Functional Magnetic Resonance Imaging and Communication Science

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Theories of message and interpersonal processing and effects in communication often attribute important roles to social, cognitive, and affective processes such as attention, memory, and emotion. Using methods that can measure these processes is critical for assessing the validity of these theories. Functional magnetic resonance imaging (fMRI) provides a powerful approach to the measurement of cognitive and affective phenomena relevant to communication research. Indeed, a large body of work over the past two decades has used fMRI to uncover the cognitive and affective processes underlying human thoughts, feelings, and behaviors that self-report or behavioral techniques often are unable to tap. However, as we describe in greater detail throughout this entry, fMRI has both strengths and weaknesses. Using fMRI effectively requires knowing the types of questions it can answer and understanding its strengths and current limitations. As a starting point, the goal of this entry is to provide an introduction for understanding and using fMRI in the context of communication science for those with little or no background knowledge. We recommend this be supplemented with readings of Falk, Cascio, and Coronel (2015) and Weber, Mangus, and Huskey (2015) which provide more extensive discussions about the uses of fMRI in communication research.

We begin by highlighting what fMRI can offer communication research. As a specific example, we discuss how fMRI has been used to examine the manner in which people perceive and evaluate race and the insights these investigations may provide for studies on the effects of media on racial stereotyping and prejudice. The second section explains the physiological signals in the brain measured by fMRI. The third section describes some of the main issues involved in linking fMRI data with a specific psychological process. A final section describes future developments in fMRI that are particularly relevant to communication research.

An illustration of what fMRI can offer

A large body of communication research has examined how portrayals of racial groups in the media can influence evaluations and behavior towards such groups (Mastro, 2003). For example, news stories disproportionately depicting Black Americans as

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crime perpetrators influence people's beliefs and behavior toward African Americans (Dixon & Linz, 2000; Dixon, 2006; Gilliam & Iyengar, 2000). Many studies have used primarily behavioral and self-report measures to examine media effects (e.g., self-reported attitudes, support for racial policies, recall of information, and so on). As a complement to this work, in recent years, researchers have used fMRI to investigate how racial groups are perceived and evaluated (for reviews, see Amodio, 2014; Kubota, Banaji, & Phelps, 2012). Collectively, brain-imaging studies provide at least two important insights relevant to media effects research on race: First, race-based evaluations are complex and involve multiple—sometimes opposing—psychological processes. Second, some of these psychological processes are not revealed in self-report measures.

For instance, many of the early fMRI studies on race processing found that White Americans show greater neural activity in a brain region called the amygdala when viewing Black faces compared to White faces (for a review, see Kubota et al., 2012). These findings were of particular interest to researchers given previous work showing that the amygdala plays a crucial role in fear conditioning in animals (LeDoux, 1992) and fear processing in humans (Adolphs, Tranel, Damasio, & Damasio, 1995). In addition, follow-up studies revealed that the degree of activation in the amygdala to Black faces correlated with indirect/implicit measures of race bias (i.e., the Implicit Association Test, startle eye blink) but was *not* associated with explicit/self-reported measures of racial attitudes toward African Americans (i.e., Modern Racism Scale) (Phelps et al., 2000). These studies highlight how fMRI may be useful in providing communication researchers an alternative means of measuring the effects of media on evaluations that are not revealed in self-reports. Like any measure, however, there are caveats to consider when interpreting the data; see later section on forward and reverse inferences.

In addition, fMRI studies on race-based evaluations have also helped explain how individuals can override automatic biases through the involvement of multiple and sometimes opposing psychological processes. More specifically, evaluations of Black relative to White faces also involve a brain region referred to as the lateral prefrontal cortex. The lateral prefrontal cortex has been previously associated with top-down executive control and the regulation of emotions. In this context, its involvement has been interpreted as a regulatory mechanism to control unwanted, implicit racial associations (for a review, see Amodio, 2014). Indeed, some studies have found that activity in the lateral prefrontal cortex is negatively correlated with amygdala activity while viewing Black faces (Lieberman, Hariri, Jarcho, Eisenberger, & Bookheimer, 2005). Researchers have interpreted these data to suggest that exposure to Black faces in liberal college students may spontaneously elicit a form of inhibitory control of negative implicit evaluations (i.e., the region is down-regulating amygdala activity)—perhaps due to people's egalitarian beliefs or concerns about appearing prejudiced. This example illustrates one way that fMRI has helped researchers to investigate the simultaneous involvement of multiple psychological processes and also provides one way of studying how multiple psychological processes may interact; participants in the studies in question are not aware of their initial spikes in amygdala activity followed by down-regulation through cognitive control mechanisms—and as such would be unable to provide the information to researchers through verbal or written self-report measures; even indirect reaction time measures would not capture this push and pull.

