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Just Because You're Imaging the Brain Doesn't Mean You Can Stop Using Your Head: A Primer and Set of First Principles

John T. Cacioppo
University of Chicago

Gary G. Berntson
Ohio State University

Tyler S. Lorig
Washington and Lee University

Catherine J. Norris, Edith Rickett, and Howard Nusbaum
University of Chicago

Developments within the neurosciences, cognitive sciences, and social sciences have contributed to the emergence of social neuroscience. Among the most obvious contemporary developments are brain-imaging procedures such as functional magnetic resonance imaging. The authors outline a set of first principles designed to help make sense of brain-imaging research within the fields of cognitive and social neuroscience. They begin with a principle few would debate—that social cognition, emotion, and behavior involve the brain—but whose implications might not be entirely obvious to those new to the field. The authors conclude that (a) complex aspects of the mind and behavior will benefit from yet a broader collaboration of neuroscientists, cognitive scientists, and social scientists, and (b) social psychologists bring important theoretical, methodological, and statistical expertise to this interdisciplinary enterprise.

Few would dispute the proposition that the operations underlying social cognition, emotion, and behavior (Ψ) emanate from the brain (Φ). Indeed, a fundamental premise of scientific psychology, dating back to its origins (e.g., James, 1890/1950, p. vi; Spencer, 1895), is that $\Psi = f(\Phi)$. Gordon Allport (1935), in his chapter in the inaugural edition of the *Handbook of Social Psychology*, for instance, defined an attitude as "a mental and *neural* state of readiness, organized through experience, exerting a directive or dynamic influence upon the individual's response to all objects and situations with which it is related" (p. 810).

Allport (1935) further contended, however, "that [attitudes] involve skeletal, cortical, and subcortical activity probably no psychologist would deny, but what these correlates are none can tell" (p. 806). In his presidential address on September 4, 1946 before the first annual meeting of the Division of Personality and Social Psychology, Allport argued that it may be a thousand years before the biological bases of social processes were understood and that analyses of and interventions for social problems could not wait. Allport (1947) was equally dubious of the value of animal and developmental research in social psychology. Although Allport (1947) recognized that verbal reports by individuals were imperfect, he held that overt expressions and behaviors could provide insight into social behavior and means of dealing with social problems.

Allport (1935) also forecasted that "reflex and automatic response have little place in social psychology" (p. 806). Just as Allport's concerns about the concept of automaticity no longer hold sway in social psychology, his concerns about biological levels of analysis have also been addressed in a fraction of the time he anticipated it would take (Berntson & Cacioppo, 2000; Cacioppo, Petty, & Tassinary, 1989). About a decade ago, a transdisciplinary perspective called *social neuroscience* was proposed that emphasized study of the relationship between neural and social processes—including the intervening information-processing components and operations at both the neural and the computational levels of analysis—and evidence for the principles of multiple determinism, nonadditive determinism, and reciprocal determinism (and the corollary of proximity) was reviewed to demonstrate how such a multilevel perspective could contribute to the development of comprehensive theories of both complex social behavior and brain–behavior relationships (Cacioppo & Berntson, 1992; see also Berntson & Cacioppo, 2003; Cacioppo & Berntson, 2002).

Although functional brain imaging has accounted for less than 5% of the studies reported at recent Society for Neuroscience

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John T. Cacioppo, Catherine J. Norris, Edith Rickett, and Howard Nusbaum, Department of Psychology, University of Chicago; Gary G. Berntson, Department of Psychology, Ohio State University; Tyler S. Lorig, Department of Psychology, Washington and Lee University.

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Correspondence concerning this article should be addressed to John T. Cacioppo, Department of Psychology, University of Chicago, 5848 South University Avenue, Chicago, Illinois 60637. E-mail: cacioppo@uchicago.edu

meetings[1] (Lorig, 2000), it was clear early on that developments in brain imaging held tremendous promise for expanding understanding of social processes, representations, and constructs:

> In decades past, studies of the neurophysiological structures and functions associated with psychological events were limited primarily to animal models, postmortem examinations, and observations of the occasional unfortunate individual who suffered trauma to or disorders of the brain. Developments in electrophysiological recording, brain imaging, and neurochemical techniques within the neurosciences have increasingly made it possible to investigate the role of neural structures and processes in normal and disordered thought in humans. The importance of these technical developments was underscored by Congress's declaration of the 1990s as the decade of the brain. (Cacioppo & Berntson, 1992, p. 1020)

This special section of the *Journal of Personality and Social Psychology* is a testament to the appeal to neuroscientists as well as social psychologists of capitalizing on knowledge and methods in the neurosciences and in cognitive neuroscience. Yet additional evidence for the growth of interest in this perspective within the social sciences and neurosciences comes from the recent special issue on this topic in *Neuropsychologia*, the forthcoming special issue on the topic in *Political Psychology*, the introduction of a new section on social neuroscience in the *Journal of Cognitive Neuroscience*, and a new book series by MIT Press on social neuroscience.

For many unfamiliar with its history, research in the area is surprisingly bountiful. For instance, Brothers (1990), referring primarily to neurophysiological recordings in nonhuman primates, proposed that the superior temporal sulcus is involved in integrative processing of conspecifics' behavior, and the amygdala and orbitofrontal cortex are subsequently involved in specifying the socioemotional relevance of social information; Kanwisher (e.g., Kanwisher, 2000; Kanwisher, McDermott, & Chun, 1997), using functional magnetic resonance imaging (fMRI) data, emphasized the role of the fusiform gyrus in face processing; and Damasio and colleagues (e.g., Adolphs, 1999; Damasio, 1994), focusing primarily on data from humans with brain lesions, have emphasized the role of the frontal (ventromedial prefrontal, orbitofrontal) cortex, amygdala, and somatosensory cortex (insula, SI, SII) in social perception, cognition, and decision making. Reviews of the functions associated with specific brain regions and of the neural substrates of social information processing are available in Adolphs (1999, 2001, 2003); Allison, Puce, and McCarthy (2000); Cacioppo et al. (2002); Frith and Frith (2001); Klein and Kihlstrom (1998); Ochsner and Lieberman (2001); Rizzolatti, Fogassi, and Gallese (2001); Schall (2001); and Scholl and Tremoulet (2000) as well as in other articles in this special section. These reviews represent the emergence of new theoretical arenas, often housing conflicting views, on the precise anatomical definition of a brain region (Brierley, Shaw, & David, 2002; Merboldt, Fransson, Bruhn, & Frahm, 2001) or the precise nature of the information-processing operations being performed by a brain structure or system (e.g., fusiform area and face processing; cf. Kanwisher, 2000 vs. Tarr & Gautheier, 2000).

