Psicológica (2006), 27, 149-167.

What does the brain tell us about the mind?

María Ruz[1*], Juan J. Acero[2] & Pío Tudela[2]

[1]University of Oxford, UK; [2]Universidad de Granada, Spain

The present paper explores the relevance that brain data have in constructing theories about the human mind. In the Cognitive Science era it was assumed that knowledge of the mind and the brain correspond to different levels of analysis. This independence among levels led to the epistemic argument that knowledge of the biological basis of cognition would not be relevant at a psychological level of explanation. Nowadays, however, modern neuroimaging technologies offer a powerful means to explore the cognitive functioning of the human brain. The authors argue that this technological revolution is associated with a new way of building theories of human cognition in which mind and brain are no longer independent nor autonomous. In contrast, the Cognitive Neuroscience era is marked by a continuous and bi-directional exchange of information between biology and cognition.

We humans are conscious rational agents and, at the same time, we are physical and biological entities shaped by evolution. This dual vision of human nature, in which mind and brain have been often regarded as qualitatively different, has helped to draw the burdens among disciplines that study the human being. The mind, which drives our rational behavior, has been investigated in disciplines such as Philosophy of Mind and Cognitive Psychology. The study of the human body, on the other hand, has been left to biological sciences. Along our history, the way in which the mind and body are separated has stressed the notion that understanding the

[*] **Acknowledgements**: This work was possible thanks to the Spanish M.E.C. grant support to P.T. (project ref. BSO2003-07292/PSCE), to J.J.A. (project ref. HUM2005-07358/FISO) and to M.R. (F.P.U. predoctoral training program). The authors would like to thank the anonymous reviewers for their helpful comments. **Contact details:** Dr. Maria Ruz. Dept. of Experimental Psychology. University of Oxford. South Parks Road. Oxford OX1 3UD. United Kingdom. E-mail: maria.ruz@new.ox.ac.uk

brain is irrelevant for understanding the mind, and vice versa. In the last decades, however, the development of techniques suitable for the study of high-level cognitive processes in the human brain has generated a conceptual revolution that may blur the dichotomy between mind and brain.

The main goal of this paper is to consider the implications that the inclusion of brain data has on investigations of the human mind. We first note some basic investigative assumptions in Functionalism and Cognitive Science to then question the independence among levels of analysis of human cognition. Next we present some ways in which data from the brain help in explaining the human mind. The conclusions highlight the essential role that brain knowledge plays in the scientific quest for a complete and accurate understanding of the human mind.

1. FUNCTIONALISM IN PHILOSOPHY OF MIND

Philosophy of Mind has been one of the main disciplines interested in describing the intentions and desires laying at the basis of human behavior. In brief, a functional description of any complex processing device contains the inputs to the machine, the series of the internal operations generated by those inputs as well as the relations among them, and finally the outputs of the machine, which in turn are dependent on the inputs and the series of internal operations. This description presents the functions that the different states have on the economy of the system. In a similar manner, Functionalism in Philosophy of Mind claims that mental states are to be characterized by their functional properties, that is, by their inputs, outputs and the role they play in the mind of agents as nodes in a complex system of causal transactions. Specifying the nature of a mental state consists in describing its functional role.

Putnam (1975) originally introduced the Computational Functionalism doctrine (also called Functionalism of the Turing Machine), in which mental states are understood in the same manner as the internal states of a computational program. The key aspect here is the distinction between function and occupant, i.e. the mental state and the physical state that realizes it (if there is only one). Describing a mental state equals to determining its role on the tasks specified by the psychological theory. In turn, the realizer is the physical state that implements the specific function.

This distinction between function and occupant, the mental state and its physical realizer, leads to the *multiple realizability* argument, a core element in the functionalist doctrine. Computations are multiply realizable in the sense that the same functions can be implemented in very different physical substrates. By way of analogy, consider a key as a simplified example. The key, as any mental state, is defined by its function, which is to either open or close a lock. However, this function can be realized by different physical means, because a key can be made out of metal shaped in a particular form or by a plastic card containing a magnetic code on it. Thus, the important thing in order to define a key is not its physical substrate but rather its functional role. In the same manner, a mental state is not defined by its material constitution but rather by its role in the net of inputs, internal states and outputs in the computational organization of the system. As there is no one-to-one mapping between a mental state and a physical feature, mental states and computations must be defined by their functions in the whole system, and not by their material realization in a specific device. Thus, talking about minds is studying material systems at a higher level, abstracting from whatever physical constituents realize them. High-level mental terms designate functional properties that are different from properties of the material stuff in which they are implemented, and thus mental states are not identifiable with, or reducible to, the material states they are realized in.