Another major advantage of fMRI is its capacity to measure cognitive and affective processes independently from, or in even the absence of, any behavioral response. For example, researchers using an fMRI experimental paradigm can ask participants to passively view Black and White faces (as we might do in everyday life), without asking them to explicitly consider race or perform any other task, and observe the resulting cognitive dynamics. Furthermore, automatic responses can be captured without the need to impose cognitive load or speed constraints (as is often necessary with other indirect measures). Finally, it is often difficult to unobtrusively measure online changes in mental processes using self-report techniques given that the measurement of these processes often interferes with the natural flow of cognition (e.g., asking someone to report their experience as it unfolds can alter the experience). Unlike most measures that obtain information after stimuli have been presented, research designs that use fMRI can allow researchers to examine responses to communication-relevant stimuli at the same time a stimulus is presented (e.g., responses to Black and White faces during the moment of exposure).

From neural activity to the BOLD signal

When researchers observe “activity in the amygdala,” however, what does that mean? Our goal in this section is to explain conceptually the nature of fMRI data and the meaning of the term “activity” in a given brain region within the context of an fMRI study. To put it simply, fMRI measures neuronal activity *indirectly* by measuring differences in blood flow across the brain. Neurons consume oxygen to fuel their biological activities and as information processing demands on neurons increase, so too does their demand for oxygen. The vascular system carries oxygenated blood to the brain areas where these active neurons reside. An fMRI scanner is able to detect differences in how oxygenated and non-oxygenated blood respond to magnetic fields, and by tracking this signal, researchers can use this to infer changes in neural activity over time. This form of fMRI, commonly used in the social sciences, is known as blood-oxygen-level-dependent (BOLD) imaging.

Since the brain is always “on” and oxygenated blood is present throughout the brain, studies generally test for differences between conditions (within a scan) in order to determine relative activity across the conditions. Thus, when a typical fMRI study states that “brain region X is active in task A,” the statement can be more accurately re-stated as “brain region X is more active in task A compared to a comparison task B.” As a consequence, the choice of tasks or conditions that the researcher will compare is critical to measuring activity, as well as any inference that can be made about this activity. To illustrate: suppose we found that neural responses to Black versus Whites faces elicited no difference (“no activity”) in the visual cortex—a brain region that processes visual information. This outcome does not suggest that exposure to Black faces failed to engage visual processing. Instead, it implies that the same amount of visual processing occurred when viewing both types of faces and hence the difference between the conditions was not different from zero; by contrast, White observers might show *relatively* more activation within the amygdala in response to Black *compared* to White faces. Researchers should therefore pay careful attention to the comparisons made in an fMRI study as they are critical in determining the type of inferences that can be drawn from brain activity.

Forward and reverse inferences of psychological processes

In our discussion so far, we have assumed that the neural activity measured by fMRI reflects specific psychological processes. In this section, we consider the inferential procedure involved in how one might link activity in a given brain region to a specific psychological process (i.e., forward inference) and the form of reasoning communication scholars are likely to employ when using this information to generate conclusions in their own fMRI studies (i.e., reverse inference).