Readers should be cautious about taking any of the functional ascriptions to brain regions in these reviews as gospel, because relevant new data are appearing nearly daily (see, e.g., http://www.biopsychology.com). New developments may call for refinements or reconceptualizations, and advances in this area are necessarily incremental. Our purpose here is to review a few essential principles we hope will help make sense of the torrent of research in this area. Given space limitations, we have limited our list to some of the most basic first principles. We begin with a brief consideration of fMRI.

fMRI

When one first reads an article in which fMRI measurements are reported, one is likely to be impressed by the apparent ability of this new technology to image the inner workings of the normal human brain. fMRI is a procedure for measuring changes in hemodynamic events in the brain. The current model of the hemodynamic response, as reviewed by Heeger and Ress (2002) and Jezzard, Matthews, and Smith (2001), posits that a transient increase in neuronal activity within a region of the brain begins consuming additional oxygen in the blood proximal to these cells but also causes local vasodilation. As a result, blood near a region of local neuronal activity soon has a higher concentration of oxygenated hemoglobin than blood in locally inactive areas. The blood oxygen level dependent (BOLD) fMRI provides a measure of these hemodynamic adjustments and—by inference—the transient changes in neuronal activity in the proximal brain tissue (cf. Buckner, 1998; Heeger & Ress, 2002; Liao et al., 2002; Raichle, 2000).[2]

If this is difficult to visualize, think of a time when you have picked up something heavy, such as dumbbells, a particularly heavy stack of books, or the Sunday edition of the *New York Times*. This neuromuscular action is accompanied by an increased rate of oxygen utilization in the muscles in your arms. The initial muscular exertion results in reduction in oxygen in your arm muscles, followed quickly by an increase in oxygen delivery to the working muscles and an increase in the relative proportion of oxygenated hemoglobin. Accompanying the increase in blood flow to the working muscles of your arms is a slight increase in blood volume in these regions. This is why, after putting down whatever heavy object you lifted, you might have noticed that your arms felt bigger and the veins in your arms were more visible. The enhanced local blood flow and oxygenation serve as the basis for brain imaging using fMRI.

A common fMRI technique for studying the time course of signal intensity changes in the brain is echo planar imaging (EPI), which can generate a complete two-dimensional image of a brain slice in as little as 40 ms following a single excitation of the spin system (Jezzard & Song, 1996). It is, however, sensitive to a number of artifacts (e.g., movement). Artifacts reduce the ability to

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[1] Given space constraints, we have limited our focus here to brain-imaging research. Theory and research in the field of social neuroscience, however, builds on work in the neurosciences, cognitive sciences, and social sciences (Cacioppo & Berntson, 1992; see also Brothers, 1990; Klein & Kihlstrom, 1998; Ochsner & Lieberman, 2001), and like cognitive neuroscience and behavioral neurology, social neuroscience depends fundamentally on the rigorous foundation of cellular, molecular, and animal research (Berntson & Cacioppo, 2003; Cacioppo, 2002). Interested readers may wish to see Cacioppo et al. (2002).

[2] For a readable description of the physics of these measurements, see Bandettini, Birn, and Donahue (2000) or Jezzard et al. (2001).

detect the signal corresponding to the BOLD response that indicates metabolic activity associated with information processing activity. Movement, cavities, and tissue impedance differences near boundary regions reduce the signal-to-noise ratio, making it difficult to detect psychologically meaningful responses. The block design allows the hemodynamic response to accrue over time, thereby increasing the signal-to-noise ratio.

The need to use block experimental designs to achieve a reasonable signal-to-noise ratio places an artificial limit on the temporal resolution of the fMRI. The need to use block designs has been lessened by the demonstrated feasibility of selective averaging techniques (Buckner et al., 1996). Ultimately, the temporal resolution of the fMRI is limited by the time it takes to completely excite protons in slices, which depends in part on field strength, and the time course of the hemodynamic response. The blood flow response typically lags behind the actual electrical signal by 1–2 s and does not track activity on a millisecond-by-millisecond basis. That is, the blood flow response is influenced by activity levels over some time interval (a few hundred milliseconds or more) and thus is less temporally specific than the neuronal activity with which it is associated. For many investigations, this temporal imprecision is of little or no importance. In studies in which higher temporal resolution is required, fMRI studies can be complemented by event-related brain potential (ERP) studies.

A series of functional scans are usually collected during a baseline and during the performance of one or more tasks. Typically, the functional images for each subject are realigned to correct for subject movement and then coregistered with a structural (T1 weighted) image. If required, the images are spatially normalized to align brains across subjects, and statistical analyses are performed to identify areas that have been activated by the experimental manipulation. The results are then displayed on individual or average structural images. Averaging images across brains can also produce apparent patterns of data that are spatially misleading, with group activity appearing in regions not found in any individual or eliminating aggregate patterns because of structural differences across individuals. As a result, the presentation of images from individual brains, at least in supplementary materials, is often advisable (see Brett, Johnsrude, & Owen, 2002). How one should perform statistical tests on such a large multivariate data set, characterized by correlated dependent variables and violations of sphericity assumptions, is important but beyond the scope of this article (Friston et al., 1995; Jezzard et al., 2001; Worsley et al., 2002).

With this background, four simple principles should be kept in mind when thinking about research in this area.

Principle 1: (We Know Already That) Social Cognition, Emotion, and Behavior Involve the Brain

There is an intuitive appeal to viewing a social psychological construct or research enterprise as more legitimate, respectable, or "scientific" if the social psychological measure, process, or representation is shown to covary with some event in the brain. Nevertheless, investigations that simply show there are changes in brain activation that correspond to some aspect of social cognition, emotion, or behavior contribute little—after all, what scientific theory would predict otherwise! There is ample evidence that in humans, the self and social behavior are maintained despite the loss of various appendages, visceral organs, and personal relationships but that they are terminated by the cessation of activity in the brain and that this is so even when the heart continues to beat.[3] A few well-publicized clinical cases in the 19th century called attention to the role of the brain, particularly the frontal regions, in social cognition, affect, and behavior.