This independence among levels of analysis is shown in Turing machines, a demonstration that the same operations can take place in very different substrates (Turing, 1950). Turing machines provide a theoretical paradigm to compute the value of an arithmetical function, while abstracting from the physical means needed to do it. On the one hand, Turing machines computations are strictly determined by the inputs, outputs and machine states; in other words, by their software, not by their hardware. On the other hand, there is one Turing Machine, the Universal Turing Machine (UM), which can compute any function computable by any Turing Machine whatsoever. The only thing you need to achieve this is to program the UM with the specific details of the machine simulated. Since any computer program is equivalent to a Turing machine program —this is the so-called Church-Turing Thesis, the real basis of Computation Theory—, the UM runs on very different kinds of material devices. Computation and implementation thus pose different theoretical as well as practical demands, and therefore it is possible to forget about the material composition of a system when studying it as a computational and algorithmic machine. From this perspective, the biology of the brain plays no significant role in the search for the mental states that constitute the human mind. A typical functionalist assertion is that when psychological theories are mature enough, it will be possible to translate the discoveries made to the actual brain substrate that corresponds to such mental states in the human brain. Even more, once such a translation is reached, and perhaps this will never be the case, adding biological data to the picture will not bring explicative power into the functional role that typically belongs to mental explanations, but will only describe how mental states are materially realized in the brain (e.g. Fodor, 1999).

The investigative approach in Functionalism, however, lacks an experimental strategy to confirm or disconfirm the facts it proposes about the mind. Defining mental states and their functions in an aprioristic manner needs some kind of experimental feedback in order to evaluate whether the operations offered to explain the human behavior are really causally efficient. Therefore, a complement to theorizing in Philosophy of Mind is the experimental approach in Cognitive Psychology. During its history, psychology has joined other disciplines in related fields trying to gain an integrated and coherent knowledge on how the human mind works. Cognitive Science and Cognitive Neuroscience are the two multidisciplinary enterprises that have worked toward this goal. Although many conceptual and methodological tools are shared by both paradigms, they differ in basic assumptions and in the role they ascribe to biological data when explaining the mind.

2. COGNITIVE SCIENCE

By the end of the behaviorist era around the fifties, the appearance of Cognitive Psychology recovered the interest in the internal representations and processes that constitute the human mind (see Tudela, 2004). This change in theoretical thinking came together with the advent of digital computers, and has come to be known as the information processing revolution. Its foundational basis was the acknowledgment that a parallel could be drawn between a computer and a human mind (the so-called mind-computer analogy). Cognitive Science was defined as the study of intelligence and its computational processes in humans (and other animals), in computers and in the abstract (Simon and Kaplan, 1989). The development of computational models able to perform complex tasks emulating human behavior (e.g. Anderson, 1983) was the main tool to describe and explain how intelligence works in different complex systems.

A basic assumption in Cognitive Science is that the human mind can be viewed as a complex information processing machine, and thus it can be decomposed into different functional modules with different specializations (see Cummins, 1983). These sets of cognitive systems are further decomposed into more detailed representations and processes, in a recursive manner up to the point of elementary mental operations (see Posner and Rothbart, 1994).

David Marr (1982) described the idea that there are different epistemic points of view from which complex processing information systems can be studied. This author noted that there is no single view of a complex system that explains everything about it. In order to obtain a complete understanding of a system, questions should be framed, and consequently explanations provided, at different levels. In the first place, a *computational theory* has to be developed, which identifies which global function the system computes and why it does so. It is at the second level where *representations and algorithms* matter, i.e. where one should deal with the representations of the input, the output and the algorithms that transform these representations. Finally, at the *implementation* level the goal is to describe the physical device that actually realizes the system.

A key proposal of Marr's philosophy is the mutual independency of levels of analysis, in a similar way as required by the Multiple Realizability argument in Functionalism. Marr considered that knowledge at the three levels had to be integrated in order to gain a complete understanding of the whole system. Each of the levels however had a unique area of inquiry, in the sense that research could be done in each of them without knowledge of results in the others. This is because questions asked and issues explained at each of these levels are fundamentally different and therefore independent from each other. As Marr puts it:

'… the explication of each level involves issues that are rather *independent* of the other two.' (Marr, 1982, page 25; italics added)

The independence assumption is adopted in Cognitive Science as well, allowing Psychology to avoid a biological reductionist approach. The same functions and computations can be carried out by very different physical substrates and for this reason knowing about the implementation of a given process is not needed to be able to obtain a complete understanding at the computational and algorithmic levels of description of a system. Thus, a model describing certain computations in the human mind can be devised with no data at all on the physical system that implements the device. This has led to an implicit "seriallity" assumption of research in Cognitive Science: First we should obtain a complete understanding of the algorithms employed by a system and their function and only after this is achieved, we are ready to start exploring the implementation in the brain of such processes. Again, this line of theorizing maintains the long-standing distinction between mind and body. Note however that although this was the prevalent view, some theorists supported the vital importance of neuroscientific data (see for example Broadbent, 1971).

3. QUESTIONING THE INDEPENDENCE ASSUMPTION

In the fifties it was very useful for research in Cognitive Science to acknowledge that the study of cognitive processes has its own level of analysis independent of biological data. Techniques available at that time were not able to measure brain activity during performance of the cognitive task of interest. Thus, the existence of a level of theorizing unique for cognitive processing was needed in order to investigate how humans represent and process information. Years of research in this discipline have shown that in fact it is possible to learn about how the human mind works without paying attention to its biological reality.

