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The Value of Brain Imaging in Psychological Research

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Abstract: We take the view that commonly used brain imaging techniques add new and informative data to psychological research. As with any new measure, we need to decide how to use it in an appropriate way. How does the measure help answer theoretical questions in ways that existing measures cannot? Is the measure best used as a dependent variable or as a predictor variable? How does it relate to other psychological variables of interest? This new imaging technology provides exciting glimpses into the workings of the brain and its relation to psychology. Researchers need to figure out how the information provided can be used to advance the understanding of psychological phenomena.
Key words: fMRI; statistical modeling; psychological theory

Introduction

Functional brain imaging offers the ability to examine a person's brain while that individual engages in a psychological activity of interest. The promise of brain imaging techniques is that they permit tracking the brain in real time. They provide the researcher the opportunity to look "under the hood." In this paper, we consider how such information is useful in addressing psychological research questions, including how anatomical localization can relate to psychological processes and how dissociation can provide a test of underlying psychological process. We write from the perspective of a traditional psychologist interested in learning more about what these techniques offer. We provide advice about how one can add these techniques to a research program to maximize the chance of useful discovery and facilitate incremental knowledge. We limit our attention to the broad category of brain imaging techniques with special attention to functional magnetic resonance imaging (fMRI).

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Background: It is all about the measure

Brain imaging techniques measure different variables. Electroencephalograph (EEG) measures electrical activity in the cortex, magnetoencephalography (MEG) measures magnetic fields that are biproducts of electrical activity in the cortex, fMRI measures oxygen levels in blood, and voxel-based morphology of magnetic resonance (MR) images measures cortical thickness. These different techniques can be construed as different measured variables. Their use in scientific research becomes relevant as long as the variable is related to the underlying psychological process under study. As with any empirical science the paradigm includes measured variables, which can be formulated as either dependent or predictor variables in theoretical and statistical models; the value of those measures is driven mostly by the scientific advances they facilitate. The basic thesis of this paper is the following: brain imaging presents a new measured variable and the value of such a measurement is driven not by any provocative construal we provide about "brain activation" and colorful images of the brain that "light up" but by the scientific advances, the theoretical developments, and the empirical testing afforded by such measurements. This is true of any measured variable used in empirical research. Just because a technology produces colorful images of the brain does not make it more scientific than any other measure used in psychology. Our tone may seem cautious and reactionary but we are responding more to what we believe are false claims and false hopes that researchers place on brain imaging, especially those new to imaging techniques.

Some have criticized recent research using brain imaging as simply being modern phrenology because it appears, to the untrained eye at least, that the goal of the program is to map and localize brain function (Uttal, 2001). Fear is in the amygdala, social psychological processing is in the medial prefrontal cortex, memories are formed in the hippocampus. Every process has a place, only now rather than probing the peaks and valleys on the scalp as did the early phrenologists, the modern scientist has access to an expensive electric magnet that produces data that can be reconstructed into images and statistical maps. We agree that some modern brain imaging contains some aspects of localization on par with the early phrenologists, but we also believe that imaging techniques hold much promise when viewed as another variable in the psychologist's toolbox. Many researchers have utilized the technology well beyond simple "phrenology." For example, Kosslyn, Thompson, and Alpert (1997) used Positron Emission Tomography (PET) to show the shared systems of imagery and visual perception, thus demonstrating the similarity of those psychological processes. Raichle, MacLeod, Snyder, Powers, Gusnard, and Shulman (2001) used brain imaging to provide novel insights into the baseline state of the human brain, helping us learn more about the psychological processes involved in "off-task behavior." In both cases, neuroimaging was used beyond localization and provided insights into psychological processes that would be difficult to uncover with behavioral data alone.