Phineas Gage was a young American railroad construction supervisor, who in 1848 accidentally detonated a dynamite blast, rocketing his tamping rod through his eye and skull and decimating the orbitofrontal and sections of the ventromedial cortex of his brain. Gage initially lost consciousness and began convulsing, hardly a surprise to those who witnessed the grisly accident. Gage, however, quickly regained consciousness and could speak and walk. He was taken to a local physician, John Harlow. Harlow treated his wound, blood loss, and subsequent infection, and Gage soon recovered from the life-threatening nature of his accident. Harlow was unable, however, to help Gage recover his former self. Prior to the accident, Gage was characterized as energetic, friendly, and reliable. Within a few months after the accident, Gage began acting in an arrogant, irresponsible, antisocial, quick-tempered, indecisive, and socially inappropriate fashion. He became incapable of holding a job or planning his future, and his friends complained that Gage was no longer the person they had known (Harlow, 1868; see also Damasio, 1994). He died penniless in 1861, 13 years after the accident, more an abomination than a twisted shadow of his former self.

In a second celebrated case, also around 1860, a patient who had suffered a neurosyphilitic lesion in the frontal part of his brain was institutionalized in Paris, France, and was attended by the physician Paul Pierre Broca. The patient, Leborgne, was known as "Tan" because this was the only word he was left able to speak. In other respects, Leborgne was more normal. In a postmortem autopsy, Broca determined that Leborgne's lesion was in the third circumvolution of the frontal part of his left hemisphere (specifically, the posterior third of the inferior frontal gyrus). This area became known as *Broca's area* and was surmised to be the "speech center" of the brain.

Less heralded but no less important to the field of brain imaging was the case of an Italian peasant by the name of Bertino, who suffered a head injury that left him with part of his frontal lobes exposed (Raichle, 2000). Angelo Mosso (1881), an Italian physiologist, observed sudden increases in the magnitude of the pulsations over the frontal lobes with the ringing of the local church bells and the chiming of a clock that signaled the time for required prayer. Mosso suspected that these changes in blood flow reflected Bertino's thoughts about prayer. When Mosso asked Bertino if this were true, Mosso observed changes in blood pulsation as Bertino processed the question and answered yes. Mosso further noted that the changes in brain pulsation were unrelated to any change in heart rate or blood flow to Bertino's forearm. When Mosso subsequently asked Bertino to multiply 8 by 12, Mosso again observed an immediate increase in brain pulsation and another just before

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[3] This was not always evident. According to Uttal (1978), the earliest localizations of mental faculties and bodily processes were most likely based on blood, or essences supposedly carried in the blood, rather than brain. The loss of consciousness and life, after all, could clearly be demonstrated to follow dramatic losses of blood.

Bertino responded with an answer. These observations set the stage for contemporary functional brain mapping using hemodynamic measurements (Raichle, 2000).[4]

The cases of Phineas Gage, Leborgne, and Bertino contributed to the view in the neurosciences that (a) the lesion of circumscribed areas of the brain could cause the loss of very specific mental or nervous functions in humans and to the complementary view that (b) activity in circumscribed areas of the brain could reflect very specific mental or nervous functions in humans. We discuss each of these views in subsequent sections of this article. For the moment, it should be apparent that it is not whether but where and how activity in the brain covaries with a social process, construct, or representation that has the potential to inform theory in social psychology and in the brain sciences. Specifically, which brain structures or systems are involved, especially when used in combination with a sophisticated understanding of the roles or functions of these structures and systems, can both foster the construction of crucial tests among social psychological hypotheses and lead to new hypotheses about the structure and function of specific social processes, representations, and constructs (Adolphs, 2001; Berntson, Boysen, & Cacioppo, 1993; Cacioppo, Tassinary, & Berntson, 2000).

Here too, however, the interpretations are not always straightforward. One cannot assume that changes in brain activity are a direct, invariant measure of the neural instantiation of the investigator's favorite construct or that the contemporary neurobiological theory regarding the function of a specific brain structure or system is everlasting (e.g., Sarter, Berntson, & Cacioppo, 1996; Uttal, 2001). For instance, despite oversimplifications that have appeared in the social sciences, the amygdala was never simply regarded as "the emotional brain" in the neurosciences, and understanding of both the amygdala and the limbic region (of which the amygdala is a part) continues to undergo revisions and refinements (e.g., Aggleton, 1992, 2000; Amaral et al., 2003; Baxter & Murray, 2002; LeDoux, 2000). Social psychology's conceptual richness, focus on elementary operations and mediating mechanisms, intricate paradigms for isolating component processes, and psychometrically sound behavioral measurements can provide an interpretable ecological context for studies of brain function, which can contribute to theory and research in the neurosciences as well. However, the most powerful tool for achieving this is not a high field strength fMRI instrument but rather remains the expertise, intelligence, and creativity of the investigators.

Raichle (2000) suggested that a major goal of functional brain imaging is to identify brain regions and their temporal relationships with the performance of well-designed tasks—a goal to which social psychological methods and theory should have much to contribute. These associations are of interest, in part, because of the notion of localization of function. We turn to uses and abuses of this concept next.

Principle 2: The Functional Localization of Component Social Processes or Representations Is Not a Search for "Centers"

Ideas about the anatomical basis of functional localization in the cortex have been debated for hundreds of years, but research on primary sensory cortices (e.g., Munk, 1881; Tunturi, 1952) and on somatosensory regions (e.g., Schaltenbrand & Woolsey, 1964) contributed to the refutation of the hypothesis that the brain was a homogeneous tissue that depended on total mass to carry out functions (cf. Uttal, 2001). A fundamental assumption underlying many brain-imaging studies in the cognitive and social neurosciences is that there is also a localization of information-processing components that bear on social cognition and behavior.

The discovery of mirror neurons is a striking illustration of putative brain localization. Mirror neurons are a class of neurons in the ventral premotor cortex of monkeys in area F5 that become active when the monkey makes a particular action or when it observes another individual making a similar action (Rizzolatti et al., 2001). The same neurons also respond on perceiving an object that affords specific kinds of motor behaviors (Grezes & Decety, 2001; Rizzolatti & Fadiga, 1998), but they do not otherwise tend to respond to the presentation of an object of an action or to the mimicking of an action in the absence of the object. Kohler et al. (2002) recorded from individual neurons in the F5 area of monkeys homologous to Broca's area in humans. They found that individual neurons responded when the monkey performed specific motor behaviors, when the monkey observed other individuals performing the same behavior, and when the monkey heard but could not see the same behavior being performed by another. These results indicate that visual and audiovisual mirror neurons code not the visual analysis of the action per se but the goal and meaning of the actions of both oneself and others as well as the perspective one takes on those actions (Ruby & Decety, 2001). A small set of cortical areas may be active in a wide range of psychological functions from action to perception to theory of mind, but across those functions the networks in which they participate may be quite different.

