%. However, another essential element of brain evolution in humans was optimization of connectivity. Larger brains require more wiring, but more wiring can become very inefficient. The human brain has therefore become reorganized for greater efficiency. The really interesting question is what the evolutionary selection pressure was for these changes. Many of the articles in this section provide evidence that the main influence was the development of our community social interactions.

Neural Communication—“Soup v. Sparks”

One of the most important recent effects of the application of new techniques in neuroscience has been to shift emphasis away from the brain’s chemical interactions (“soup”) toward its electrical activity (“sparks”). The basic currency of the brain is electrical—the action potential; and the section on Biophysics in this Module covers this. Each neuron sends the results of its individual processing of its synaptic inputs onward to the next neurons with which it connects by means of 100 mV electrical impulses. Their frequency defines all our sensations, thoughts, feelings, and actions. At their termination in synapses on their target neurons, they cause the release of transmitters that dock onto receptors on the next neuron. These can be chemically manipulated; and this is the basis of much of the modern drug industry. The section on Biophysics and Intercellular Communication covers these as well.

The brain’s transmitters and their receptors are ubiquitous. Administering chemical manipulants (drugs) to the whole brain is likely therefore to have a “blunderbuss” mixture of wanted and unwanted effects, rather than the precisely aimed “magic bullets” as dreamed of by Paul Ehrlich. But recent technological advances have opened up the possibility of being able to modulate the electrical activity of the brain both experimentally and for the treatment of disease, with scalpels like precision. The next few years will undoubtedly see great advances in our understanding of the electrical activity of the brain.

Neural Development, Neuroanatomy

The next sections cover the development, the basic structures, and the aging of the brain, from individual cells through aggregations of cells into “nuclei” to the organization of the long- and short-range connections between them. Understanding these subjects is crucial to elucidating how the brain works as a complex system.

Representations: Sensory, Sensorimotor Systems, Cognition

The next three sections in this Reference Module cover Sensory and Sensorimotor Systems, and Cognition. They deal with how sensory input is processed, memorized, and used to control motor output and for cognitive planning. The most important feature of the connections between neurons is that their strengths are altered each and every time they are activated. This underlies the “plasticity” of the brain, allowing us to lay down memories and acquire skills. It is the brain’s plasticity that enables it to perform its main function, namely the “representation” of the outside world and our plans inside our skulls. These representations are then used to remember past experiences and to use current sensory input and these memories to choose the most useful behavior in any given circumstances and then to organize appropriate behavior to achieve it. Thus, for example, there is a distorted “homunculus” in the somesthetic area of the cerebral cortex that accords each receptor in the skin the same processing space in the cortex so that the tips of the fingers containing many more receptors, receive much more space than the arm that supports them, and the neighboring motor cortex matches this skin representation with larger processing areas, to represent and control the large number of different kinds of movements the fingers can make. In the prefrontal cortex what is represented are the plans for future behavior and the means of making decision about which will be most suitable.

Regulatory Systems, Reward and Emotion

The next three sections deal not just with the “housekeeping” of the brain—ensuring adequate supplies of nutrients, oxygen, and water, temperature control and effective responses to stress and danger, control of arousal and reproduction—but also with the systems that motivate behavior beyond immediate satisfaction of needs. The hypothalamus provides the main control over our endocrine and autonomic nervous systems. Four simple instincts or drives (hunger, thirst, sex, and self-preservation) provide the basic motivation for all human behaviors. Our emotions are the conscious feelings generated by these drives, colored by the autonomic and behavioral responses that they provoke, by our past experiences, and by our expectations. Much of motivation operates
via a neural reward system that energizes behavior, satisfying the drives in proportion to how long since they were last met. Animals will forego food, etc., to electrically stimulate this reward system directly themselves. However, interestingly, when stimulated in humans, it does not generate pleasure. The reward system comprises two main pathways: the dorsal, noradrenergic route and the medial forebrain, dopaminergic bundles. These feed into a network of primitive brain structures, known as the Papez circuit which links association cortex with the hypothalamus. The right hemisphere plays a greater role in the expression and interpretation of emotions, compared with the left.

**Neurological and Psychiatric Disorders**

The next two sections cover the plethora of disorders that occur when the central nervous system is malfunctioning. Neurology used to consist mainly of very clever neurologists diagnosing rare diseases that were untreatable. Now, however, brain imaging has made diagnosis much easier, and advances over the whole field of neuroscience have made treatments vastly more effective. Likewise 50 years ago, psychiatry was extremely primitive. Psychiatrists chose one of the four main diagnoses: anxiety, depression, schizophrenia, or dementia and administered crude treatments to try to alter their course, such as psychosurgery, electroconvulsive therapy, or powerful drugs which had horrible side effects, such as Parkinsonian dyskinesias. But the last 25 years have seen the beginning of a marriage between psychiatry and neurology at least at the research level, hence much greater understanding of the genetic and neurological bases of psychiatric disorders has emerged and with it the promise of more effective treatments. These are sorely needed; the costs each year of mental disorders including dementia now far exceed those of cardiovascular disease plus cancer.

**Computational Modeling**

The last section of this Reference Module in Neuroscience and Biobehavioral Psychology concerns computational modeling of the nervous system. This is another area that has advanced by leaps and bounds over the last few years. After the "Dartmouth Conference" in 1956, whose bold conclusion was that "human intelligence can be so precisely described that a machine can be made to simulate it," there was a widespread belief that the operations of the brain were sufficiently like those of a computer that successful artificial intelligence was only a few years away. Quite soon, however, the enthusiasm faded as it was quite clear that these optimistic predictions could not be fulfilled any time soon. There was a brief rekindling with more powerful computers making the training of neural networks by error back propagation a practical technique. But even this faded away as it became clear that back propagation was physiologically implausible and anyway merely achieved what simple statistical techniques can provide much more transparently. However, in the last few years, enthusiasm has arisen again with yet more powerful computers, such as Deep Blue beating Gary Kasporov at chess and AlphaGo beating Lee Sedol at Go. Perhaps the human mind will, after all, finally be able to understand its own operations completely.

**The Future**

The overall lesson to be gained from surveying the contents of this Reference Module in Neuroscience is that we are indeed beginning to make significant advances in understanding the way the brain works and how it goes wrong. So long as governments continue to support our research and we continue to improve methodology and apply our results to the patients who need them, then the future is bright. Studying the brain is not only fascinating in itself, but also potentially of incalculable benefit for alleviating brain disorders and improving the life chances of everyone.