

Functional Neuroimaging and its Implications for Cognitive Science: Beyond Phrenology and Localization

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Abstract

The localization approach in neuroimaging is an attempt to find where a cognitive function is located in a specific area of the brain, which seems to be similar to an old effort, called phrenology, to relate the skull bumps to specific mental faculties. Using neuroimaging just to find “where” a function occurs doesn’t tell us much about “what” that function is and “how” it happens. The localizationist view has been criticized especially because of the dynamic nature of mind, the difficulty in definition and decomposition of cognitive functions, and the distribution of brain areas involved in most cognitive processes. In the present article, we are pointing out some problems with localizationist approach and trying to show the proper use of functional neuroimaging, especially fMRI, in the study of neural correlates of cognition. We discuss the application of functional neuroimaging as a part of interdisciplinary methods in cognitive science.

Keywords: Neuroimaging; fMRI; localization; methodology

Introduction

[T]o state it [mind-brain relation] in elementary form one must reduce it to its lowest terms and know which mental fact and which cerebral fact are, so to speak, in immediate juxtaposition (James 1890, p. 177).

In their quest for mind-brain relation, researchers have long employed various neuropsychological and neurophysiological methods such as lesion studies, electrical and magnetic recording, and direct stimulation of the brain. However, only recently has a relatively reliable measurement of the neural correlates of cognitive processes been possible. Despite some controversies in its success, a new neuroscientific method known as functional neuroimaging has attracted much attention among researchers interested in taking into account the brain activation in studying cognition. The most used functional neuroimaging methods are those based on the energy consumption of the brain while subjects are performing cognitive tasks. The increase in energy consumption of the brain elevates the regional Cerebral Blood Flow (rCBF) which is used in the Positron Emission Tomography (PET) and Single Photon Emission Computed Tomography (SPECT). The PET and SPECT are based on the injected radiotracers that make them invasive and limited but still powerful in some cases. A more recent method that is noninvasive is the functional Magnetic Resonance Imaging (fMRI). There are many fMRI methods with special applications but the most popular one is based on the Blood Oxygenation Level-Dependent (BOLD)

response. The BOLD response is a function of the rCBF, blood volume, and especially deoxygenation of hemoglobin. Decrease in deoxyhemoglobin, which is paramagnetic, leads to the inhomogeneity of the local magnetic field in a way that can be measured by the receiver of the MRI scanner to create a map of the brain activation.

Since the first functional neuroimaging studies using PET and fMRI in the 1980s and 1990s, respectively, many scientists have looked at the brain areas involved in a wide range of the mental functions, from word and face recognition to morality and religion. Apparently, the simple applications of these methods have been the search for specific areas activated by cognitive tasks. Using these techniques to find the locations of cognitive processes is similar, to some extent, to the old effort of localization that has long been tried in neuroscience and psychology. In this article, we review some problems with the localizationist approach and then discuss the possibility of using neuroimaging, especially the fMRI in conjunction with the cognitive theories, to go beyond simple localization by looking for the complex and dynamic neural correlates of cognition.

Localization and Phrenology

The assumption in localization approach is that cognitive functions are modularly located in the specific areas of the brain. One of the first localizationist methods was phrenology proposed by Gall at the end of 18th century (c.f., Hubbard, 2003; Uttal, 2001). Gall as the leader of phrenology claimed that the mental faculties are located in the specific brain areas and are detectable by looking at the skull bumps (e.g., Gall and Spurzheim 1806/1967). This approach finally turned out to be false but other forms of localization still continue nowadays. Issues related to the localization view are very important for cognitive science (c.f., Hubbard, 2003; van Gelder, 1999) especially because they are related to the age old debates on the mind-brain (or the function-structure) relations.