Well-defined localization of sensory and motor functions poses as a hypothesis but does not prove that more complex integrative processing by the brain is similarly compartmentalized. Unfortunately, the nuances and empirical support for the localization hypothesis are easy to oversimplify, especially by investigators who are not intimately familiar with a specific area of research (cf. Brett et al., 2002; Farah, 1994; Passingham, Stephan, & Kötter, 2002; Uttal, 2001). As Uttal (2001) pointedly noted,

> We need to distinguish between a nonhomogenous brain in which different regions can influence different mental or behavioral processes, on the one hand, and the hypothesized role of these regions as unique locations of the mechanisms underlying these processes, on the other. It is the failure to make this distinction that fuels many of the more imaginative theories of cognitive localization in the brain. (p. 11)

Aphasia—the selective loss of language from a cerebral lesion—is a case in point. According to Bogen and Bogen (1976), a cortical lesion producing aphasia (an *aphasiogenic lesion*) in right-handed persons occurs in the right hemisphere less than 2% of the time; said differently, an aphasic person has 50:1 odds of a lesion in the left hemisphere. Within the left hemisphere, Bogen and Bogen noted, it is unlikely the lesion would be in the occipital pole, temporal pole, or frontal pole, but further specification be-

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[4] Mosso (1881) also went on to document that fear influenced breathing patterns and cardiovascular activity, including brain pulsations, and in collaboration with Cezarre Lombroso (1895) produced the first scientific evidence for the physiological detection of human deception (Committee to Review the Scientific Evidence on the Polygraph, 2003).

comes difficult. Not all aphasias are alike, of course, and the absence of clear, psychometrically sound definitions of specific components of categories of aphasias (or higher integrative processes generally) contributes to the problem of functional localization (Bogen & Bogen, 1976; Uttal, 2001).

Wernicke (1874) emphasized a specific kind of aphasia—the loss of verbal comprehension, in contrast, for instance, to the loss of verbal production following a cortical lesion such as Broca studied in the case of Leborgne. Whereas Broca's area was defined anatomically, Wernicke's region was defined functionally in terms of the brain region that when lesioned causes a deficit in language comprehension. "The question with Wernicke's region is 'where is it?'" (Bogen & Bogen, 1976, p. 835). Wernicke himself gave several different answers to this question. Bogen and Bogen (1976) provided a nearly humorous review of the elusive cortical locus of Wernicke's region. Their conclusion that there is no single anatomical brain region that has been identified as the invariant substrate for speech comprehension has implications for how one might think about localization:

> Is there *any* way to draw a satisfactory picture of Wernicke's region? One answer would be that we need a picture, resembling a topographic map, that shows a probability distribution: that is, a map, which shows the likelihood at any particular locus of a comprehension deficit from a lesion at that locus. (Bogen & Bogen, 1976, p. 842)

Not only is there no single invariant brain region that is responsible for speech comprehension, Bogen and Bogen (1976) argued, but there is no associative cortical region that serves only one function: "So some people have tended to use the term 'language area' to mean 'language and only language.' This is a serious misconception, because it happens that almost all cerebrocortical tissue serves more than one function" (Bogen & Bogen, 1976, p. 838).

Indeed, the category error in cognitive neuroscience refers to the intuitively appealing notion that the organization of cognitive phenomena maps in a 1:1 fashion into the organization of the underlying neural substrates. Memories, emotions, and beliefs, for instance, were each once thought to be localized in a single site in the brain. Current evidence, however, now suggests that most complex psychological or behavioral concepts do not map into a single center in the brain. What appears at one point in time to be a singular construct (e.g., memory), when examined in conjunction with evidence from the brain (e.g., lesions) reveals a more complex and interesting organization at both levels (e.g., declarative vs. procedural memory processes). Even if there is localization, it will likely be elusive until there are coherent links between psychological–behavioral constructs and neural operations (see also Adolphs, 2003). Multilevel integrative analyses are needed to foster appropriate revisions to understanding of the targets of study at each level of analysis.

Passingham et al. (2002) have further argued that each cortical region has unique patterns of cortico–cortical connections, and it is these more distributed subsystems of brain regions that produce the observed (more localized) differences in neural activity during different tasks. The central nervous system also builds in redundant systems for achieving a variety of intraorganismic (e.g., regulatory) and behavioral functions (e.g., Berntson & Cacioppo, 2003; Berntson et al., 1993).

Functional brain imaging can now be performed noninvasively in normal humans to identify the activation of localized brain regions associated with task components—at least as viewed through local hemodynamics (cf. Heeger & Ress, 2002; Raichle, 2000). The cortical regions of activation in imaging studies are often described in terms of Korbinian Brodmann's (1909) cytoarchitectonic map—a numerical designation for areas of the cerebral cortex based on the ways their cells are arranged in layers and on their proximity to related cortical tissue (i.e., *cell architecture*). Cell architecture, as a general rule, reflects cell function, so the mapping of a task-processing component to a particular Brodmann's area may be interpreted as implying that the area is associated with a particular information-processing function. Brodmann's (1909) admonition, shared by Raichle (2000), is therefore worth repeating here:

> Indeed, recently theories have abounded which, like phrenology, attempt to localize complex mental activity such as memory, will, fantasy, intelligence or spatial qualities such as appreciation of shape and position to circumscribed cortical zones. These mental faculties are notions used to designate extraordinarily involved complexes of mental functions . . . . One cannot think of their taking place in any other way than through an infinitely complex and involved interaction and cooperation of numerous elementary activities . . . . In each particular case [these] supposed elementary functional loci are active in differing numbers, in differing degrees and in differing combinations . . . . Such activities are . . . always the result . . . of the function of a large number of suborgans distributed more or less widely over the cortical surface. (Brodmann, 1909; quoted in Raichle, 2000, p. 35)

The common use of Brodmann's areas to specify cortical brain regions in fMRI studies should be viewed with two other caveats in mind: (a) Brodmann mapped only *gyri* (convoluted ridges between grooves, or *sulci*), not sulci, where most of the cortical mantle is located, and (b) Brodmann's maps were based on dissection and staining of only a few brains—itself a major achievement in the early 1900s but hardly enough to allow depiction of individual variability. Individual differences in the anatomy of the human brain are now widely recognized (Brett et al., 2002) and have fueled ongoing efforts to develop more sophisticated cytoarchitectonic techniques on the basis of larger samples, with the goal of providing probabilistic brain maps (e.g., maps that would provide a probability that a specific region in an MRI fell within a given brain area).

