Hypothetical High-Level Cognitive Functions Cannot Be Localized in the Brain: Another Argument for a Revitalized Behaviorism

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A key epistemological difference between behaviorism and cognitivism concerns their respective attitudes toward the analysis of so-called cognitive processes into functional modules. Behaviorists generally say it is not possible. Cognitivists argue that this is an achievable goal. The question has been concretized by recent developments in brain imaging technology. A consideration of the matter suggests that technical and conceptual difficulties abound in the effort to localize “high-level cognitive functions” in narrowly circumscribed regions of the brain. Some of the most serious involve the ambiguous definition of the putative mental components that are to be localized and the generally unacknowledged nonlinear complexity of both psychological processes and the brain. In addition, the imaging techniques themselves are replete with technical difficulties that raise additional questions about this particular application, even though these wonderful machines can make extraordinary contributions to our knowledge of brain anatomy and physiology. The cumulative implication of these difficulties is that the cognitive approach to the study of scientific psychology has once again set out on a search for a chimera. New approaches to behaviorism may be required to set psychology back on the correct track.

Key words: cognition, localization, brain imaging

Throughout the history of cognitive neuroscience, a persistent goal has been the search for localized regions of the brain that represent or control specific cognitive functions. Prior to the last couple of decades, the predominant method was surgical extirpation of brain regions followed by the study of behavioral deficits. For a number of reasons, interest in this kind of study has waned. One reason, not as frequently acknowledged as are the practicalities of cost and ethics of animal treatment, is that progress in the surgical program began to run into what were insurmountable conceptual and logical difficulties. This older approach was doubly challenged. First, the searches for cognitive functions were, at best, inadequately defined and may have, in fact, represented hypotheses rather than psychobiological realities. Second, there was a surprising lack of appreciation that the brain was

a highly complex, heavily interconnected system displaying nonlinear properties that precluded its simple analysis into independent functional units.

Now a new technology holds center stage in the effort to answer the same localization questions. Surgical extirpation has largely been replaced by functional magnetic resonance imaging (fMRI) and other imaging studies that seek to correlate regions of high levels of brain metabolic activity (the deoxygenation of hemoglobin) with particular cognitive functions. Because of the noninvasive and nonradiological nature of fMRI techniques, this approach initially promised to offer enormous advantages over the surgical techniques. The approach has become increasingly popular and publications appear to be growing exponentially since the discovery of this method by Ogawa, Lee, Nayak, and Glynn (1990) only 14 years ago. In spite of their advantages, the new techniques still suffer from many of the conceptual and technical difficulties that bedeviled surgery and related techniques.

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Some General Points

Before I present some of the persistent difficulties and challenges still faced by the cognitive imaging enterprise, several general points must be made. First, like all others who are admirers and recipients of the benefits of modern biomedical advances, I am firmly convinced that the various kinds of MRI devices that are now available or under development represent some of the most important medical advances in human history. The MRI technique is likely to be eventually compared with the milestone of anesthesia with regard to its ability to alleviate human suffering. It has already provided opportunities for diagnosis and treatment that would have exceeded the imagination of medical scientists only a few years ago. As the technology progresses, it is also likely to introduce new techniques such as intra-operative imaging, MRI spectroscopy, and microscopic imaging that will open previously closed doors to understanding the structure and biochemistry of the brain, especially in degenerative diseases.

Second, there is little question that some processes and activities are more or less localized in the brain. The locations of sensory, motor, and some emotional and appetitive regions have been known for years, and newer imaging studies have repeatedly confirmed the basic facts of this aspect of brain organization. On the other hand, the idea that the so-called high-level cognitive processes such as decision making or problem solving are uniquely represented in localized regions of the brain is, some of us suggest, suspect. (In addition to Uttal, 2001, the reader is referred to such articles as the one by Faux, 2002, previously published in this journal.) It seems far more likely that each region of the brain is involved in many "cognitive processes," each of which is encoded by activity in widely distributed brain regions.

Third, by no means am I arguing

that the brain is a homogeneous mass of undifferentiated, equipotential regions in the sense that Lashley (1950) once proposed. Somewhere between that extreme and the concept of a collection of relatively isolated functional brain modules coincident with cognitive modules lies what we must consider to be the truth about brain organization. Most probably, a compromise will ultimately appear that accepts distributed neural representations with some degree of specialized localization.