However, technical developments in the last years have offered the possibility of measuring brain activity while humans are performing complex cognitive tasks. Different techniques, such as fMRI, PET, TMS or neuropsychological studies, enable the localization of brain areas that correspond to specific computations, and it is also possible to study the time course at which these areas come into play by the use of HDERP (see Posner and Raichle, 1994; Mazziotta and Toga, 1996)[1]. Moreover, electrophysiological recordings in non-human primates offer insights into the mechanisms of neural cognitive processing (see, for example, Miller, 1999) and, together with brain imaging techniques, they show the kind of representations that a specific region supports (Naccache and Dehaene, 2001). These techniques are not exempt of limitations, however (see Uttal, 2001, for an extensive critique). FMRI and PET are very useful in localizing activations in brain regions, but their temporal resolution is severely limited. HDERPs can overcome this limitation as they offer excellent temporal information although lack the spatial precision that former techniques offer. Besides, neuroimaging data provide information about the involvement of brain regions in different tasks, but cannot inform about whether or not those regions are necessary to perform the tasks. Neuropsychological and TMS studies can though offer this information by looking at the effect on behavior of the permanent or transient inactivation of brain regions. Another important drawback is the current poor understanding of the physiological meaning of the indices used in neuroimaging research (i.e. the precise neural origin of the BOLD signal in fMRI or the brain electrophysiological potentials measured by HDERPs), although significant progress has been made in the last years on this respect (e.g. Logothetis and Pfeuffer, 2004).

[1] fMRI: Functional magnetic resonance imaging. PET: Positron emission tomography. TMS: Transcranial magnetic stimulation. HDERP: High-density Event-related potentials.

The most powerful strength of Cognitive Neuroscience is to use the techniques in combination to tackle the same problem, which ameliorates their weaknesses. This way, these facilities are providing data on how the brain actually performs the computations that have been studied in Cognitive Psychology for a long while (see Gazzaniga, Ivry and Mangun, 1998; Gazzaniga, 2000, 2004). Concepts used in Cognitive Neuroscience clearly differ from Biology's classical conceptual repertoire, i.e., Cognitive Neuroscience is not "pure biology" (see Stoljar and Gold, 1998). The sort of questions that are asked about the primate brain in Cognitive Neuroscience are aimed at learning about its cognitive functioning rather than about the physical properties of its constituents.

A central question stemming from the technological and conceptual revolution that Cognitive Neuroscience has brought up is how important data obtained from the brain are in theorizing about mental phenomena at the level of computations and algorithms. In other words, now that we are starting to acquire knowledge about cognitive brain functioning, can we still consider the three levels of analysis proposed by Marr as independent from each other? One crucial point in answering this question relates to the main goal of the research.

Although the same computation or general function can be performed by very different material substrates, as Turing Machine computations show, the physical structure of a specific device conforms how the function is performed. That is, the kind of physical composition and material structure constrains to a great extent the sort of algorithms, or representations and processes that are used to perform the function the system has to fulfil. The UM devised by Turing performs the same computations as any other formally structured device, in the sense of generating the same output state from the same input. However, the kind of steps or algorithms that this machine employs to resolve the task can be rather different compared to those of the system it is emulating. This is because its internal structure constrains the way the task is decomposed, represented and processed; that is, how the output pattern is actually obtained from the input the device receives (Pylyshyn, 1989; Sejnowski and Churchland, 1989). Think again in a key as example of something having a functional property. Although the same function can be performed by very different physical substrates, how the function is performed depends on the specific material the key is constructed from. A key made out of metal must have a specific shape to fit into the lock. However, a plastic card key opens the lock with the magnetic code it contains. The operations by which the key performs its function are completely different in both cases, and it is the material arrangement what constrains the operations. How a system is materially arranged will make its internal operations to be of a specific kind. Therefore, we must know about how the human brain works in order to explain how we humans process information, which is the goal of Cognitive Psychology.

Investigative strategies in Functionalism or Cognitive Science cannot offer a complete picture to explain how the human mind actually works. Here, mental states and their functions, or processes and representations, are described a priori and their implementation is left as a posteriori problem, just as a description at a different level of analysis. However, theorizing about mental states or mental computations as something that does not need to be informed by the human brain is a naïve enterprise nowadays. As stated above, this strategy has the serious risk of inviting us to set up psychological theories that describe plausible ways of how a cognitive system may function but that are far away from how the human mind actually works. Research on cognitive processing in the brain will constrain which explicative concepts are useful and which ones are not. This is because the three levels of analysis are neither independent from each other nor autonomous in themselves. The interchange of information across levels will bring out an adjusted view on how cognition is carried out in the human brain. Researchers in the field of Cognitive Neuroscience are investigating the human mind from this perspective.

4. COGNITIVE NEUROSCIENCE: INSIGHTS FROM COGNITION IN THE BRAIN

Cognitive Neuroscience is a multidisciplinary scientific endeavour for the study of the cognitive functioning of the human brain. Its emergence was driven by two separate achievements (see Posner and Raichle, 1994). In the first place, the development of non-invasive brain imaging techniques allowed the recording of brain activity while humans were engaged in different cognitive tasks. In the second place, a broad spectrum of theories of mental processes and of tasks suitable for the study of human cognitive processes were provided by more than half a century of Cognitive Psychology. These tasks can now be used to study how the brain performs the computations studied in Cognitive Psychology for a long time.

