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introduction

The biology of behaviour: scientific and ethical implications

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The human brain is the most complex of all biological organs; it not only gives rise to consciousness—that most fascinating but elusive phenomenon—but also mediates our behavioural responses. The structure of the brain and its higher cognitive functions are the product of evolutionary history, embedded within the genome. One of the great scientific challenges today is therefore to integrate the results from two different lines of investigation into the biology of behaviour—using genes and the brain—with the goal of bringing both to a deeper level of understanding.

Modern biology has taught us how genes and genomes serve as blueprints for all living organisms. Not only physiology, but also some forms of behaviour seem to be innate or predisposed by genes. Today, most scientists agree that genes alone do not cause behaviour, but merely influence how an individual will react to a particular set of environmental and biographical circumstances. Genes are seen as determinants of behaviour insofar as they code for the assembly of the neural circuits that are necessary for the development and survival of the organism. But how does the brain, which owes its functional structure partly to the concerted action of genes, give rise to or cause behaviour? These were some of the questions that were addressed at the seventh European Molecular Biology Laboratory (EMBL)/European Molecular Biology Organization (EMBO) joint science and society conference on 'Genes, Brain/Mind and Behaviour', held on 3–4 November 2006 at the EMBL in Heidelberg, Germany, which are discussed further in this special issue of *EMBO reports*.

Basic research on behavioural genetics is thriving. Researchers have developed powerful tools to disentangle the underlying complexity between genes and behaviour, and are amassing a body of knowledge about how phenotypic variation relates to and influences distinct patterns of behaviour. Although researchers recognize the importance of environmental factors in the development of living organisms, they have also produced solid evidence showing how genes are relevant to basic forms of behaviour. Giovanni Frazzetto and Cornelius Gross emphasize the complex relationship between genotypes and phenotypes in their article (pS3). Similarly, Pierre Roubertoux critically reviews some of the overly simplistic assumptions that geneticists have made (pS7). In particular, Roubertoux stresses how pleiotropy, epistasis, interactions between genes and the environment, alternative splicing and neuronal integration give rise to, and contribute to, many aspects of behaviour.

The manifold steps that lead from genes to brains to behaviour are highly complex, but scientists are gradually elucidating the molecular and cellular mechanisms behind brain structure and function. The biggest challenge now is to understand how neurons interconnect to form larger networks, and how these intricate neural structures give rise to consciousness and a sense of self. Neuroscientists are confident that they now have the tools to enable them to solve this mystery. As a background, the essay by Anne Harrington provides an illuminating historical overview of how people in the Western world have perceived the mind–body relationship (pS12).

Even today, there are differing opinions on whether the human mind can be fully elucidated. Whereas many scientists remain wary that we will ever understand human consciousness, optimists claim that the brain sciences will eventually explain how we are constituted from the molecular level up to the cerebral level. Hence, the second main topic at the 2006 conference was neuronal organization and cognitive functioning of the brain, and how basic molecular mechanisms and neural networks give rise to awareness. In his essay, Wolfgang Singer succinctly deconstructs an image of a 'self' that is seemingly disconnected from the brain (pS16). By explaining how neurons encode information through varying the amplitude and/or adjusting the precise timing of electric discharges, Singer lays out a model of the brain as a complex nonlinear system with emerging properties, which does not need a higher-order controlling structure or *res cogitans* to create consciousness.

The second group of essays in this special issue focuses on new technologies that have grown out of behavioural genetics and the brain sciences, and on the influence that their application has, or will have, on society. These essays deal with various applications of science to monitor and map the brain, and to influence human behaviour, as well as the ethical questions that many such applications entail.

Stéphanie Perreau-Lenz, Tarek Zghoul and Rainer Spanagel argue that a better understanding of clock genes can pave the way for new therapeutic approaches to treat pathological conditions such as addiction and depression (pS20). These are examples of what has been termed 'neurotechnology': tools that are designed to analyse, cure and

enhance the functions of the human nervous system, especially the brain. At the leading edge of neurotechnologies are various forms of brain imaging and neuropharmacology. These techniques not only have been used for understanding normal brain function, but also provide new insights into the physiological basis of neuropsychiatric disorders. Their future uses might extend to forensic and commercial purposes, such as in marketing or research on consumer preferences.