Fourth, I came to the conclusion that a behavioral approach is preferable to a reductive cognitive one from a very different background than most readers of *The Behavior Analyst*. I was, by training, a physiological psychologist, or as the field is now known, a cognitive neuroscientist. Most of my early writing was in this field, with particular application to visual psychophysics. Two decades ago (Uttal, 1981, 1988), I tried to extend ideas from this field to "higher level visual cognition" and failed completely. The data were highly equivocal and the theories unsatisfying. It dawned on me in the 1990s that the task may not be doable for the most profound reasons; any effort at neurological or cognitive reduction into separable brain modules or cognitive components may be a search for a chimera. On this basis, I now believe that a holist, nonreductive approach to psychology is better formulated in behavioral terms than in those of cognitive psychology. This essay is an effort to show that even the most objective of new neurological measuring instruments may be misleading us in fundamental ways. In fact, they are actually telling us a story more consistent with the traditional tenets of behaviorism than with present-day cognitivism.

I now argue that what is currently missing in the excitement of the new technology is sufficient discussion of the conceptual and technical obstacles that abound in this new endeavor and of possible alternative interpretations of the imaging data. In the remainder

of this article, I discuss some of these obstacles and make the argument that the enormous commitment of resources and human energy to this particular scientific approach may be ill advised.

On the Definability of Cognitive Processes

One of the most profound problems facing those who seek to localize cognitive processes in the brain is the tenuous nature of these hypothetical constructs, as defined by MacCorquodale and Meehl (1948). Throughout the long history of the interest in classifying mental processes, there has been little agreement on what are the components, modules, faculties, or traits of human thought. Indeed, one of the great unanswered questions of psychology is whether these proposed subdivisions of the "mind" actually exist in any biological or physical sense. It may well be that they are only figments of our experimental designs or convenient artifices to organize our theoretical models and that a more molar and behavioral approach is to be preferred for our science.

There is, thus, a real but unacknowledged possibility that many of the "cognitive" components for which brain locales are sought are idiosyncratic to a particular experiment, are very poorly defined, or are simply names applied to concretize measured behavior. If this turns out to be correct, then many of the sought-after cognitive processes do not represent real isolable entities, but, rather, are simply inferences or "nominal" hypotheses drawn from the measures of the particular results of an experiment. This idea is hardly new; it has been suggested by many behaviorally oriented psychologists, most notably including B. F. Skinner. Because of the neutrality of behavior (Uttal, 1998), a profound logical difficulty remains cogent—any behavior may be "explained" by many plausible internal mechanisms; therefore, mental terms or findings cannot, in principle, designate or define specif-

ic internal mechanisms, whether they are cognitive or neural.

In spite of this possibility, hypothetical cognitive modules are often reified as specific organs, objects, or modules whose mechanisms are narrowly localized in the brain. There is at least a reasonable possibility that the "mind" is a far more integrated, molar, unified entity than a system of quasi-independent faculties. If so, the assumption of localizable cognitive modules is just wrong, and the analytic goals of cognitive psychology are ill advised.

The Nonlinearity of the Cognitive and Brain Systems

Let us assume, for the sake of argument, that both the brain and its cognitive functions are modular in the way required for the imaging approach to succeed. Is it likely that the neural and hypothetical mental components at issue here are so simply interconnected that they can be dissected and examined in isolation? The brain is hardly likely to meet this criterion; it is an immensely complex organ whose many regions are well known, from years of anatomical and physiological research, to be heavily interconnected. The best known example of this interconnection is to be found in the organizational chart of the anatomy of the relatively simple visual system produced by Felleman and Van Essen (1991).

This complexity of interconnection was one of the difficulties that confronted the earlier generation of surgical localizers. What the earliest anatomical studies discovered, and the functional studies later confirmed, was that the centers and nuclei of the brain spoke to each other along many different pathways. Complex networks existed with feed back, feed forward, and multiple lateral connections.

It is now thought that the task of determining the hierarchical ordering of the brain components of the visual system may be intractable due to this nonlinearity. According to Hilgetag, O'Neill, and Young (1996, 2000), the

task is mathematically impossible, and no additional amount of research can ever overcome this fundamental problem.

Complex interactions across brain regions make it impossible, for example, to determine whether activity in a region is (a) sufficient to support a putative cognitive process, (b) simply a transmission pathway for the flow of critical information, or even (c) an inhibitor of an inhibitor whose surgical removal or activation could produce a simulation of localization. In other words, we may obtain strong evidence of *necessity* (i.e., required participation) without being able to strongly argue that a particular region of the brain is *sufficient* to represent the neural equivalent of a particular cognitive process.

Contrary to current cognitive dogma, psychological functions are also subject to this same kind of nonlinear constraint on our analytical ability. For example, Pachella (1974) argued that certain unrealistic simplifying assumptions are required to fractionate reaction times into such components as perception, decision, and response times, respectively. He argued that it would be necessary to assume that the components were activated in serial order; that the components were stable enough to remain unchanged when task requirements change; and that the data used to choose between these postulated components were sufficiently precise to distinguish between alternative explanations. None of these assumptions can be empirically supported.