It seems that there are two extremist views related to localization. The scientists with the first view argue for the existence of modular and encapsulated domains in the mind (Fodor, 1983), regardless of their neural bases. This classical functionalist theory of cognition is called “the functionalism without identity” by Bechtel (2002). In this sense, understanding of a function is possible without knowing the related structure. Another extremist approach, but using neuroscientific methods especially functional

neuroimaging, is an attempt to localize cognitive functions in a specific brain region. Despite the importance of studying the neural basis of cognition, employing neuroimaging just for finding “where” a function occurs, even if it turns out being possible, doesn’t tell us about “what” that function is (Uttal, 2001) or “how” that function occurs. Uttal (2001) in his famous book critiques the latter trend and dubbed it the “new phrenology”. Uttal (2001) critically reviews the history of localization and finally lists a number of technical and conceptual problems in functional neuroimaging of cognitive processes, especially higher-order ones. He concludes that history has shown the failures of localization except for a few specific successes. Instead, he argues that a “system of nodes and loci” is involved in the behavior and raises the possibility of failure of any effort to study this system by looking at its connectivity using neuroimaging, because of the dynamics and complexity in the brain and cognition. As an alternative he leaves the option of returning to a sort of behaviorism. Although his book seems to be an attack on functional neuroimaging, it is more about “the limit of localization”, as the subtitle of the book shows, and therefore attracted much attention. In a related article (Uttal, 2002), he admits that his book doesn’t contain any “killer argument” against the functional neuroimaging technique, rather it is meant to raise caution on the studies using it. Uttal (2001) points out that the complexity of the methods, processes, and equipment leads to misunderstanding and misinterpretation of neuroimaging. He also questions the rCBF and BOLD because they are indirect measures of neural activities.

However, despite some controversies, the BOLD response is relatively an acceptable measure of the neural activities (e.g., Huettel et al., 2004; Logothetis et al., 2001, 2004). Based on this evidence, and knowing the gradual progress in neuroimaging technique, in the following section we focus only on the main problems of localization. We specially discuss the non-localizationist neuroimaging approach in the last section. In both sections, the strengths and weaknesses of Uttal (2001) are mentioned to show the problems with the localizationist approach and to support the potential utilization of neuroimaging in the study of the neural basis of cognition.

Problems with Localization

As Uttal (2001) says, the difficulty in making a distinction between specialized locations and distributed neuronal networks leads to looking for localization. Posner (2003; see also Lloyd, 2000) in a reply to Uttal (2001) notes that in neuroimaging no one seems to accept the Fodorian (encapsulated) modularity which is specially challenged by Uttal. Even the primary visual cortex (V1) is influenced by top down control (c.f., Posner, 2003). As another example, we can mention the “somatic marker” theory arguing for a localized unconscious process that affects the decision making and initially works independent of conscious control (Bechara et al., 1997; Damasio, 1994). Using their gambling task, Bechara et al. (1997) argued that a focal lesion in

Ventro-Medial Pre-Frontal Cortex (VM-PFC) leads to disadvantageous decisions (i.e., choosing cards from decks with large but rare gains instead of choosing cards from decks with small but frequent gains). As elucidated by many studies, the evidence that supports the “somatic marker” theory is unlikely to be true (e.g., Fellows and Farah, 2005a; Maia and McClelland, 2004). Fellows and Farah (2005a) questioned the “somatic marker” theory by showing that lesions to the other areas of the frontal cortex such as Dorso-Lateral PFC (DL-PFC) can also lead to the disadvantageous behavior measured by gambling tasks. Whereas Bechara et al. (1997) showed that subjects are unable to report the reason for their decision in the so called unconscious phase, Maia and McClelland (2004) found the opposite result using a better verbal report method, a result that is in conflict with the “somatic marker” theory. Another challenge to localisation is a lesion study by Fellows and Farah (2005b). They showed that patients who had lost almost their entire dorsal Anterior Cingulate Cortex (dACC) performed normally in the cognitive tasks well known for conflict and attentional control (e.g., Stroop and go–no go tasks).