Clinical depression is the leading cause of disability in the USA and other countries today, and is expected to become the second leading cause of disability worldwide—after heart disease—by the year 2020 (Murray & Lopez, 1997). Klaus-Peter Lesch describes in more detail how variants of the serotonin system give rise to depression and other anxiety disorders (pS24), while Turhan Canli describes how his group has made the link from research on the molecular level of behaviour to clinical psychology, in an approach that he has termed genomic psychology (pS30). The pharmaceutical industry has already responded to the apparent increase in behavioural disorders with new anti-depressants such as selective serotonin reuptake inhibitors and stimulants to treat attention-deficit hyperactivity disorder. Although their prescription—to children in particular—is rapidly increasing, there are few clinical studies on young patients who take psychotropic drugs. The article by Ilina Singh therefore provides a unique insight into how children who are subjected to stimulant treatment engage in clinical research as capable and informed actors, and she convincingly refutes protective impulses to exclude children from clinical studies (pS35).

Degenerative disorders of the brain, such as Alzheimer disease and Parkinson disease, are among the largest public-health problems in fast-ageing populations. But intense efforts by the pharmaceutical and biotech industry have produced no cure or treatment to halt or even reverse neurological degeneration in older individuals. Lars Sundstrom describes a new drug-development strategy that might help to provide these much-needed therapies: so-called 'chemical genomics' (pS40). Instead of identifying possible drug targets and then searching for compounds that interfere with them, numerous compounds are tested on biological material—cells, tissues or model organisms such as *Drosophila* or zebrafish, for example—to see if they can trigger the desired physiological response.

Future neurotechnologies will not be limited to medical uses alone, as shown by the emerging field of 'neuroeconomics', which analyses neurological determinants of decision-making as well as their social and economic implications. The essay by Michael Kosfeld provides an interesting introduction to the general approach of neuroeconomics through his case study of the neurobiology of trust (pS44). Kosfeld describes a key experiment that proves the important role of the neurohormone oxytocin in the willingness of individuals to trust others.

The essays in the third and final section of this special issue are concerned primarily with the ethical questions that are raised by the new brain sciences and their applications. One of the main issues is whether philosophical and ethical questions about genetics and genomics acquire an accrued urgency when they are re-examined in the context of neuroscience. Many talks and debates at the Heidelberg conference focused on whether these developments justify the establishment of a new branch within the field of bioethics: neuroethics. This term seems to be used with two distinct meanings: on the one hand, neuroethics concerns itself with the study of moral dispositions, which it assumes are hard-wired in the human brain; on the other hand, neuroethics commonly refers to concerns about the sociocultural repercussions of the new knowledge and technologies of the brain. Kathinka Evers prefers to distinguish between 'applied neuroethics' and 'fundamental neuroethics', the latter being geared towards deciphering the network of causal connections between the neurological, sociocultural and contingent historical perspectives that allow moral 'norms' to be enunciated at a given time (pS48).

Adina Roskies (pS52) and Judy Illes (pS57) both argue for recognizing neuroethics as an emerging field within bioethics. In their view, neuroethicists should monitor how the brain sciences develop, and should critically review new ways of enhancing, controlling and reading the mind. According to these authors, the stakes might be high if new tools become available that allow us to distinguish lies from truth, veridical versus false memories, the risk of future violent crime, styles of moral reasoning, the inclination to cooperate and even specific contents of thought. Erik Parens and Josephine Johnston, by contrast, express reservations about the neuroethical turn in bioethics (pS61). Stressing the underlying commonalities between many different uses of modern-day science and technologies, they argue that dividing bioethics into several branches—each focusing on a separate set of issues—could do more harm than good. In the closing essay, Raymond de Vries provides the perspective of a sociologist on this new field in bioethics (pS65). de Vries proposes that, along with its declared objectives of weighing the ethical implications of imaging, measuring and altering the brain, neuroethics is just as much about the mindset and the interests of it practitioners. His sociological critique focuses on neuroethicists as being engaged in constructing new boundaries, carving out their territory within the academic landscape and 'colonizing' a new area of bioscience. Together, the last two essays in this special issue of *EMBO reports* present a critical rethinking of the role that the practitioners of bioethics/neuroethics have assigned themselves.

Time will tell whether the new brain sciences explain human consciousness, or provide the tools needed to analyse and treat neurological and psychiatric disorders. In the meantime, scientists will undoubtedly discover many of the fundamental determinants of animal and human behaviour. Such new knowledge will inevitably be applied, and it is important that this is done for the benefit of both individuals and societies—hence the need for a broad deliberation, well in advance and beyond disciplinary boundaries. The collection of essays in this special issue of *EMBO reports* should contribute towards those goals.

REFERENCE

Murray CJ, Lopez AD (1997) Alternative projections of mortality and disability by cause 1990–2020: Global Burden of Disease Study. *Lancet* **349:** 1498–1504

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doi:10.1038/sj.embor.7401012