The theoretical implication of Raichle's (2000), Brodmann's (1909), and Passingham et al.'s (2002) arguments is that a search for centers or "spots" in the brain to which personality or social psychological constructs can be assigned will produce a morass if the overarching framework is a phrenology of social cognition. A localized brain region activated during a particular task (or the correlation between task performance and activation of the brain region) can be described as a specific processing component being related to the activation of the specific cortical region. However, this activation may not reflect the locus in which a particular integrative information processing component originates but rather may reflect a region that is part of a more distributed network of processing mechanisms that work together to perform the task (e.g., Passingham et al., 2002) or a region that is an earlier (or later) stage in an information-processing sequence.

Furthermore, such a result would not mean that this cortical region necessarily operates solely to perform this function or that in a different context or when using a different comparison task what appears to be the same information-processing operation could not be related to activation in a different region of the cortex. To take a simple example, an overt smile could reflect the activation of the pyramidal or extrapyramidal tracts, because deliberately constructed overt smiles depend on the pyramidal (cortical) motor tracts to the facial nerve nuclei being intact, whereas spontaneous smiles depend on the extrapyramidal upper motor neurons traveling to the facial nerve nuclei being intact (Rinn, 1984). An apparent correlation between smiling and the activation of a region in the motor cortex (pyramidal tract) in one investigation and, for instance, the basal ganglia (a part of the extrapyramidal tract) in another investigation might appear to be inconsistent findings in the literature. Given that the motor system of the central nervous system has been carefully detailed in the past century and a half of research, one would know this was not likely the case and instead that the separate investigations failed to design the task in such a way as to differentiate behaviorally between spontaneous and deliberate smiles. When the appropriate parsing of processing components for understanding brain function are not already well specified, as for instance when examining the neural basis of romantic love (Bartels & Zeki, 2000), the brain region that marks lying (Langleben et al., 2001; Lee et al., 2002), or the brain region for speech comprehension (Bogen & Bogen, 1976), one should not be surprised when studies appear to yield “inconsistent” observations. The apparent inconsistency in findings may not derive from methodological differences between studies but from the activation of different components or circuits of a distributed system (Cacioppo, in press).

In sum, the localization hypothesis has considerable intuitive appeal and undeniable empirical support. There is evidence for a “localization” of functions, although these functions are distributed broadly and are rerepresented across all levels of the neuraxis. Sensorimotor systems, for instance, are arranged such that neural circuits respond to increasingly abstract aspects of complex stimuli as the distance—measured in the number of synapses from the external world—grows (Fischbach, 1992). As with many scientific hypotheses, however, localization is a nuanced hypothesis that in practice demands of investigators a continued vigilance for conflicting results or evidence of more complexly orchestrated functional processing operations, underlying neural mechanisms, and overarching neural circuits and systems. This vigilance is especially important when one is examining integrative mechanisms responsible for orchestrating complex social behaviors—that is, the kind of information processes in which social psychologists tend to be interested (cf. Berntson & Cacioppo, 2003; Berntson et al., 1993). Localization is more apparent at the lowest levels of organization (i.e., lower sensory and motor processes). As processes become more complex, localization necessarily becomes more distributed, if for no other reason than more processes are involved. Moreover, because of levels of organization in the central nervous system, even simple processes such as motor acts have wide representation (cortical, extrapyramidal, lower motor neurons, somatosensory feedback regulation, etc.). In the next section, we examine two additional assumptions underlying the search for localized neural substrates using brain imaging.

Principle 3: Localized Changes in Brain Activation That Differ as a Function of a Task Do Not, in Themselves, Signal a Neural Substrate

Scientists must make various assumptions in any complex field of work, but the unquestioning acceptance of these assumptions can lead to what appears to be a field strewn with conflicting findings and inconclusive results. Delineating the assumptions; recognizing their potential biasing effects on experimental design, measurements, and interpretation; and identifying convergent methods are therefore important to the development of a reliable, cumulative field of scientific inquiry. In this section, we briefly discuss two assumptions that have commonly been made in brain-imaging studies of social process. Readers may recognize, on the basis of the preceding discussion of localization, that these assumptions should not be accepted unquestioningly.

1. When a region of differential brain activation is active during a specific information-processing operation, this brain region is the neural substrate for the information-processing operation.

2. When a region of the brain is not active during a specific information-processing operation in a study, this brain region is not a neural substrate for the information-processing operation.

On initial reading, these two statements may appear axiomatic—the very foundation on which the enterprise of brain imaging rests. It is simple to show that these statements are not necessarily true and that brain-imaging data can nevertheless be invaluable when testing a hypothesis. It is equally simple to show that the unquestioning assumption that the statements are true can produce erroneous interpretations of brain-imaging data even when appropriate statistical power for confirming a null effect exists (cf. Sarter et al., 1996).

To illustrate, consider a simple physical metaphor in which Φ represents a heater (analogous to a neural mechanism in the brain) and Ψ the temperature inside a house (analogous to an information-processing manifestation of this neural mechanism). Although the heater and the temperature are conceptually distinct, the operation of the heater represents a physical basis for the temperature in the house. Thus, $\Psi = f(\Phi)$. A bottom-up approach—that is, $P(\Psi/\Phi)$—makes clear certain details about the relationship between Ψ and Φ, whereas a top-down approach—that is, $P(\Phi/\Psi)$—clarifies others (Cacioppo & Tassinary, 1990). For instance, when the activity of the heater is manipulated (i.e., Φ is stimulated or lesioned), a change in the temperature in the house (Ψ) is observed to result. This represents a bottom-up approach to investigating the physical substrates of cognitive or social phenomena. The fact that manipulating the activity of the heater produces a change in the temperature in the house can be expressed as $P(\Psi/\Phi) > 0$. Note that the $P(\Psi/\Phi)$ need not equal 1 for Φ to be a physical substrate of Ψ. This is because in our illustration there are other physical mechanisms that can affect the temperature in the house (Ψ), such as the outside temperature (Φ') and the amount of direct sunlight inside the house (Φ''). That is, there is a lack of complete isomorphism specifiable, at least initially, between the functional dimension (Ψ) and a physical basis (Φ).