Additionally, localization is typically not the primary goal of brain imaging, nor should it be. Our field has deep psychological questions that go beyond where a specific psychological activity is located in the brain. Further, localization may play an important role in developing theories about a network of brain responses and how brain structures work as a system to take multiple stimuli and multiple internal processes to produce multiple behaviors, cognitions and emotions. Thus, localization is one use of brain imaging techniques, but it is not the only use, nor necessarily the best use. We acknowledge, though, that localization knowledge may be useful as we develop and test psychological models. Localization can potentially help to classify a set of cognitions and actions that may be difficult to classify with behavioral experimentation alone. However, we must not constrain our thinking and view brain imaging techniques as limited to only localization. The techniques provide measured variables and their value depends on how we use them in our research, whether these measured variables allow us to test burning research questions, and whether these variables prompt us ask new research questions and propose new experimental tests.

This view parallels the use of reaction time measures in psychology. That one psychological process takes longer than another is not necessarily useful information in isolation, but used in a clever way reaction time measures can provide new tests of psychological processes that were not readily available with other measures. For example, Sternberg (1966) used reaction time to demonstrate that recognition time of an item in short term memory depends in part on the number of items in storage. Luce (1986) reviewed the rich set of reaction time studies on detection, identification and matching paradigms, along with mathematical models, showing the deep lessons that can be learned about cognition by knowing how to work with a dependent variable. These examples illustrate that reaction time can provide information beyond which condition yields faster response. The localization that emerges in imaging studies should analogously be viewed as information that can help us make inferences about psychological processes. In short, we do not view localization information as the best method for making psychological inferences nor should it be the sole end goal of an imaging study. We will discuss other uses of fMRI that extend beyond localization, which will be beneficial to psychological theorizing.

Different Technologies

There are different technologies that can be used in brain imaging studies. It is helpful to categorize these techniques along a set of dimensions that relate to psychological questions. One dimension is brain function versus brain structure. Are we interested in imaging the brain during psychological activity (functional) or are we interested in morphological properties such as the thickness of the cortex or the fidelity of white matter connections that form the major routes of neural activity (structural). Some research questions, such as those involving age-related changes in cognition, may invoke both structural and functional research questions so more than one imaging technique may be relevant. Are there any structural differences in the brain between older and younger adults? Are there functional brain differences that relate to behavioral differences between older and younger adults? Are there age differences in brain networks?

Another dimension is the relative importance of spatial versus temporal resolution. Do we want to optimize our ability to localize specific brain activation to a particular spatial locale or do we want to optimize our ability to measure when brain activation occurs at the expense of not knowing the precise location of that activity? This dichotomy is not due to some theoretical limit related to some uncertainty principle in physics, rather existing technology does not permit both high spatial and temporal resolution concurrently in the same technique, though this is an active area of research and some promising new developments have been made. Some researchers have been successful at using two methodologies concurrently (such as EEG and fMRI) in order to realize both spatial and temporal resolution (e.g., Goldman, Stern, Engel, & Cohen, 2000).

Research questions

Many of us are not aware of the extent to which the particular paradigm or methodology we use can constrain the types of research questions we ask. This usually emerges early in our psychological training as young graduate students when we are socialized into a particular research lab, a particular way of doing science, a particular research literature, a set of friends we cite and foes we seek to dismantle with our creative studies. If we commonly use reaction time data, then we tend to ask questions that can be tested by a reaction time paradigm; if we commonly use self-report data, then we ask research questions that lend themselves to testing with self-report data. The reader may be familiar with the “culture shock” associated with entering a new domain of research where “things are done differently,” perhaps a different measure is taken, or a different paradigm reigns supreme, or a different type of stimulus is used. Sometimes our reaction to the new is skepticism because it seems messy and foreign to us; the rituals about how to process the data or how to test subjects seem ad hoc. Some researchers retreat back to the safe known world of what was learned in graduate school, but others venture out to tackle the unknown. In doing so we may come to realize that what was so natural and straightforward to us is also in a sense ad hoc and full of ritual.