By conjoining techniques, data and theories at the cognitive and biological level of explanation (Marr, 1982), research on Cognitive Neuroscience tries to provide a coherent and integrated explanation of the biological basis of human cognitive behavior (Posner and Raichle, 1994). Its main goals have been defined as explaining how the brain enables the mind (Gazzaniga et al., 1998), translating the phenomenology of cognition to biological processes (McIntosh, Fitzpatrick and Friston, 2001), localizing cognitive processes in the brain (Corbetta, 1998; Humphreys, Duncan, and Treisman, 1999; Posner and Raichle, 1994; Posner and Rothbart, 1994) and discovering the cognitive functions of brain regions (Naccache and Dehaene, 2001).

The recording of brain activity while the person is performing carefully designed tasks allows researchers to discover the dynamics of the neural networks implementing the cognitive processes under scrutiny. A great deal of progress has been made in the mapping of perceptual, mnemonic, linguistic, emotional, learning and attentional processes onto different brain networks (see Gazzaniga, 2004, for a comprehensive overview). Here, the independence between levels claimed by the functionalist doctrine breaks down; the continuous interplay of questions and answers among levels is driving an integration of theoretical concepts among them.

Several years of research in Cognitive Psychology offer the conceptual tools necessary to study how cognition works in the brain, by focusing research questions and offering paradigms and task analyses (Humphreys et al., 1999; Posner and DiGirolamo, 2000). Questions asked in this discipline by different research paradigms are not about the physical mechanisms by which the brain works (i.e. the nature of neurotransmitters, ionic currents or action potentials) but about the neural mechanisms of cognitive information processing (i.e. how different sorts of information are coded and stored in the brain, or how attention to a selected code changes the pattern of activity in the cells coding those representations). Thus, the role left for biology is not just descriptive, as it was in Cognitive Science and Functionalist doctrine, but *explicative*; the way in which the human brain works helps to explain why the algorithms used to process information have the specific design they seem to have. Biology, therefore, far from being a complement to the understanding of how cognition is built, is deeply integrated into the same theoretical project.

A simplistic view of research in this discipline argues that the localization of already described cognitive processes in their neural substrate brings no hints on those processes (Fodor, 1999). However, most theorists in the field of Cognitive Neuroscience support the opposite view: results in this field are starting to change theoretical ideas on major psychological issues (Driver, 2001; Humphreys et al., 1999; Posner and DiGirolamo, 2000). That is, theories on cognitive processes are being modified or even created by results driven from research in Cognitive

Neuroscience (see Ruz, *in press*, for a description of the role of neuroscience data in research on the cognitive system of Attention).

5. HOW DOES THE BRAIN HELP US IN EXPLAINING THE MIND?

As noted above, until quite recently most investigations on human cognition have been shaped by the notion that mind and body-related concepts belong to completely different levels of description. Although descriptions at a 'pure cognitive' or a 'pure biological' level are still possible, research on the fast growing field of Cognitive Neuroscience may be starting to blur the boundaries between our minds and our brains. Here, classical cognitive concepts together with tasks designed to study them, are being used to ask the brain how those internal operations are performed by our neural tissue. At the same time, brain data can be used in a feedback manner to consolidate, refine or modify how existing theories decompose or analyse mental operations (Churchland, 1986; Posner and DiGirolamo, 2000). This endless interchange of information from cognition to brain functioning drives the inclusion of biological concepts into theories of cognition while at the same time organizes our knowledge of brain functioning into cognitive dimensions. The results are theories in which is difficult to disentangle where the difference lies between the mind side and the body side of human cognition (see Gazzaniga et al., 1998, for a comprehensive overview).

Although the field of Cognitive Neuroscience is admittedly young, the incorporation of data from the brain for studying the human mind is starting to show several advantages over previous approaches, some of which are outlined below.

5.1. Multidimensional data sets are obtained from each task.

Research in behavioral Cognitive Psychology confronts the problem that a few data points are derived from each trial in an experiment. In this discipline, analyses are usually made on the basis of reaction times and/or accuracy to respond to stimuli. Thus, the whole chain of internal processes that takes place from a stimulus to a response is measured with only one or two markers per trial, which might not be sensitive to some of the internal operations needed to perform the task. However, brain imaging shows activations and deactivations in different parts of the brain as well as the temporal ordering of these processes (see Cabeza and Kingstone, 2001), and this even in the absence of a behavioral response (see Leopold and Logothetis, 1999).

For example, Lumer and Rees (1999) studied the brain correlates of human consciousness in a binocular rivalry paradigm. Using knowledge on the temporal profile of the binocular rivalry of the participants in the study, they were able to infer the brain activity associated to conscious experience without the participants generating an overt response about the content of their consciousness. These authors found that consciousness was related to functional interactions of coordinated activity between different brain areas such as visual and prefrontal cortices, linked in previous studies to visual perceptual analyses, working memory and control of attention processes. Thus, the multidimensionality of data obtained by means of neuroimaging can be used to analyse the brain as a whole, to study how some areas activate in concert with other areas (what is called brain functional dynamics) and the constrains anatomy imposes on these interactions. This is a very useful approach for studying the dynamics of a complex system such as the human brain (see, for example, Sporns, Tononi and Edelman, 2000), which was not available for research until the advent of neuroimaging techniques.