Now we can examine the first of the axiomatic assertions about what some hold to be the logic of brain imaging. Consider the indicator light on a thermostat that illuminates when the heater is operating. In this case, the indicator light represents a physical element that would show the same covariation with the temperature in the house as the operation of the heater as long as a top-down (e.g., functional brain imaging) approach was used. If the complementary bottom-up approach were used, it would become obvious that disconnecting (lesioning) the heater can have effects on the temperature in the house whereas disconnecting (or directly activating) the indicator light has none. This simple example makes it clear that a region of differential brain activation that corresponds to a specific information-processing operation does not necessarily mean that this brain region is the neural substrate for the information-processing operation.[5]

Has anything like this been observed in the kind of brain-imaging research in which social psychologists are likely to be interested? Consider the recent study on the implicit association test (IAT) in which Phelps et al. (2000), using fMRI, found that the activation of the amygdala to Black versus White faces was correlated with the participants' racial evaluation as measured by the IAT. This result was interpreted as indicating that the amygdala was involved in indirect or nonconscious responses to racial groups and, hence, in the performance of the IAT (e.g., Phelps et al., 2000). Phelps, Cannistraci, and Cunningham (2003) conducted a follow-up to this study by comparing the responses to the IAT of two groups of participants: a patient group who had bilateral amygdala damage and a matched control group. Phelps et al. (2003) replicated prior research on the IAT (and related measures) in the control group. They further demonstrated, however, that the patient group did not differ from the control group on any of their measures. That is, they showed comparably negative evaluation toward Blacks on the IAT, suggesting that the amygdala is not critical for the indirect or nonconscious responses to racial groups. It will take additional research to determine whether the differences between studies are attributable to a statistical or methodological artifact (e.g., the original empirical result was a chance finding) or whether the differential activation of the amygdala in the original study was a spurious correlate of the neural operations underlying the differential performance on the IAT.

The second of the axiomatic assertions about what some consider to be the logic of brain-imaging research is equally fragile. The fact that the temperature in the house increases reliably when the heater is activated does not necessarily imply that changes in the temperature in the house will be associated with variations in the activity of the heater. In some contexts (e.g., winter months, homes in the far north), changes in the temperature in the house may be associated with corresponding changes in the activity of the heater. In such cases, the subtraction of a thermographic recording in the late morning (once the heater has warmed the home) minus one from the early morning (prior to the heater being activated to warm the house in advance of the residents rising) would show differences in home temperature and the thermal signature of the heater. In other contexts (e.g., summer months, homes in the far south), however, the thermographic recording might still differ between late and early morning measurements even though the heater remains uniformly inactive across this period. This is possible because house temperatures may rise during the morning because of the operation of other physical factors (e.g., outside temperature, exposure to direct sunlight). The subtractive procedure in this second context, rather than identifying the physical locus as the heater, is more likely to identify the physical locus as areas warmed by the sun (e.g., curtains). Such a difference in physical locus (heater vs. curtains) for a functional state (temperature) may be interpreted as a conflicting result, and the tendency in such instances is to search for subtle differences in the experimental protocols. In our simple example, however, we know that the environmental context is modulating which of the physical mechanisms (heater, sunlight) is determining room temperature. In brain-imaging studies, this means that when specific regions are found to be active as a function of a cognitive operation in some studies but not in others, there may be important contextual factors that are influencing which mechanism is operating to achieve the same function. Indeed, it is just this capacity of the brain to achieve the same functional outcomes through diverse neural mechanisms that neurologists rely on when treating individuals for a functional loss following a localized stroke or lesion.

It may be a bit disconcerting to think that neither is it the case that a region of differential brain activation that corresponds to a specific information-processing operation is necessarily a neural substrate for the information-processing operation nor is it the case that a region of brain activation that is unaffected by a specific information-processing operation in a study is necessarily ruled out as a neural substrate for the information-processing operation. In this sense, however, functional brain imaging is no different than self-report, behavioral, or reaction-time measurements. For some reason, it seems more surprising and somehow more disappointing that the clarity of theoretical hypothesis, the cleverness of the experimental design, the validity and reliability of the experimental operationalizations, and the appropriateness of the statistical analyses remain critical to the interpretation of social psychological data when these data represent images of the brain. The take-home point is not to be disappointed by the limitations inherent in brain-imaging research but simply to realize that just because you're imaging the brain doesn't mean you can stop using your head.

In sum, a region of differential brain activation that corresponds to a specific information-processing operation is consistent with the hypothesis that this brain region is involved in this information-processing operation, but it does not address the alternative interpretation that the brain region is simply a marker or

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[5] As noted above, a category error refers to the intuitively appealing notion that the organization of cognitive or social phenomena maps in a 1:1 fashion into the organization of the underlying neural substrates. The notion that an engram of a memory or an attitude exists in a localized spot in the brain is an example of what is likely a category error. The temperature of the house, for instance, does not map into a single "temperature center" in the house, but rather it is determined by several different physical mechanisms. We anticipate that 1:1 mappings between Φ and Ψ will ultimately be achieved. Reaching this ultimate aim is fostered by a recognition of the preliminary state of our knowledge and the attendant implications for strong inference (Cacioppo, Tassinary, & Berntson, 2000). Given the complementary nature of the data from brain imaging, direct stimulation and lesion studies, and simulation and computational modeling approaches, progress in social neuroscience should be fostered by the integration rather than a progressive segregation of these approaches and literatures.

concomitant (Cacioppo & Tassinary, 1990). Moreover, a region of brain activation that does not correspond to the specific information-processing operation is consistent with the hypothesis that this brain region is not a neural substrate for the information-processing operation, but even with technical issues about localization, signal-to-noise ratios, and statistical power aside, such a result would not rule out the hypothesis that the region is part of a sufficient but not a necessary neural mechanism for the information-processing operation. If one thinks about brain-imaging data as sharing much in common with chronometric data in studies of social processes (Cacioppo & Petty, 1986; Sarter et al., 1996), then this conclusion is neither surprising nor disappointing.

In the next section, we describe briefly the importance of comparison conditions for making sense of brain-imaging data. The bottom line is that fMRI data (and related measurements) can be rendered as dramatic images of the brain, but unless the comparisons are intelligently conceived the data will remain mute regarding their possible functional significance.

Principle 4: The Beauty of a Brain Image Does Not Speak to the Psychological Significance of the Image

Scientific developments in the neurosciences have produced molecular biological and brain-imaging techniques that were science fiction but a score of years ago. It is therefore understandable, even if not entirely rational, how stunning brain images and arguable assertions about their psychological significance have appeared in some of the most prestigious scientific journals in recent years. Science is nothing if not self-correcting, so it may be useful to ask how one might fruitfully think about the psychological significance of brain-imaging data.