Moving a traditional psychological laboratory to incorporate brain imagining techniques carries with it an analogous set of issues on at least two levels. First, the psychologist must learn relevant neuroscience. It is not sufficient to work at the level of the psychological theory and invoke psychological constructs. Rather, one must learn a little physiology, a little neuroanatomy, and a little biopsychology. This is not easy because it involves learning new fields, not merely new areas within a field. However, doing so will pay great dividends, and lead to much more coherent imaging research with relevance to psychological theory. Second, the psychologist must learn the relevant details of the brain imaging technique. If one wants to study positive emotions in the fMRI scanner, how does being confined in a tube emitting a loud jackhammer-type noise influence the type of emotion that a subject could possibly experience? An imaging design requires the paradigm to keep track of various onset times, with psychological processing happening within, say, 15-30 second trials, but if our usual social psychological paradigm involves participants reading a long paragraph and then answering five open-ended questions, there will be a mismatch — the psychological paradigm will have to be re-worked to match the constraints of the interpretable information the fMRI scanner can provide. Of course, if a new paradigm is developed for use in the scanner, the careful researcher should also replicate a few standard results in the field to verify that the new paradigm still yields the same underlying behavioral conclusions. In other words, the researcher needs to demonstrate that the new "neuroimaging ready" paradigm produces results consistent with those in the literature. Therefore, understanding the research context, the methodology, the limitations of the method, along with the constraints that the methodology places on types of research questions that can be asked, are important considerations when adding brain imaging to one's psychological research program. One should not merely hire a technical person to handle the details of developing the fMRI paradigm. The psychologist needs to be actively involved in guiding the research paradigm so it maintains the fidelity of the psychological question.

Localization, Association and Dissociation

There are several types of hypotheses that can be addressed with brain imaging research. One is localization, which amounts to mapping psychological function to anatomical structures. While this may be an important type of question, in our view it is one of the least interesting in terms of providing new psychological understanding about process (see also Cacioppo et al, 2003). It isn't clear that knowing that social anxiety is located in one place in the brain or another adds much to our body of knowledge, other than perhaps a useful boundary condition or another way to classify a psychological process. This qualification about location, however, mostly applies to the current type of location information offered by existing brain imaging techniques (e.g., blood flow). It is possible that advances in brain imaging technology and methodology could provide more useful localization information, such as providing information about neurotransmitters and neural circuitry — essentially localization involving detailed information about the underlying neural mechanisms. Current types of atlas-style localization (e.g., amygdala, anterior cingulate cortex, medial prefrontal cortex) are too gross to pinpoint underlying neural mechanisms given that there are so many substructures (or layers) within structures, different types of transmitter receptors, etc.

There are other types of research questions that can be asked with brain imaging techniques that can lead to deep and unique information about psychological process. One such research question involves association. Somewhat analogous to converget validity, these types of research questions relate two or more processes to each other. An example is the association between brain activity as measured by BOLD and subsequent choice in a decision making task, or the association of multiple brain structures working in tandem as a network. Another example, is the one we cited earlier about the similarity between imagery and perception as found by Kosslyn et al. (1997).

A third type of research question involves dissociation. Dissociation is analogous to discriminant validity. If we are investigating two psychological processes we can examine whether they are differentially driven by anatomical structures. We may be able to dissociate, say, the emotion of regret (which involves counterfactual thinking) from the emotion of disappointment (which involves an evaluation of the current state); see, for example, Chua, Gonzalez, Taylor, Welsh & Liberzon, 2009). Behaviorally, it is not easy to distinguish regret from disappointment because they both can be strong negative emotions in response to a negative decision outcome. Brain imaging data, for instance, can help dissociate these two processes by finding brain regions that either respond differently in these two states or respond differentially to different experimental manipulations. For similar distinctions between different types of research questions that can be asked in a brain imaging context see Berman, Jonides, & Nee (2006) and Knutson & Greer (2008).