Over the last two decades, cognitive and social neuroscientists have used fMRI to determine the neuroanatomical correlates of a multitude of cognitive functions for the dual purpose of understanding the organization of the brain and mind. More specifically, researchers have attempted to map the neural correlates of a mental function by examining which areas of the brain are more active while participants perform a task designed to selectively elicit the target mental function compared to a control condition that does not. These functions range from what some might label as "basic" (e.g., visual, auditory processing) to "high-level" mental operations (e.g., working memory, attention, memory, cognitive control, self-related processing, mentalizing, valuation, and so on). Forward inference involves demonstrating that neural activity in a given brain region changes with manipulation of a specific psychological process (Henson, 2005, 2006). In most cases, forward inference studies compare two critical conditions: a target condition and a control condition, which is designed to elicit all the mental processes present in the target condition *except* the mental function of interest. This design is often referred to as a "cognitive subtraction" since the goal is to subtract away the non-focal mental processes by contrasting the two conditions. This type of design has two key assumptions. First, it assumes that the theorized mental function actually exists and that the brain executes this mental operation in the manner conceptualized by the researcher. Second, it assumes that the comparison across conditions isolates only the mental function of interest. If the above assumptions are met, one can then make the inference that the brain region is *activated* by the cognitive process. However, activity elicited by a specific cognitive process cannot be used to infer that the activated brain region is *necessary* for the implementation of the cognitive process. By "necessary" we mean that attempts to exogenously inhibit neuronal activity in that area or, in the most extreme case, destroying the brain area will lead to impairment of the cognitive function. Demonstrating necessity requires other techniques such as the lesion method (i.e., using people with brain damage) or brain stimulation devices that temporarily alter brain function (see Rorden & Karnath, 2004).

Once a mental process has been "mapped" in the brain using forward inference methods, communication scholars (or other social scientists, etc.) may be interested in using this neural region (or regions) as a measure of the psychological process in their new studies. This is reverse inference. Poldrack (2006) posed this problem in the following way: If brain activity was previously observed in brain region R when cognitive process P was active, can we then use the presence of activity in brain region R in a new study as evidence that cognitive process P was active in the new study? For example, previous fMRI studies have found that activity in the amygdala is associated with fear processing in a fear conditioning task (i.e., task in which stimuli is paired with a shock) (LaBar, Gatenby, Gore, LeDoux, & Phelps, 1998). Many of the studies we described earlier found that the amygdala was activated when participants viewed Black compared to White faces. How strongly can we conclude that participants were engaged in fear processing while looking at Black faces in these studies?

The main problem is that reverse inference is a logical error of affirming the consequent: If the presence of P (fear) leads to the occurrence of R (activity in amygdala), this does not necessarily imply that the occurrence of R (activity in the amygdala) entails the presence of P (fear). An analogous example outside of neuroscience is that turning on a heater (P) can cause the inside of a house to warm (R), but a warm house (R) does not necessarily mean that the heater is on (P) (e.g., it could be summer) (Cacioppo, Tassinary, & Berntson, 2007). Indeed, issues associated with reverse inference are not exclusive to fMRI as they are also applicable to other behavioral and psychophysiological techniques used by communication scholars. For example, studies that use self-report responses, reaction times, eye-movements, event-related potentials, heart rate, and so on, as indexes of mental operations employ reverse inference reasoning in the interpretation of data and are therefore susceptible to its problems as well.

In the context of fMRI, there are ways of dealing with the issues raised by reverse inference, given that there is rarely a case when R occurs *if and only if* P occurs (i.e., R never occurs without P). As noted by Poldrack (2006), two ways to improve confidence in reverse inference are to "increase the selectivity of response in the brain region of interest, or increase the prior probability of the cognitive process in question" (p. 5). Selectivity can be increased by choosing more targeted brain regions, and by examining networks of regions that together may be more selective for a given psychological process than a single region. The former can be accomplished by using a functional localizer task. This is a task performed in addition to a researcher's main task of interest. It is often designed using the logic of forward inference and is therefore meant to isolate the neural regions associated with a specific cognitive function. A researcher can then extract neural data, using the region defined by the localizer task, from one's main task of interest. In addition, databases that automatically conduct large-scale neuroimaging meta-analyses (such as BrainMap and Neurosynth) can allow researchers to estimate selectivity, and hence provide information about the strength of the inference.