5.2. Resolution of long-standing questions in Cognitive Psychology.

For a long time there have been some debates in the field of Cognitive Psychology that have framed an important part of the research and for which no clear and definite answer has been found. One of them is the locus of selection of information (Broadbent, 1958, Posner and DiGirolamo, 2000). Theorists argue about whether attentional selection operates at early stages of information processing at the perceptual level of analyses (Broadbent, 1958; Posner, 1980) or whether this selection only takes place at later stages such as response selection or access to conscious representations (Deutsch and Deutsch, 1963; Pashler, 1994). Research with brain imaging techniques has shown, however, that selection of information can take place at both early and late stages of processing. In brain dynamics, paying attention to a stimulus causes the amplification in the firing of the neurons that code for that stimulus (Corbetta et al., 1991; Desimone and Duncan, 1995). This enhanced activity helps the neural representation coding for the attended stimulus to win the competitive processes between brain areas that take place for the control of action (Desimone and Duncan, 1995; see Rees, Frackowiak and Frith, 1997). Research with neuroimaging techniques has revealed that this attentional amplification in neural signals can take place in both early (Hillyard, Vogel and Luck, 1998; Posner and Gilbert, 1999) and late brain regions (see, for example, Driver and

Vuilleumier, 2001). Therefore, the answer from Cognitive Neuroscience to the old research question is that attentional selection can take place at several levels of processing (Luck and Hillyard, 2000). The question for research now is which the task characteristics are that drive the brain to select information at different levels of representation (Lavie, 2000; Luck and Hillyard, 2000).

Another area of research illuminated by brain imaging has been that of conscious vs. unconscious processing of information (see Merikle and Daneman, 2000). For a long time it was not clear whether stimuli that are not consciously perceived are processed at all (Holender, 1986). By measuring brain activity after unconscious stimulation it has been shown that a great deal of cerebral processing takes place even when participants lack the subjective experience of the stimulation (see Dehaene and Naccache, 2001; Kanwisher, 2001, for an overview) both in normal and in neuropsychological patients. Neuroimaging data show that unconscious stimuli such as words or faces activate to a great extent the extrastriate areas in the cortex specialized for high order visual analysis (see Dehaene et al., 2001; Rees, 2001). Now, the research question has turned to which characteristics of brain dynamics are related to conscious awareness. Multiple results show that consciousness is associated with covariation of activity in multiple extrastriate ventral, parietal, and prefrontal cortical areas, suggesting that the interchanging of information between areas involved in visual perceptual analyses and those related to attentional selection and cognitive control may contribute to conscious awareness. These results, in turn, support models of consciousness that conceive it as a high-level stage in brain processing where information from multiple sources is integrated and used in the control of explicit behavior (i.e., Baars, 1988; Dehaene and Naccache, 2001). Therefore, results in the field of Cognitive Neuroscience are helping to solve old questions that had found no clear answers from traditional methods in Cognitive Science. At the same time, data obtained from neuroimaging are generating new questions on human cognition, which in turn will look at the brain dynamics to find an answer to them.

5.3. Generation of new hints on the parallelism between different sides of cognition.

As neuroimaging results accumulate, an increased amount of knowledge is gained about the cognitive functions of different brain areas and networks (see Cabeza and Nyberg, 2000; Naccache and Dehaene, 2001). The finding that a certain behavior activates a set of cerebral regions may help to elucidate the cognitive processes that the task recruits by inferring this from other studies that find overlapping brain activations. Therefore, parallelisms as well as dissociation among different tasks can be found by comparing their respective pattern of activations (Humphreys et al., 1999; see also Poldrack, 2006). For example, measurements of brain activity while persons are performing tasks that require the generation of internal visual images have shown that the brain areas recruited overlap to a great extent with those regions that respond when persons actually perceive visual stimulation in their environment (Thompson and Kosslyn, 2000). This result suggests that the act of imaging a situation is performed by internally activating part of the same perceptual brain areas that are used to construct a percept when the stimulation comes from the external world.

The work of Lieberman (2000) is another example of this strategy. This author proposes that social intuition skills have their basis on knowledge obtained by means of implicit learning processes. Apart from the conceptual similarities that could be drawn between those two domains of cognition, it has been shown that they both depend on similar portions on the brain, in particular on normal basal ganglia functioning. This brain region is strategically located and connected to other brain regions for it to serve as a brain mechanism to unconsciously detect subtle relevant regularities in the environment. Thus, intuition could be the subjective experience associated to the use of knowledge obtained trough implicit learning processes (Lieberman, 2000). In a related field, research in the new area of social cognitive neuroscience is showing the intimate relation between emotion and social cognition (see also Adolphs, 2003). Hence, data from Cognitive Neuroscience can be used as a source of insights in order to draw parallelisms, as well as dissociation, among conceptual domains that could seem to be far apart when examined only by means of pure behavioral methods of analyses.