Neuroimaging Environment

One needs to select phenomena that can be studied with the chosen brain imaging technique, but be mindful of the neuroimaging environment, which is more confining than the typical laboratory setting. If one wants to study the gut level reaction that emerges when seeing a disgusting scene, MRI may not provide the best temporal resolution for that psychological process. One may have to alter a tried and true familiar paradigm to fit the constraints of a brain imaging study. The usual social psychological or decision making paradigm of having participants read a paragraph scenario may not work in the fMRI scanner because the brain activity involved in reading and comprehending a paragraph makes it difficult to define when a psychological event occurs if it is not known when particular brain activation should show up. Or, if one wants to study positive emotion, the context of the loud confining fMRI tube may swamp any positive mood induction created by the most well-intentioned behavioral paradigm. If one is studying sexual attraction, then the researcher must be mindful that the skull cap in the EEG study may make the research subject feel unattractive to the research assistant of the opposite sex, and may lead to an emotional state that contaminates the study. Scanning children creates a new host of challenges given that the child must stay still for a relatively long time. In many cases it is difficult to maintain a child’s interest throughout many trials of a relatively boring psychological study, let alone doing the task inside an MRI scanner.

Design

As stated previously, the type of design one uses may need to be adapted to fit into a brain imaging context. One may be accustomed to using between-subjects manipulations in a behavioral setting, but a within-subjects design may be more efficient in a brain imaging context. This means revamping a traditional behavioral paradigm, which may open up new issues as one switches the details of the paradigm to a within-subjects design (e.g., Greenwald, 1976). In order to have sufficient statistical power in such psychological domains, researchers simply test more subjects. Financial and time constraints may lower the practicality of this solution in an imaging context, and researchers may have to develop new designs and manipulations that can be adapted to the brain imaging technique. This is especially important considering the amount of noise in neuroimaging data (e.g., Parrish, Gitelman, LaBar & Mesulam, 2000).

Another important issue of design involves the particular method of presenting the experimental manipulation and the experimental stimuli. The researcher must decide whether a block design is feasible or whether an event-related design is more appropriate for the type of research question being tested. A block design involves a sequence of similar experimental trials organized in common “blocks” of trials (e.g., ten happy trials, followed by ten sad trials, or a set of high frequency word trials followed by a set of low frequency word trials), which optimizes signal, but does not allow the modeling of individual trials. An event-related design involves a design where experimental trials are interleaved (e.g., a happy trial, followed by two sad trials, followed by a happy trial, etc, where trials are usually randomly assigned) allows one to model individual trials and individual hemodynamic responses at the expense of power. While on the surface this appears to be merely a methodological point, the decision should also be informed by the particular psychological state that the researcher hopes to achieve in the research participant. Is it too awkward for the subject to switch psychological states randomly on each trial? Does presentation of conditions in blocks set up an expectation that the subject can guess what comes next (e.g., “oh, these are the trials where I’ll see angry faces”)? The pros, cons and relative merits of different experimental designs should be evaluated against the psychological research question being tested.

Variables

Brain imaging data are typically used as a dependent variable. Does the medial pre-frontal cortex respond more to self-related emotions or to other-related emotions such as empathy? In this situation the researcher can use the BOLD signal as measured in a specific region of interest and compare it to signals across different experimental conditions. This is no different than say a research question asking whether responses will be faster in one condition or another, or whether performance will be better in the experimental condition than in the control condition. As with any dependent variable, the merit and overall utility of the measurement rests on whether the collected data allow one to answer the research question.

Brain imaging data, like other measures, can also be used as a predictor variable. BOLD response on the current trial can be correlated with the behavior, the response or the evaluation on the subsequent trial. This addresses a research question in the spirit of “Does brain activity in this region predict subsequent behavior?” Here imaging also plays the role of a measured variable but is treated as a predictor variable in a time series regression. For example, Eichele et al. (2008) found that changes in brain networks associated with the default state and the executive network could be used to predict whether participants would commit an error on a flanker task (a typical cognitive task). In fact changes in brain networks that occurred 30 seconds before the trial of interest could be used to predict whether an error would occur on that trial. Other researchers have also used similar techniques to use brain activation patterns to predict behavior and psychological states (Hasson et al., 2004; Haxby et al., 2001; Polyn et al., 2005; Davatzikos et al, 2005), again bolstering the power of neuroimaging in a psychological context.

