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On social neuroscience methodologies and their applicability to group processes and intergroup relations

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Abstract

Group processes and intergroup relations are one of the most important topics examined by social psychologists. Recent advancements in social neuroscience methodologies provide valuable insight into these processes by allowing researchers to examine different psychological phenomena via neural processes that instantiate them while individuals interact with ingroup and outgroup members. This includes responses that occur outside conscious awareness or are deemed undesirable to overtly express. The purpose of this review is to provide an overview of the different social neuroscience methodologies that afford these possibilities. Specifically, functional magnetic resonance imaging (fMRI), electroencephalography (EEG), functional near infrared spectroscopy (fNIRS), transcranial magnetic stimulation (TMS), and genetic approaches will be discussed. Each section includes a discussion of what the methodology is and how it is used to assess neural function. A secondary goal of the review is to highlight recent studies that have utilized the aforementioned tools to better understand intergroup processes and interactions. Throughout, advantages and limitations of each approach are discussed, particularly with respect to the study of group processes and intergroup relations.

Keywords

EEG, fMRI, fNIRS, genetics, group processes, social neuroscience, TMS

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Group processes and intergroup relations are one of the most important topics examined by social psychologists. To understand how individuals interact with others that are similar to or different from them is to understand the cornerstones of human society. Such knowledge provides insight at every level from small-scale to large-scale social networks. Traditional approaches to understanding intergroup relations have relied heavily on self-report and videotaping interactions. While there is no better way to examine individuals' meta-cognitive interpretations of interactions or impressions of others, these approaches are inherently at the

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mercy of the type of information a given individual understands or feels comfortable revealing about themself. With respect to perceptions of outgroup members or intergroup interactions, the type of information deemed worthy to share is particularly vulnerable to the individual's biases, motivations, and self-presentational concerns.

Advances in neuroscience methodologies over the past three decades have engendered a scientific revolution, including the birth of a new field: Social neuroscience. The field of social neuroscience involves the use of neuroscience methodologies to understand social psychological phenomena, particularly mechanisms or cognitive processes involved in social psychological topics of interest. The other contributions of the field stem from the fact that social psychological theory and methodologies can also reveal integral knowledge about neural function in general, particularly with respect to how different social contexts can engender dynamic and varied interactions between neural networks involved in perception, cognition, and emotion (Forbes & Grafman, 2013; Stanley & Adolphs 2013).

Importantly, social neuroscience methodologies can also provide valuable insight into group processes and intergroup relations. Specifically, neuroscience methods allow researchers to examine different psychological phenomenon via neural processes thought to instantiate them on-line, or while individuals interact with ingroup and outgroup members. Neuroscience methods also afford the possibility of examining responses to intergroup members that occur outside of an individual's conscious awareness or that they otherwise might not feel comfortable disclosing (e.g., visceral, negative affective reactions elicited in response to outgroup compared to ingroup members). Finally, neuroscience methodologies, particularly EEG, also allow researchers to examine the time with which different psychological processes unfold (on the order of milliseconds). This in turn can provide valuable insight into the degree to which given processes and mechanisms of interest occur more or less outside the conscious awareness of individuals (De Houwer, Teige-Mocigemba, Spruyt, & Moors, 2009).

Thus much can be gained from employing a social neuroscience approach to better understand group processes and intergroup relations. Recent advances in technology provide even better means for this as it has become increasingly possible to examine neural responses within the context of dyadic and group interactions. That is, researchers can examine brain–brain interactions while individuals interact with one another. The purpose of this review is to provide an overview of the different social neuroscience methodologies that afford these amazing possibilities. Specifically, functional magnetic resonance imaging (fMRI), electroencephalography (EEG), functional near infrared spectroscopy (fNIRS), transcranial magnetic stimulation (TMS), and genetic approaches will be discussed. Note that social endocrinology is also an important facet of social neuroscience research. For a comprehensive discussion of this approach see Page-Gould and Akinola (2015) in this special issue. Each section begins with a discussion of what the methodology is and how it is used to assess neural function. A secondary goal of the review is to highlight recent studies that have utilized the aforementioned tools to better understand group processes and intergroup relations. As such, each section contains a discussion of relevant literature. Throughout, advantages and limitations of each approach are discussed, particularly with respect to intergroup processes.

Functional Magnetic Resonance Imaging

Advancements in fMRI have almost singlehandedly fueled the social neuroscience revolution and our understanding of both the neural correlates of intergroup processes and how different group contexts alter neural function. fMRI provides an index of neural activation with excellent spatial resolution (i.e., where in the brain things are occurring), but the method itself is founded on a series of assumptions that are ultimately interpreted as evidence of neural activation in a specific neural region. The basic tenets of the fMRI methodology are as follows: A given task or

stimulus activates neurons within specific neural regions that are integral for the completion or perception of said task or stimuli. This increased local neural activity increases metabolic demand within that region. To account for this increased metabolic demand, the brain's default response is to flood the region with oxygenated hemoglobin; more oxygenated hemoglobin than is actually needed or consumed (it is still unclear why this happens). This surplus response results in unequal concentrations of oxygenated compared to deoxygenated hemoglobin in the neural regions involved in the task or perception of stimuli. That is, there are greater concentrations of oxygenated hemoglobin than deoxygenated hemoglobin in a given neural region.