Although the localizationist view, at least recently, is not dominant in neuroimaging studies there are many examples in the literature. Here we just mention a few localizationist conclusions based on some recent review papers. Although reviews and meta-analyses can help to find the different distributed networks in the brain (e.g., Cabeza and Neyberg, 2002), some have been used to show the localization of a specific function in the specific area(s). For example, Snow (2003) by a review of some neuroimaging studies concluded that four specialized areas (based on Brodman Areas; BAs) in the PFC are “responsible” for the four different modules of the mind: These modules include the “social mind” for emotional intelligence (BA9), the “temporal mind” for the future and goal (BA10), the “material mind” for practicality (BAs 45 and 47), and finally the “abstract mind” for hypotheses generation (BA46). Snow argued that these areas are heritable and their sizes determine the personality differences. As discussed in the latter sections, it is not easy to make these sorts of generalizations and oversimplifications at least based on the current state of neuroimaging. Another example is Aron (2003) who reviewed the findings of several techniques including neuroimaging and concluded that the location of inhibition is in the right Inferior Frontal Cortex (IFC) (but see Konishi et al., 2003). He used evidence from neuroimaging and especially lesion studies for his conclusion which is inconsistent with the neuroimaging results, as he also admitted, of the role of different parts of the PFC in several functions and the involvement of one part in different processes (e.g., Konishi et al., 2003; Ridderinkhof et al., 2004). Finally, another example of this kind but with less extremism is Walsh (2003) who reviewed the related neuroimaging studies and concluded that temporal, spatial, and numerical processes overlap and are located in two systems, one in the Inferior Parietal Cortex (IPC) and another in the PFC. The practical problem with these localizationist conclusions is that if the cognitive functions were located in encapsulated and

specific brain areas, the current flexibility and power of cognitive system would be unlikely. Not only are there ongoing debates on the specific role of different parts of the brain in higher-order cognitive processes, but also controversies continue on the localization of well known specific domains such as face processing (e.g., Gauthier et al., 1999; see also Price and Friston, 2005 for a strong argument against a specific area for word recognition) and numerical cognition (e.g., Shuman and Kanwisher, 2004). Recent evidence shows the involvement of different areas in the different stages of face processing (Rotschtein et al., 2005) and supports the distribution of numerical cognition (Shuman and Kanwisher, 2004). However, Posner (2003), in a reply to Uttal's critique, related the inconsistency in the imaging results to the different variables involved in the studies. For example in word recognition studies, he attributed the controversies to the degrees of regularity in letter-sound relation of the languages used, to the different instruction for the tasks, and to the variability of teaching methods. Posner also accepted that the area involved in word recognition is also involved in other similar processes.

In addition to the problems specific to neuroimaging, the main problem raised by Uttal (2001) is about the reality and meaning of cognitive functions as there is no consensus among scientists on the definition of these processes. He notes that arbitrary experimental designs have become the definition of cognitive processes. However, one cannot question the localization in neuroimaging by questioning the difficulty of definition and decomposition as it is also a problem with behavioral data of tasks used in cognitive psychology (Landreth and Richardson, 2004), and it is only problematic when the decomposition is wrong (Bechtel, 2002) or a specific task instead of a generalizable description is used as the definition of a function¹.

Beyond Localization

The localizationist approach has not been the main trend in functional neuroimaging. As most critics of Uttal (2001) point out (e.g., Posner, 2003; Landreth and Richardson, 2004), the commitment of researchers to localization has been overstated by Uttal (2001). Many studies, even before Uttal's book, for example on memory (for a review see Cabeza and Nyberg, 2000) and language (e.g., Deacon, 1998), supported the distribution of the neuronal network engaged in a given cognitive process without any commitment to a strongly localized or modular approach (see also, Landreth and Richardson, 2004; Lloyd, 2000). According to Cabeza and Nyberg (2002), a general conclusion can result from many studies that use various functions. They refer to this as "seeing the forest through the trees", for example the result of studies on verbal and nonverbal stimuli that generally show some degrees of

¹ Moreover, Uttal seems to misrepresent some aspects of fMRI (c.f., Landreth and Richardson, 2004) such as subtraction methods and threshold levels. Simple subtraction is not the only analysis method, and threshold cut-offs and significance levels are mainly for removing the noise not just the lower activations.

specializations of the hemispheres. The neuroimaging studies can also be used for evaluating debatable theories such as 'central processing bottleneck' (e.g., Jiang & Kanwisher, 2003) or for comparing two competing theories (e.g., Corlett et al., 2004). For example, Corlett et al. (2004) compared two theories, probabilistic (e.g., Macho and Burkhard, 2002) and predictive (e.g., Dickinson and Burke, 1996) learning, and argued in favor of the latter instead of just looking for localization. More importantly, neuroimaging can be used along with computational models and cognitive theories to guide and support each other (e.g., Anderson et al., 2004; Corlett et al., 2004). This exchange reveals the interdisciplinary nature of the cognitive science.