Before the development of hypothetic–deductive logic by Sir Francis Bacon in 1620, scientists were content with performing an experiment and recording their observations. As in some contemporary brain-imaging research, these observations would represent a starting point for a series of internally consistent propositions, culminating in a general conclusion supported by observations guided by a confirmatory bias. Bacon's important contribution was the rigorous application of a special kind of inductive reasoning proceeding from the accumulation of empirical observations to the general conclusion (see Brazier, 1959; Cacioppo & Tassinary, 1990).

Although fMRI studies could be designed to conform to hypothetic–deductive logic, this is not common practice to date. Consider a recent study on an undeniably important topic in social psychology, romantic love. Romantic love and attachment in adults contributes to reproductive success by fostering both sexual activity and nurturance of offspring during their years of maturation and dependency. The neural mechanisms underlying an aspect of social cognition that is as evolutionarily important as romantic love, one might reason, should produce clear and theoretically compelling results if one simply looks.

Bartels and Zeki (2000) undertook such a study using fMRI to investigate "the neural basis of romantic love"(p. 3829). From the approximately 70 volunteers who professed romantic love for their partner, 17 participants were selected for further study on the basis of an interview and a short written statement describing how much they were in love. During the scan, participants viewed color pictures of the faces of four people on a neutral background: their loved partner and three friends of the same sex and age as their partner. Participants were instructed to view the pictures, to think of the viewed person, and to relax.

The general analytic framework guiding the design and interpretation of this study, which is typical in this area, was the subtractive method that has been adapted from studies of mental chronometry. Donders (1868/1969), a Dutch physiologist, proposed that the duration of different stages of mental processing could be determined by subtracting means of simpler tasks that were matched structurally to subsequences of more complex tasks. At the simplest level, experimental design begins with an experimental and a control condition. The experimental condition represents the presence of some factor, and the control condition represents the absence of this factor. The experimental factor might be selected because it is theoretically believed to depend on n information-processing stages, and the construction of the control condition is guided to incorporate $n - 1$ information-processing stages.

The principle underlying the extension of the subtractive method to fMRI studies is twofold: (a) Physiological differences between experimental conditions thought to represent n and $n - 1$ processing stages support the theoretical differentiation of these stages, and (b) the nature of the physiological differentiation of experimental conditions (e.g., the physiological signature of a processing stage) may further support a particular psychological characterization of that information-processing stage. This leads to a linear combination that would seem to be easily decomposed using a subtractive approach. According to the subtractive method, the systematic application of the procedure of stage deletion (across conditions of an experimental design) makes it possible to deduce the physiological signature of each of the constituent stages underlying some psychological or behavioral response. For instance, if the experimental task (n stages) is characterized by greater activation of Broca's area than the control task ($n - 1$ stages), this is consistent with both the theoretical conception of the experimental and control tasks differing in one (or more) processing stage(s) and the differential processing stage(s) relating to language production.

In Bartels and Zeki's (2000) study, images from all four viewed people were modeled using a multiple regression analysis, and contrast images for comparisons for lover versus friends and friends versus lover were calculated. This yielded 17 sets of images—one set for each of the 17 participants—each of which consisted of images designating the regions (voxels) in which the BOLD signal revealed greater activity when participants viewed lovers than friends, and a corresponding set of images designating the regions in which the BOLD signal revealed greater activity when participants viewed friends than lovers. A second-level analysis was performed on the 17 sets of contrast (i.e., subtracted) images to identify the areas that were activated at the nomothetic level of analysis.

Of course, the interpretation of the psychological significance of the fMRI data in these subtracted images depends in large part on the nature of the psychological differences between the comparison conditions. Bartels and Zeki (2000) constructed the contrasts with the notion that the psychological difference between the conditions is romantic love. Is romantic love a single process or unified construct? Might there be other differences between these conditions? Although the authors controlled for length of relationship, might the participants have had more knowledge about, interest in, sexual attraction to, perceived similarity to, personal investments in, commitment to, and conflicted feelings or anxieties about a romantic partner than a friend? Are these necessary components of romantic love and if so, which components are responsible for which variations in brain activation? Are friends all alike such that averaging across the scans while viewing the three friends yields a meaningful comparison image that can then be subtracted from the image derived from the scans obtained when participants thought of their beloved?

The subtractive method also assumes and depends mathematically on the assumption that the information-processing stages are arranged strictly linear and additive. That is, the strength of a signal at a given point of time is assumed to be the linear sum of the influences of each of the information-processing stages in the tasks. As in the analysis of response-time data, investigators need to be cognizant of the possibility that slightly different tasks can elicit very different component processes, and even when component processes differ by only one stage the effects of these stages may not be linearly additive (McClelland, 1979; Townsend & Ashby, 1983).

Among Bartels and Zeki's (2000) findings were that viewing a loved partner, relative to friends, activated two anterior cortical regions: the middle insula (primarily on the left) and the anterior cingulate cortex (bilaterally). Analyses also indicated activation in two subcortical regions of the cerebrum, the head of the caudate nucleus and the putamen (stronger on the left), and two sites in the cerebellar region. Neither the visual area in the occipital cortex nor the fusiform face area was significant, consistent with the assumption that comparable visual attention was paid to the faces of friends and lovers.

The reverse contrast showed sites that were more activated when viewing friends than loved partner and, as such, were interpreted as regions that were deactivated by romantic love. The cortical regions were clustered in the prefrontal, parietal, and middle temporal cortex; medial prefrontal cortex; and posterior cingulate gyrus. Deactivation was also found subcortically in the posterior amygdaloid region.[6] Bartels and Zeki (2000) noted that "what seems to be certain is that . . . the pattern of activation observed here was nevertheless unique, both in the identity and combination of sites involved" (p. 3832). The fact that romantic love is associated with discernible changes in brain activation is not theoretically informative to neuroscientists or social scientists, however.

Although the scans produced clear differences in the images, and the images were consistent with the notion that there was a common brain reaction to viewing a loved partner, the question of what specific process or state was elicited remained unanswered. Activation of the insula has been reported in other studies of emotion, such as those in which visceral afferentiation is involved, although the region of the insula that has typically been activated in these studies is anterior to the region found in Bartels and Zeki's (2000) study. The anterior cingulate is large and consists of several functionally distinct components. As Bartels and Zeki noted, prior research has found dorsal regions of the anterior cingulate (BA 32) to be associated with positive states and theory of mind tasks. The area within the anterior cingulate activated in Bartels and Zeki's study, however, did not coincide with the region activated in these prior studies but rather was limited to a ventral area of the anterior cingulate (BA 24). Unless the information-processing operations that differ between comparison tasks are clearly and narrowly specified, the fact that the data were collected using fMRI and can be rendered in dramatic fashion on anatomically precise MRIs may not help address the psychological or theoretical significance of the data.