5.4. Evaluation of general assumptions in theories about the mind.

The information processing approach in Cognitive Psychology divides cognitive tasks into constituent operations and uses mental chronometry to measure those elementary processes (Posner, 1978). In the same vein, results in Cognitive Neuroscience are showing that complex brain functions can be decomposed into simpler processes which can be anatomically localized and that correlate with simple behavioral processes (Posner and DiGirolamo, 2000; Posner and Rothbart, 1994). For example, some cognitive theories on how visual perception is accomplished state that the input from the environment is decomposed into several dimensions (lines, orientation, motion, form, color and the like) and then they are arranged to form a complex object in higher levels of analyses (Marr, 1982). The study of visual perceptual regions in the brain has shown that there are different areas in charge of representing the attributes in which the perceptual input is decomposed and that other areas represent objects as a whole (see Zeki, 1993). Therefore, brain analysis has validated a group of theories developed in the field of Cognitive Psychology because it has shown that the primate brain is organized in the same dimensions as the theory postulates. Another assumption held for a long time by several theories in the field of visual perception was that of sequential and serial steps of processing along modules containing encapsulated information. However, it has been shown that perceptual information is processed in the brain in a recurrent and interactive fashion instead of in a linear and encapsulated manner (see Churchland, Ramachandran and Sejnowski, 1994; Lamme and Roelfsema, 2000), a discovery that invalidates the seriallity assumption held by several models. Therefore, part of the assumptions that have driven research in Cognitive Psychology for a long time are now being validated by functional brain imaging and others are proven wrong, thus forcing models to be reconsidered in the light of results from Cognitive Neuroscience.

5.5. Clarification of the adequate level of analysis in the brain for theorizing about the mind.

The behavior indeterminacy claim states that by using behavioral data alone it will never be possible to find a strong equivalence between a model and the psychological reality in the human brain (see Pylyshyn, 1989). Different theories describe the same psychological phenomena by using concepts at different levels of abstraction. Discovering the right level at which a certain problem has to be explained (i.e. from individual neuron behavior to brain networks dynamics) is a key factor for success in research (Ramachandran and Hirstein, 1997). In a not so distant future, results in Cognitive Neuroscience may provide invaluable insights into the adequate level of analysis to study how the brain processes information. The appropriate ontological level in the analysis of cognition in the brain may depend on the specific problem under study. For example, while attentional selection may be explained at the level of competition among neuronal groups coding for different stimuli, it might be more useful to study the interactions among different brain regions in order to explain memory consolidation or conscious awareness phenomena. In any case, it will be research in Cognitive Neuroscience what will serve as a reference point to elucidate which theories and concepts are either useful or not in explaining how the human mind works.

6. CONCLUSIONS

Some decades ago, the main goal of Cognitive Science was to determine the computations of intelligent systems. Thanks to the acknowledgement of a specific level of analysis for cognition, research in this area has considerably advanced our knowledge on how humans represent and process information. The independence assumption stemming from the Functionalist doctrine was adopted in Cognitive Science and thus the role for biological data was left as a posteriori description of already described mental phenomena. More than fifty years later, technological developments allow us to translate questions on cognition to the human brain. Cognitive Neuroscience is turning out as a main source of knowledge of the neural mechanisms of cognitive processing.

The type of questions that can be addressed in this discipline are varied in nature. Obviously neuroimaging techniques can be used to localize and characterize the temporal dynamics of processes already described in psychological theories. On the other hand, brain data can be used to define cognitive processes, to build taxonomies of them and to describe the mechanisms by which they work (see Ruz, in press). As they offer multidimensional data sets from each task, they allow the study of cognitive processes in the brain as a whole. Neuropsychological data and TMS manipulations help in drawing causal relations between brain regions and tasks. Moreover, results in Cognitive Neuroscience are sometimes useful to clarify long-standing questions in Cognitive Psychology and to generate new hints on the parallelism between different sides of cognition. At the same time, results in this discipline are a tool for the evaluation of theories in Cognitive Psychology, as well as a means to find out the adequate level of analysis of the brain to approach a research problem.

The fast development of Cognitive Neuroscience is thus offering an explanation of human cognitive functioning in which Marr's levels of analysis are no longer autonomous. Thinking on the human mental operations and their functions as something completely independent of their material substrate does not take profit from the technological and conceptual developments in the last years. Indeed, in a not so distant future, theories explaining human cognition may use concepts in which mind and body are no longer understood as independent phenomena.

RESUMEN

¿Qué nos dice el cerebro sobre la mente?. El presente artículo explora la relevancia que tienen los datos del cerebro en la generación de teorías sobre la mente humana. En la era de la Ciencia Cognitiva, se asumía que el conocimiento sobre el cerebro y la mente corresponden a dos niveles de análisis diferentes. Dicha independencia condujo al argumento epistémico de que el conocimiento acerca de las bases biológicas de la cognición humana no es relevante para las explicaciones psicológicas. Hoy en día, sin embargo, las tecnologías de neuroimagen son una vía excepcional para explorar el funcionamiento cognitivo del cerebro. Los autores defienden que esta revolución tecnológica está asociada a una nueva manera de construir teorías sobre la cognición humana, en la que la mente y el cerebro no se consideran autónomos ni independientes el uno del otro. Al contrario, la Neurociencia Cognitiva se caracteriza por un intercambio continuo y bidireccional de información entre la biología y cognición humanas.

REFERENCES

Adolphs, R. (2003). Cognitive neuroscience of human social behavior. *Nature Reviews Neuroscience, 4*, 165-168.