Whereas many neurophysiological methods are used in the animal studies, only neuroimaging can easily and non-invasively be used in human studies. In addition, the neuroimaging by looking at the macrolevel can guide neurophysiological studies that look at the microlevel (e.g., William et al., 2004). At least, the neuroimaging result can be used as a dependent variable in conjunction with the reaction times and accuracy. The brain activations can be used as a multivariate measure with (Henson, 2005) or without (Wilkinson & Halligan, 2004) behavioral data. Although behavioral data may not be necessary in some neuroimaging studies (Wilkinson and Halligan, 2004) it is the best, if not the only, way to make sure that subjects are doing what is expected by the experimenter. Moreover, in a study on face recognition by Yovel & Kanwisher (2004) different configurations of the face parts affected the activation in an area known as the Fusiform Face Area (FFA), whereas the behavioral data didn't change. In challenging cases like this, one may look for differences in other areas of the brain or improve the study design. Behavioral data can also be used as an index of a given cognitive process and be included in the statistical analysis as a variable. For example, the longer reaction times are indices of the conflict and can be used as a regressor to predict the activation in the different areas of the brain (e.g., Walton et al., 2004). However, the behavioral data are the final product of cognition and not completely correlated with the whole process (c.f., Henson, 2005). In the studies that reaction times do not show enough differentiation, it is the brain activations that make the differences understandable. For example, Dehaene et al. (2003) showed that the dACC is activated in conscious conflict but not when the conflict was unconscious. But, in this study the behavioral data were similar for the conscious and unconscious conditions.

The main assumption in neuroimaging is finding a "systematic function-structure" relationship, defined by Henson (2005) as follows: "within the current experimental context, it is not the case that some regions are associated with a function in one condition but other regions are associated with the same function in the other condition." However, the function of a region depends on the activation of the network the region belongs to (Henson, 2005) and the dynamic behavior of the network in the context (cognitive set or learning), as there is evidence that this assumption is

not generalizable to some circumstances. For example, the brain is wired to have the flexibilities to adapt to the requirements of tasks in the case of training, strategy, and practice (e.g., Eden et al., 2004; Erickson et al., 2004; Konishi et al., 2003), plasticity (e.g., Small et al., 1998) or development (e.g., Passarotti et al., 2003). These dynamic changes in the activation of brain networks may result from the learning of abstract rules (e.g., Duncan, 2001), using strategies (e.g., Konishi et al., 2003), or generally relying on different knowledge domains (e.g., Anderson et al., 2004). However, as some of these studies illustrate, neuroimaging can also be employed to study the effect of the above mentioned factors. Henson (2005) lists some cases of function-structure relations such as “one function” to “one structure”, “one function” to “many structures”, and “many functions” to “one structure”. To include cases in which a network is involved in many functions based on the conditions described above, it’s better to add the case of “many functions” to “many structures”. However, in this case and the case of “one function” to “many structures”, only one of the networks is active, in any time frame or condition, while the activation of the other is overridden by the more active network (Noppeney et al., 2004). But, this cannot be considered as a complete dissociation of the two networks. As discussed earlier, an example is the involvement of an unconscious system for predicting the advantage of a decision (Bechara et al., 1997). Bechara et al. argued that subjects at initial stages were not aware of the consequence of their choices. But a recent study shows that the knowledge of the decision is brought to the verbally reportable conscious system even at the initial trials (Maia and McClelland, 2004). This interconnection between lower level and higher level cognitive processes is incompatible with the encapsulated modularity, and support the integration and connectivity in the normal brain. These flexibilities can occur as the results of remedial intervention such as phonological training in developmental and acquired dyslexia (e.g., Eden et al., 2004; Small et al., 1998), task demand (Erickson et al., 2004; Walton et al., 2004), or generally the levels of the functional and structural hierarchies (Harrison et al., 2005; Henson, 2005; Price and Friston, 2005). As Henson (2005) notes, one has to know the hierarchies of the function and structure, as a function at the lower levels is performed by more than one structure and that structures at the higher levels are involved in different functions. Indeed, the modularity of lower level processes has been accepted even by the critics of neuroimaging (e.g., Cacioppo et al., 2003; Uttal, 2001).