Whenever a physiological response (or profile) found previously to vary as a function of a psychological processing stage or state is observed, the possibility is raised that the same processing stage or state has been detected. This was Bartels and Zeki's (2000) approach when they reviewed what functions had been associated with brain activation in regions similar to those observed in their study. However, one cannot logically conclude that a processing stage or state has definitely been detected simply because a regional brain activation found previously to vary as a function of a psychological processing stage or state has been observed. (The logical flaw in this form of inference is termed *affirmation of the consequent*.)[7]

It is also important to note a critical difference in the properties of the kinds of measures used for response-time experiments and for fMRI measurements. If we assume that a process takes a certain period of time because it is composed of a series of steps that each takes a measurable time and wherein each must be completed before the next is begun, the decomposition of the total time into the time for each step seems relatively transparent. However, the conditions under which this kind of analysis fails are precisely those that hold in many brain-imaging experiments. Each measurement (e.g., the hemodynamic response in a particular spatially located voxel in the brain) is a time-varying (dynamic) function of the conditions that came previously, plus other incidental processing that took place between conditions. This measurement may not be a single number composed of the simple (linear) sum of a set of components but may be a function of a number of parameters (e.g., interstimulus interval, stimulus amplitude, nature of the response, etc.), many of which have nothing to do with the experimental question, as well as nonlinearities in activation and deactivation. Whereas the total reaction time in an experiment might be changed by responding with foot, finger, or voice, the task components of interest would not generally be affected. In brain measurements, this is not as clearly the case: Voice responses may interact with cortical areas involved in working memory more so than foot responses. This means that both a subtractive analysis and an additive factors analysis should be used with attention to their interpretive limitations.

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[6] A follow-up analysis (independent component analysis) that examined the separability of the changes in these neural regions indicated that the activations of the insula and of the anterior cingulate cortex were independent from one another and from the changes observed in the remaining regions, suggesting they may serve distinct roles. No analyses were reported in which the scores on the passionate love scale were correlated with BOLD signals.

[7] Readers interested in a general framework for thinking about relationships between psychological concepts and physiological (including fMRI) signals might wish to consult a series of articles on this topic by Cacioppo and Tassinary (1990); Cacioppo, Tassinary, and Berntson (2000); and Sarter et al. (1996).

When a particular hypothesized stage of information processing is thought to be responsible for the differential impact of two different conditions on behavior, analyses of regional brain activation can be informative in one of two ways. If the patterns of regional brain activation resulting from the isolation of presumably identical stages are dissimilar (e.g., the subtracted image reveals substantial differences in regional brain activation), the similarity of the stages is challenged even though the behavioral outcomes of these two processes may look similar (e.g., responses predicted by self-perception vs. cognitive dissonance theory). If, on the other hand, similar patterns of regional brain activation result from the isolation of stages that are hypothesized to be identical, convergent evidence is obtained that the same fundamental stage is operative. As we noted above, these data do not provide strong evidence that the fundamental stage is in fact the same, but the more peculiar the physiological profile is to a given stage within a particular experimental context—that is, the greater the alternative interpretations that can be rejected to account for the data—the greater the value of the convergent evidence (Cacioppo & Tassinary, 1990; Platt, 1964).

In sum, fMRI has revealed task-specific increases in regional brain activation that are associated with various mental activities. The specification of brain–behavior relationships, however, cannot come from imaging studies alone but depends on multiple methods in which the brain region (structure or system) serves as both an independent–blocking variable and a dependent variable. Moreover, the interpretation of the subtracted images of fMRI depends fundamentally on the conditions that produced the images in the first place. To construct the set of comparison tasks using the subtractive method, one must already have a clearly articulated hypothesis about the sequence of events that transpires between stimulus and overt response. This assumption may render the subtractive method more useful in testing an existing theory about the stages constituting a psychological process and in determining whether a given stage is among the set constituting two separate processes than in formulating theory de novo. Confirmatory evidence can still be questioned by the assertion that the addition or deletion of a particular stage results in an essentially different set of stages or substages. For instance, baselines in fMRI studies, which may be used in contrasts to derive subtracted images, are often treated as if they are passive mental conditions. Interesting new work indicates that the resting brain during baselines is not a passive state but rather involves its own set of mental operations that must be understood to make sense of subtracted images involving baselines (e.g., Binder et al., 1999; Gusnard & Raichle, 2001; Raichle et al., 2001).

Conclusion

Collaborations between cognitive scientists and neuroscientists are helping to unravel puzzles of the mind, including aspects of perception, imagery, attention, and memory (Kosslyn & Andersen, 1992). Most aspects of the mind, however, require a more comprehensive approach to reveal the mystery of mind–brain connections. Winston, Strange, O'Doherty, and Dolan (2002) conjectured that "human survival has depended to a large extent on accurate social judgments and that, as an evolutionary consequence, modular cognitive processes are devoted to such functions" (p. 277). To simplify the study of the mind, many scientists initially ignored the social aspects of human behavior with the notion that social processes could be considered later if the need arose; would be more explicable once the basics of the brain and mind were determined; or had minimal implications for basic development, structure, or processes of the human brain or mind. Evidence that humans are fundamentally social animals who can exist only in a web of relationships (Cacioppo, Berntson, Sheridan, & McClintock, 2000) and that even basic information processes (e.g., learning) can be modulated by the presence of actions of conspecifics (Cacioppo, 2002; Cacioppo et al., 2002), belies these early notions.

Shallow research questions are designed to provide support for monism. These include what one can see with a new measure (e.g., fMRI); what one finds when looking at a variable not studied previously (e.g., face vs. object); and whether differences in thought, emotion, or action have a measurable effect on the brain. Interdisciplinary collaborations between neuroscientists and social scientists have the potential to seek answers to deeper research questions that have been of interest to social psychologists since the inception of the field—questions such as which of two competing processes best accounts for a social outcome, what are the nature and causal consequences of the processes or component processes for a social outcome, and under what conditions are particular component processes operating. Combining the emerging knowledge and new techniques from the neurosciences and cognitive sciences with expertise in social psychology and the most important tool in the scientist's armamentarium—the capacity for reasoning, analysis, and synthesis—the developments and advances in social neuroscience should produce a field of which even Gordon Allport would have been proud.

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