In addition, behavioral and psychological variables must be selected carefully in a brain imaging study. Psychological paradigms that have subjects respond by writing paragraphs to open-ended questions cannot currently be used in a straightforward manner in an fMRI paradigm. Not only is the MRI scanner too confining to permit writing, but also the physical act of writing would create a strong MR signal that may be difficult to dissociate from the psychological process one is studying in the experiment. We find it difficult to construct convincing control conditions to compare or contrast open-ended writing. This suggests that, for fMRI with the current technology, the response in the scanner should be limited to very specific responses (e.g., a yes or no click, a five button response box with one response corresponding to each finger of one hand), which will reduce motion artifacts.

Constraints

A research paradigm places constraints that limit the researcher from spinning stories about empirical data. The constraint imposed by biological systems, such as physiological and neural systems, is seen by some as a way to ground behavioral psychology. Interesting psychological hypotheses and tests can emerge, for example, when one considers evolutionary constraints on behavior. Some explanations of behavior can be ruled out, or alternative explanations of behavior can be tested, based on taking an adaptability view of the process under study. In much the same way, there is promise that using brain imaging data can provide analogous constraints in theory building of behavioral psychology. A psychological interpretation of a decision making task involving stress will have problems if the stress axis does not appear differentially activated relative to a non-stress condition. There is much to be said for this view of constraints. Unfortunately, the imaging field may be too immature at this stage to apply this as a criterion to judge success of the imaging enterprise in psychology. Many of the paradigms are still being understood, so it isn't so clear how to interpret imaging data in the context of a psychological experiment, which in some cases relies on behavioral data to provide an interpretation. At this early stage there is some reciprocity, or dual flow of information, between scanning data and behavioral data. As we learn more about interpreting data from brain studies, then this criterion of imaging as a constraint will be easier to apply and will likely provide useful means of testing psychological theory. It is probably the case though that existing methods in cognitive, affective and social neuroscience are inadequate at providing sufficient constraints to test psychological theory. In many cases the imaging paradigms themselves are prone to alternative explanations and they cannot always provide the level of constraint necessary. This important use of neuroscience information in psychological theory testing will undoubtedly make use of more tools and techniques from neuroscience, including techniques involving lesion patients, animal models, single cell recordings, molecular biology, and genetics.

Expansion of ideas

Biologically related constraints to one's theory testing provide one benefit of incorporating paradigms such as brain imaging. We also believe that brain imaging techniques can take one's research into new directions and may lead to new research ideas—in this way having an expanding effect on the research directions taken by empirical psychology. A recent example is a study by Sharot, De Marino and Dolan (2009) showing that in a standard dissonance paradigm there is pre-choice activation that predicts the magnitude of the dissonance effect. This challenges the traditional view that dissonance is unrelated to pre-choice psychological processing, and thus opens the gate to new theories and insights about dissonance processes that was until now closed shut. Further, conceptualizing psychological activity as arising from a network of structures, each playing a different role can provide new directions for psychological theorizing, and new experimental tests involving purported psychological mechanisms can be conceived. Richer psychological explanations, involving multiple levels of analysis (neuroscience and behavioral) and multiple systems, will emerge. To us, the potential for new ideas and new empirical tests is perhaps a more important benefit of brain imaging and the use of neuroscience more generally, than any advantage offered by constraints as described in the previous section. It is exciting to think about how the field of psychology will look like in 10 years. We hope that the future brings new theories, new paradigms and new research questions, rather than merely more of the same just with more constraints and boundary conditions.