In the neuroimaging studies of higher-order cognition, usually a function is related to many regions if the threshold and statistical methods are chosen properly. These networks are usually distributed all around the brain, and the role of some areas depends on the task stages and cognitive demands (e.g., Erickson, 2004; Harrison et al., 2005; Konishi et al., 2003; Rotschtein et al., 2005). To find the involvement of these interconnected networks in different conditions, some statistical methods are available such as multivariate analysis (e.g., Harrison et al., 2005) and

especially the Dynamic Causal Modeling (DCM) (Friston et al., 2003) that go beyond simple subtraction methods and static patterns of activations. Although, DCM is promising, if more than a few areas are included in the model, it’s not too much powerful in the higher-level processes such as decision making (Sohrabi and Smith, 2005), compared with the relatively lower-level processes tested with these methods so far, such as attention to simple visual stimuli (e.g., Friston et al., 2003). Finally, whereas phrenology was based on the correlational methods, in neuroimaging many interventions and manipulations are possible (c.f., Henson, 2005). Using better controlled designs as well as statistical analyses such as DCM can help to study the dynamics of the neural basis of cognition and even to find the modulation and control among the neuronal networks.

Conclusion

The current evidence and assumption in neuroimaging support that a widely distributed network is involved in any specific cognitive process. However, in different cognitive processes the components of the related networks have overlaps and multi-functionalities in a dynamic and context-dependent way. One meaning of this notion is that a partial group of neurons in each area is involved in a specific condition or stage of a task, as shown for example in differentiated parts of the dACC (e.g., Walton et al., 2004; William et al., 2004). The neuroimaging results *per se* are just about “where”. It is the analysis method based on activation, distribution and time course of the brain activities, and the related theories that can tell us about the “what” or “how”. As mentioned above, for this purpose several treatments exist including better cognitive tasks based on current theories, dynamic analytical methods, and insight from computational models. Also, the design of an experiment can help to have a better interpretation of the neuroimaging results (e.g., Donaldson, 2004).

However, oversimplification of complex behaviors such as love (Bartels & Zeki, 2000), cooperation and competition (Decety et al., 2004), social judgment (Winston et al., 2002) and morality (Greene et al., 2004), if the decomposition of the related processes is not explained and treated cautiously, can mislead the studies in these complex and special domains (see Cacioppo et al., 2003 and Willingham and Dunn, 2003, for a discussion on the problems with the neuroimaging of social cognition). Some higher-order functions, including social behaviors, are composed of many cognitive processes. In the case of competition (Decety et al., 2004) and moral judgment (Greene et al., 2004), it is possible that brain activation is the result of one of those processes (e.g., conflict monitoring) not the social cognitive construct *per se* (for other critiques and cautions see Willingham and Dunn, 2003). This conceptual issue related to the complexity of the decomposition of cognitive processes is the central problem raised by critics of neuroimaging studies (e.g., Uttal, 2001).

Overall, if neuroimaging is being used properly, it seems to be an important neuroscientific method, but not the only

one, for the study of cognitive functions and the underlying brain connectivities. Using some experimental designs and statistical methods, neuroimaging can be employed to study the connectivity in the brain, the time course of cognitive processes, and the modulatory and top-down effects that some areas exert on the others. In addition, behavioral data are needed for validating the neuroimaging results but sometimes they are not as explanatory as the brain activations. At least the brain activations can be used as dependent variables in combination with the behavioral data. Neuroimaging, especially fMRI by its noninvasive application for humans, can guide neurophysiological and other neuroscientific methods. Moreover, neuroimaging, computational modeling, and cognitive experimentation and theories are complementary and, in the best way, illustrate the interdisciplinary nature of cognitive science. The new terminology and visualization that neuroimaging method has brought to cognitive science has made it an excellent tool for cognitive studies. However, we have to keep in mind the correlational but not the causal nature of the activations in the brain areas. Finally, knowing that neuroimaging is a tool not a goal (c.f., Huettel et al., 2004), the researchers have to use it in the service of developing the cognitive theories and avoid the substitution of the underlying cognitive processes with a simple description of the imaging results.

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