Anderson, J. R. (1983). *The architecture of cognition*. Cambridge, MA: Harvard University Press.

Baars, B. J. (1988). *A cognitive theory of consciousness*. Cambridge, UK: Cambridge University Press.

Broadbent, D. E. (1971). *Decision and stress*. London, UK: Academic Press.

Broadbent, D. E. (1958). *Perception and Communication*. Oxford, UK: Oxford University Press.

Cabeza, R. & Kingstone, A. (Eds.), (2001). *Handbook of functional neuroimaging of cognition*. Cabridge, MA: The MIT Press.

Cabeza, R. & Nyberg, L. (2000). Imaging cognition II: An empirical review of 275 PET and fMRI studies. *Journal of Cognitive Neuroscience, 12*, 1-47.

Corbetta, M. (1998). Functional anatomy of visual attention in the human brain: Studies with position emission tomography. In R. Parasuraman (Ed.), *The attentive brain*, (pp. 95-122). Cambridge, MA: MIT Press.

Corbetta, M., Miezin, F. M., Dobmeyer, S., Shulman, G. L. & Petersen, S. E. (1991). Selective and divided attention during visual discrimination of shape, color and speed: Functional anatomy by positron emission tomography. *Journal of Neuroscience, 11*, 2383-2402.

Cummins, R. (1983). *The nature of psychological explanation*. Cambridge, MA: MIT Press.

Churchland, P. S. (1986). *Neurophilosophy: Toward a unified science of the mind-brain*. Cambridge, MA: The MIT Press.

Churchland. P. S., Ramachandran, V. S. & Sejnowski, T. J. (1994). A critique of pure vision. In C. Koch and J.L. Davis (Eds.), *Large-scale neuronal theories of the brain*, (pp. 23-60). Cambridge, MA: MIT Press.

Dehaene, S. & Naccache, L. (2001). Towards a cognitive neuroscience of consciousness: Basic evidence and a workspace framework. *Cognition, 79*, 1-37.

Dehaene, S., Naccache, L., Cohen, L., LeBihan, D., Mangin, J. F., Poline, J. B. & Rivière, D. (2001). Cerebral mechanisms of word masking and unconscious repetition priming. *Nature Neuroscience, 4*, 752-758.

Desimone, R. & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neurosciences, 18*, 193-222.

Deutsch, J. A. & Deutsch, D. (1963). Attention: Some theoretical considerations. *Psychological Review, 70*, 80-90.

Driver, J. (2001). A selective review of selective attention research from the past century. *British Journal of Psychology, 92*, 53-78.

Driver, J. & Vuilleumier, P. (2001). Perceptual awareness and its loss in unilateral neglect and extinction. *Cognition, 79*, 39-88.

Fodor, J. (1999). Let your brain alone. *London Review of Books, 21*, 19.

Gazzaniga, M. S. (Ed.), (2000). *The new cognitive neurosciences, 1st Ed.* Cambridge, MA: The MIT Press.

Gazzaniga, M. S. (Ed.), (2004). *The new cognitive neurosciences III.* Cambridge, MA: The MIT Press.

Gazzaniga, M. S., Ivry, R. B. & Mangun, G.R. (1998). *Cognitive Neuroscience: The biology of the mind.* New York, USA: W.W. Norton & Company.

Hillyard, S. A., Vogel, E. K. & Luck, S. J. (1998). Sensory gain control (amplification) as a mechanism of selective attention: Electrophysiological and neuroimaging evidence. *Philosophical Transactions of the. Royal Society of London B, Biological Sciences, 353,* 1257-70.

Holender, D. (1986). Semantic activation without conscious identification in dichotic listening, parafoveal vision and visual masking: A survey and appraisal. *Behavioural and Brain Sciences, 9*, 1-66.

Humphreys, G. W., Duncan, J. & Treisman, A. (1999). Introduction. In G.W. Humphreys, J. Duncan & A. Treisman (Eds.), *Attention, space, and action: Studies in cognitive neuroscience*, (pp. 1-9). Oxford, UK: Oxford University Press.

Kanwisher, N. (2001). Neural events and perceptual awareness. *Cognition, 79*, 89-113.

Lamme, V. A. F. & Roelfsema, P. R. (2000). The distinct modes of vision offered by feedforward and recurrent processing. *Trends in Neurosciences, 23*, 571-579.

Lavie, N. (2000). Selective attention and cognitive control: Dissociating attentional functions through different types of load. In S. Monsell & J. Driver (Eds.), *Attention and performance XVIII: Control of cognitive processes,* (pp. 175-197). Cambridge, MA: The MIT press.

Leopold, D. A. & Logothetis, N. K. (1999). Multistable phenomena: Changing views in perception. *Trends in Cognitive Sciences, 3*, 254-264.

Lieberman, M. D. (2000). Intuition: A social cognitive neuroscience approach. *Psychological Bulletin, 126*, 109-137.

Logothetis, N. K. & Pfeuffer, (2004) On the nature of the BOLD fMRI contrast mechanism. *Magnetic Resonance Imaging, 22*, 1517-1531.

Luck, S. J. & Hillyard, S. A. (2000). The operation of selective attention at multiple stages of processing: Evidence from human and monkey electrophysiology. In M. S. Gazzaniga (Ed.), *The New Cognitive Neurosciences, 1st Ed* (pp. 687-700). Cambridge, MA: The MIT Press.