Statistics

Brain imaging techniques present a host of new statistical problems and opportunities for new statistical developments. Images need to be pre-processed to deal with artifacts, confounders, and noise. Images have to be corrected for the participant's movement during the scanning session, warped to fit into a standard atlas, smoothed etc. These and other issues present a wide range of statistical challenges for the neuroimaging researcher. In addition, these issues will differ between imaging techniques such as EEG, MEG and fMRI. In this short paper we focus on two analysis challenges: dealing with multiple p-values and dealing with temporal and spatial correlation.

Concern with p *values*

Some areas of statistics are concerned with the problem of inflated Type I error rates when one performs multiple tests of significance. For example, in a traditional analysis of variance design of a behavioral paradigm, some psychologists may be concerned with the inflated Type I error rate from the 15 *post hoc* pairwise tests between the six cell means that emerge in a 2 × 3 experimental design. Those 15 tests seem like a lot and usually a call for some correction to the Type I error rate is made (e.g., a Tukey test, a Bonferroni correction). However, in brain imaging analysis most published studies involve tens of thousands of *t* tests. Therefore, concern with *p* value correction occupied much time in the early development of statistical methodology for brain imaging. We agree this is an important problem, but it appears that the way to solve it is not through finding the right patch, whether it be Bonferroni, Tukey or a false discover rate correction, but through re-conceptualizing the analysis. If one is performing tens of thousands of statistical tests, rather than think about how to patch the situation maybe we should re-conceptualize the analysis so that we aren't making so many statistical tests. Some researchers have moved in this direction with tailored analyses around regions of interest (ROIs; e.g., Poldrack, 2007), but much more can be done, including entirely new ways of conceptualizing statistical models of such data. There is much current activity in developing new statistical procedures for imaging data. For example, Peltier, Polk and Noll (2003) used self-organizing maps as a way to characterize default networks in the brain in a model-free way. Such analyses could be used to characterize other brain networks. In addition, Mitchell et al. (2004) have discussed how machine learning algorithms can be applied to fMRI datasets to classify cognitive states and could also lead us to new empirical questions. Many of these techniques will alleviate some of the multiple comparison problem, and may lead to new discoveries.

Spatial time series

An open area of research for analytic techniques in brain imaging involves spatial time series. Currently, most analytic strategies for, say, fMRI involve treating each voxel as an independent unit in a general linear model. The most common way that spatial intercorrelations are addressed in the usual analyses involves smoothing, which is a way to average activation patterns across multiple voxels, thus making the data more uniform. The general linear model analysis can be extended to include clustering and mixture modeling, which provide sophisticated algorithms for modeling collections of voxels (e.g., Tohka et al, 2007). Some techniques attempt to model the relation across the parameters of the general linear model, but much more work is needed to address this important data analysis issue. For example, the usual two-level approach can be expanded so that BOLD data are modeled simultaneously at multiple levels of nesting with appropriate specification of fixed and random effects: time, voxel, subject, treatment group (Beckman et al, 2003). Further, new insights perhaps from dynamical systems theory will be helpful in understanding both the temporal and spatial patterns of the BOLD signal (for an initial example see Kamba, Sung & Ogawa, 2004).

Conclusion

Brain imaging techniques, and the role of neuroscience across the subfields of psychology, are here to stay. Progress in developing new imaging technology continues and there will likely be new techniques available in the near future. As a whole, brain imaging provides a new set of measured variables for psychologists to use in their research. We believe that these measures extend the types of research questions that can be tested and asked. For an empirically grounded field the development of validated new measures, which extend what we can currently measure and explore, is a step in the right direction.

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脑成像在心理学研究领域的价值

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摘　要　现在普遍使用的脑成像技术给心理学研究增加了新的数据和资料。和任何新的方法一样，我们需要决定如何以适当的方式应用这项技术。这项技术如何以现有的方法所不能的方式帮助回答理论问题？这项技术最好是作为因变量还是作为预测变量来使用？它如何与其它感兴趣的心理变量相关？这种新的成像技术有助于我们了解大脑的运作及其与心理学的关系。研究人员需要弄清楚如何利用这项技术提供的信息加深对心理现象的理解。

关键词　fMRI; 统计建模; 心理理论

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