In short, the foundation idea of cognitive psychology—that the mind is a system of quasi-independent modules that can be localized in narrowly circumscribed regions of the brain—is at least questionable and probably unsustainable. In mathematical terms, the localization of component cognitive processes in the brain is an ill-posed problem! That is, there would not be enough power to solve it even if we possessed all possible data. The prob-

lem is, from this point of view, totally intractable for formal reasons. No amount of additional research, however energetic, can overcome this barrier, no matter how ingenious may be the invention of mental faculties or modules or post hoc theories.

The Subtraction Process

The basic methodology used in fMRI imaging of cognitive process is to subtract the image of an experimental condition from a control condition. However, the words *experimental* and *control* in this case refer to questionable manipulations of the “cognitive” processes under study. Instructing a subject to “think about something” and then to “not think about something” leaves many questions open about what the brain is doing and what the subject is actually thinking. The degree to which control is possible over the highly varied and adaptive ways in which humans can adapt to instructions will always leave a residue of doubt about what the subject is actually doing, covertly or overtly, under each condition and thus introduces uncertainty into any drawn conclusions.

More fundamentally, the subtraction of one image from another, even if done with great accuracy, obscures the fact that many regions other than those highlighted may be active and involved in the putative cognitive process under study. Even though the cumulative activity in these other regions may appear to be unchanged, this does not mean that the underlying patterns of neuronal activity are identical in the two conditions. The fMRI is an integrated measure, and the details of the neuronal interactions may differ greatly even though the cumulative values remain the same. Thus, there is a logical flaw built into the subtractive method; it ignores places where activity may be constant in integrated quantity but quite different in microscopic detail.

The Arbitrariness of Statistics and Thresholds

There are a number of other technical and data problems that have to be

considered in terms of what has already been accomplished in the quest to localize psychological functions in the brain. Among the most serious are those that have to do with the massaging and pooling of fMRI data by statistical and experimental design protocols. Individual differences can have an enormous impact on the apparent localization of a putative cognitive process. Activities that are broadly distributed across the brain for individuals can, when averaged, produce relatively small apparent regions of activation in the same way that the “common, overlapping region” of a Venn diagram is much smaller than the portions of the individual regions that do not overlap. (See Uttal, 2003, for a complete discussion of this difficulty.)

Even more important, however, is the arbitrariness with which thresholds can be set to define the boundaries of an activated region. The experimenter is free to determine what activation levels will be considered to be significant. High levels of significance reduce the apparent size of an activated region, whereas low levels broaden it. Injudicious assignment of significance levels and thresholds can, therefore, grossly distort the apparent degree of “localization.”

The Question of Data Reliability

The reliability of the obtained experimental results should be paramount in evaluating the success of a scientific study. Thus, newly emerging meta-analytical comparisons of the results from a number of experiments are particularly important in evaluating the success of the cognitive imaging enterprise.

What is arguably the most comprehensive meta-analysis yet carried out in the field of cognitive localization is that reported by Cabeza and Nyberg (2000). They compared the regions that were activated by what were assumed to be common cognitive processes. Regions that were associated with some sensory or motor activities

(e.g., “perception” or “language”) did show relatively narrow localization to the classic visual or Broca and Wernicke’s areas. However, when Cabeza and Nyberg compared the results for higher “cognitive” processes such as “working memory” or “problem solving,” the data from different laboratories were very broadly distributed. In fact, the reported peaks of brain activity associated with these kinds of psychological activity were spread over at least a quadrant and, more typically, an entire hemisphere of the brain!

It is clear from Cabeza and Nyberg’s (2000) meta-analysis that no narrowly circumscribed region of the brain was uniquely associated with any of the putative high-level cognitive functions studied. Although individual reports may suggest such a conclusion, the variability of the reports from different laboratories suggests that narrow localization is, to a substantial degree, mythical.

Conclusion

This essay is much too short to permit the presentation of the entire case against the cognitive localization enterprise and the cognitive approach to scientific psychology in general. (For a more complete discussion of the technical and conceptual difficulties facing this field of research, see Uttal, 2001.) What is clear is that there has been a rather reckless community decision to commit an inordinate portion of psychology’s limited resources to this one research program. Obviously, some knowledge will come from this new approach. However, until we consider the basic assumptions, the epistemological constraints, and the forthcoming data in detail, the potential for enormous waste and theoretical misdirection continues unabated.

On a general theoretical level, the search for the modules of human thought—the basic quest of current cognitive psychology and cognitive neuroscience—is brought into question. There just may be, in what these sci-

ences offer up as their best available justification of their quest, an even better argument for a return to a new and polished version of behaviorism.

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