Lumer, E. D. & Rees, G. E. (1999). Covariation of activity in visual and prefrontal cortex associated with subjective visual perception. *Proceedings of the National Academy of Sciences of USA, 96*, 1669-1673.

Marr, D. (1982). *Vision: A computational investigation into the human representation and processing of visual information*. San Francisco, USA: W.H. Freeman.

Mazziotta, J. C. & Toga, A. W. (1996). *Brain mapping: The methods*. San Diego: Academic Press.

McIntosh, A. R., Fitzpatrick, S. A. & Friston, K.J. (2001). On the marriage of cognition and neuroscience. *NeuroImage, 14*, 1231-1237.

Merikle, P. M. & Daneman, M. (2000). Conscious vs. unconscious perception. In M. S. Gazzaniga (Ed.), *The new cognitive neurosciences, 1st Ed* (pp. 1295-1303). Cambridge, MA: The MIT Press.

Miller, E. K. (1999). Prefrontal cortex and the neural basis of executive functions. In G. Humphreys, J. Duncan & A. Treisman (Eds.), *Attention, space and action: Studies in cognitive neuroscience, (*pp. 251-272). Oxford, UK: Oxford University Press.

Naccache, L. & Dehaene, S. (2001). The priming method: Imaging unconscious repetition priming reveals an abstract representation of number in the parietal lobes. *Cerebral Cortex, 11*, 966-974.

Pashler, H. (1994). Dual-task interference in simple tasks: Data and theory. *Psychological Bulletin, 116*, 220-244.

Poldrack, R.A. (2006). Can cognitive processes be inferred from neuroimaging data?. *Trends on Cognitive Science, 10*, 59-63.

Posner, M. I. (1978). *Chronometric explorations of mind*. Englewood Cliffs, New Jersey: Erlbaum.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*, 3-25.

Posner, M. I. & DiGirolamo, G. J. (2000). Cognitive neuroscience: Origins and promise. *Psychological Bulletin, 126*, 873-889.

Posner, M. I. & Gilbert, C. D. (1999). Attention and primary visual cortex. *Proceedings of the National Academy of Sciences of USA, 96*, 2585-2587.

Posner, M. I. & Raichle, M. E. (1994). *Images of mind*. New York, USA: Scientific American Library.

Posner, M. I. & Rothbart, M. K. (1994). Constructing neuronal theories of mind. In C. Koch & J. L. Davis (Eds.), *Large-scale neuronal theories of the brain*, (pp. 182-199). Cambridge, MA: The MIT Press

Putnam, H. (1975). *Mind, laws and reality*. Cambridge, UK: Cambridge University Press.

Pylyshyn, Z. W. (1989). Computing in cognitive science. In M. I. Posner (Ed.), *Foundations of Cognitive Science*, (pp. 51-91). Cambridge, MA: The MIT Press.

Ramachandran, V. S. & Hirstein, W. (1997). Three laws of qualia: What neurology tells us about the biological functions of consciousness. *Journal of Consciousness Studies*, 4, 429-457.

Rees, G. (2001). Neuroimaging of visual awareness in patients and normal subjects. *Current Opinion in Neurobiology, 11*, 150-156.

Rees, G., Frackowiak, R. S. J. & Frith, C. D. (1997). Two modulatory effects of attention that mediate object categorization in human cortex. *Science, 275*, 835-838.

Ruz, M. (in press) Let the brain explain the mind: The case of attention. *Philosophical Psychology*.

Sejnowski, T. J. & Churchland, P. S. (1989). Brain and cognition. In M. I. Posner (Ed.), *Foundations of Cognitive Science*, (pp. 301-356). Cambridge, MA: The MIT Press.

Simon, H. A. & Kaplan, C. A. (1989). Foundations of Cognitive Science. In M. I. Posner (Ed.), *Foundations of Cognitive Science*, (pp. 1-47). Cambridge, MA: The MIT Press.

Sporns, O., Tononi, G. & Edelman, G. M. (2000). Connectivity and complexity: the relationship between neuroanatomy and brain dynamics. *Neural Networks, 13*, 909-922.

Stoljar, D. & Gold, I. (1998). On biological and cognitive neuroscience. *Mind and Language, 13*, 110-131.

Thompson, W. & Kosslyn, S. M. (2000). Neural systems activated during visual mental imagery. In A. W. Toga &. J. C. Mazziotta (Eds.), *Brain mapping: The systems*, (pp. 535-560). San Diego, CA: Academic Press.

Tudela, P. (2004). Cognitivism. In C. D. Spielberger (Ed). *Encyclopedia of applied psychology, Vol. I,* (pp. 393-401). Amsterdam, NT: Elsevier.

Turing, A. M. (1950). Computing machinery and intelligence. *Mind, 49*, 433-460.

Uttal, W. R. (2001). *The new phrenology: the limits of localizing cognitive processes in the brain*. Cambridge, MA: The MIT Press.

Zeki, S. (1993). *A vision of the brain*. Oxford, UK: Blackwell Scientific Publications, Inc.

(Manuscript received: 12 July 2005; accepted: 18 November 2005)