Finally, although reverse inference is largely viewed as a limitation, it can be especially useful in cases when one finds a set of unexpected brain regions activated by one's task or behavior of interest. In particular, one can use the wealth of information we have about particular brain regions, such as what conditions influence the involvement of these regions in other studies, how does damage to specific regions affect cognitive processing and behavior, and so forth, to interpret and generate novel hypotheses about other cognitive processes (beyond those that were expected) that may be making important contributions to one's outcome of interest. These hypotheses can then be tested using additional designs that employ the appropriate behavioral or psychophysiological technique. For example, the finding showing that the negative relationship between activity in the lateral prefrontal cortex and the amygdala while looking at Black versus White faces suggests that individuals may be inhibiting unwanted negative responses when evaluating outgroup members. Such a hypothesis can be tested independently outside an fMRI context using behavioral techniques (see Richeson & Shelton, 2003, for examples in the context of interracial interactions).

Considerations in conducting fMRI research

Temporal resolution

The temporal characteristics of blood flow in the brain measured with fMRI limit its temporal resolution (order of several seconds; although its resolution is faster compared to other neuroimaging techniques such as PET). As a result, fMRI is not appropriate to answer questions about how information processing operations unfold over time for processes that occur at millisecond resolution (i.e., when or in what order do cognitive processes occur). Therefore, converging evidence from other techniques is especially critical. For example, other psychophysiological techniques (e.g., event-related potentials or ERPs) offer excellent temporal resolution in tracking the engagement of cognitive processes. Ultimately, a converging methods approach that uses fMRI with a combination of techniques (e.g., psychophysiological measures that provide millisecond resolution, self-report surveys, and behavioral observation) is best to advance knowledge of communication-relevant processes and outcomes.

Ecological validity of the fMRI environment

Confining investigations to the laboratory, or more specifically inside an fMRI machine, leaves open the question of whether the psychological processes elicited in a lab/fMRI environment operate in a similar fashion within the real-world environment. For instance, participants are asked to lie down when inside an fMRI scanner and they are usually constrained from moving their heads. An emerging body of work has addressed this question by showing that neural activity in response to stimuli (e.g., persuasive messages) obtained from the fMRI laboratory can predict population-level outcomes of attitudes or behaviors in response to these stimuli when they are disseminated in the real world (Berns & Moore, 2012; Falk, Berkman, & Lieberman, 2012). These studies provide a method to link the psychological processes elicited in the laboratory to real-world environments (for a review, see Berkman & Falk, 2013).

Future developments

The field is rapidly evolving and new techniques in the design of fMRI studies and analysis of neural data allow scholars to ask new and different questions from the ones we mentioned earlier. One promising set of techniques involves examining the extent to which neural activity (and by extension, cognitive processes) in response to stimuli are *synchronized* across participants (Hasson, Nir, Levy, Fuhrmann, & Malach, 2004). Thus, in addition to asking whether a given task engages neural activity in brain region X, one can use fMRI to ask the separate question of whether the patterns of activity within a given brain region unfold in a similar manner (i.e., correlated time course) across participants. This set of tools is particularly relevant to communication scholars given emerging evidence that persuasive messages are associated with greater levels of neural synchronization across people (Schmalzle, Hacker, Honey, & Hasson, 2015).

A new set of analytical tools have also emerged that can allow fMRI researchers to examine interactions between distinct brain areas (Van den Heuvel & Hulshoff Pol, 2010). In particular, instead of mapping functions onto localized brain areas, these techniques often called "connectivity analyses" investigate the extent to which distinct neural regions connect, interact, and coordinate with each other to implement specific cognitive functions. This technique is particularly important given the emerging theoretical view that cognitive functions arise from dynamically configured neural networks (Bressler & Menon, 2010). Under this account, the role played by any given brain area, and the cognitive function it helps support, differs depending on the state of the network of which it is currently a part. This set of tools, along with others similar to it, is likely to help move the field away from thinking in terms of mapping functions onto localized brain areas.

SEE ALSO: Electrocardiography (ECG); Electrodermal Activity (EDA); Electroencephalography (EEG); Experiment, Laboratory; Experimental Design; Measurement of Affect/Emotion; Measurement of Attitudes; Measurement of Cognitions; Quantitative Methodology; Secondary Task Reaction Time

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Further reading

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