The acquisition of the functional MRI signal is predicated on the concentrations of oxygenated compared to deoxygenated hemoglobin in a given neural region while an individual completes a task compared to when they are completing a task that does not involve the cognitive process of interest or they are at rest; hence the term blood oxygen level dependent (BOLD) signal. Ultimately, the concentrations of oxygenated and deoxygenated hemoglobin have different magnetic properties that release different energy profiles when excited by radio frequencies elicited by coils around an individual's head while they complete a task or are exposed to stimuli of interest. Concentrations of oxygenated hemoglobin within a predetermined sized cube (termed a voxel) at rest (or in the control conditions or blocks) are then contrasted with concentrations of oxygenated hemoglobin during the task of interest. Thus it is assumed that fMRI is an index of neural activation but obtainment of the BOLD signal is completely dependent on magnetic properties of oxygenated and deoxygenated hemoglobin.

The BOLD response itself is quite slow. Even the briefest of stimuli presentations will elicit a BOLD response that begins about 3–5 seconds after stimulus onset and takes 6–8 seconds to peak (Glover, 1999). This obviously poses an issue when designing fMRI experiments, thus careful planning is required to ensure that stimuli of interest are not presented in regular intervals with respect to one another. To account for these issues, two experimental design approaches are typically utilized: Blocked designs and event-related designs. In a blocked design, trials of similar type are lumped together and presented in succession over a specified length of time. For instance, if a researcher was interested in how the brain responds to the presentation of novel White compared to Black faces they would design the experiment such that all novel White faces were presented in one block and all Black faces were presented in another block. Conversely, event-related designs present stimuli in close temporal proximity with one another but utilize pseudorandom intertrial intervals (termed jitter) or optimized trial order to accurately estimate the BOLD response to stimuli of interest. With respect to the previous example, this means that both novel White and Black faces can be presented in the same block, assuming an appropriate jitter within and between the different face types are utilized. Event-related designs are the dominant design used by social neuroscientists currently (for a detailed review of the fMRI methodology see Berkman, Cunningham, & Lieberman, 2014).

Regarding data collection itself, typically anatomical scans are collected at the beginning of an experimental session. Once participants begin a task, whole brain functional scans or volumes are collected approximately every 2 seconds. These functional scans are then compiled postexperiment and run through a series of preprocessing procedures that allow researchers to examine the BOLD response in one brain to other brains within and between conditions of interest. These preprocessing procedures consist of a number of cleaning, shuffling, and normalizing steps that ultimately allow one to compare multiple volumes within an individual session to the volumes collected from another person or session that is possibly much different on a number of parameters (e.g., size and shape of brain; Berkman et al., 2014).

Once data is preprocessed it is typically analyzed via a general linear model. The first level of

the model accounts for the within-subject components of fMRI designs (e.g., the timing of the trials, trial types, subject motion, etc.) by generating a predicted BOLD response for each voxel that comprises the relationship between the within-subject components and a canonical hemodynamic response function. These predicted BOLD responses are then included as regressors in a multiple regression model designed to predict the observed BOLD response. The association between the predicted and observed BOLD response results in a beta weight and corresponding *t*-value for every voxel (usually about 3 mm^3 in size) representing the entire brain (Berkman et al., 2014; Huettel, Song, & McCarthy, 2008).

Condition effects are necessarily evaluated via contrasts between conditions of interest. For instance, in the previous example we could compare beta weights associated with Black faces to beta weights associated with White faces, that is, conduct a Black face > White face contrast, to determine which voxels in the brain significantly differ from one another when individuals are exposed to Black faces compared to White faces. This approach represents the dominant paradigm used by researchers and lays the foundation for more complex analyses that examine functional connectivity between brain regions, brain regions that may correlate with psychological variables of interest (termed parametric modulation), or more advanced machine learning approaches referred to as multivoxel pattern analysis (aka MVPA, but note that MVPA can also be conducted on more raw signal as well; Huettel et al., 2008).

The second level of analyses takes all of the information derived from the first level of analysis and allows for comparisons to be made across the brain (i.e., every voxel in the brain) at the group level. The primary means of comparison are *t*-tests and correlations, which normally would yield a substantial Type I error rate given the number of voxels involved in analyses. However, statistical thresholding is typically applied in conjunction with a priori requirements for cluster sizes (i.e., requiring a specific number of contiguous voxels in a given anatomical region to be statistically different in one condition compared to another) in an effort to optimize the ability to detect true effects while minimizing Type I error rates (Berkman et al., 2014; Huettel et al., 2008).

Given its popularity, much has been learned about group processes and intergroup relations via fMRI. Most fMRI-based research pertinent to intergroup processes has revolved around perceptions (including cognitive, emotion, and motivational based) of ingroup and outgroup members (e.g., Cunningham et al., 2004; Forbes, Cox, Schmader, & Ryan, 2012; Harris & Fiske, 2006; Lieberman, Hariri, Jarcho, Eisenberger, & Bookheimer, 2005; Phelps et al., 2000; van Bavel, Packer, & Cunningham, 2008), self-regulation evoked by the presence of, or after interacting with, ingroup and outgroup members (e.g., Richeson et al., 2003), taking the perspective of others or mentalizing (van Overwalle & Baetens, 2009) and predicting others' behaviors with respect to stereotypes or via personal experience (Frith & Frith, 2006; Mitchell, Banaji, & MacRae, 2005). These studies have revealed that perceptions of outgroup members are biased at very early stages of information processing and throughout the information-processing stream and are typically more negative in nature (e.g., fear-based responses as indexed by the amygdala). This basic negative response, in turn, recruits more effortful self-regulatory processes that are metabolically demanding and finite in nature (e.g., increased activity in dorsolateral prefrontal cortex, a region integral for executive function and down-regulating amygdala-based arousal), particularly among individuals with egalitarian motivations, which ultimately engender more negatively biased perceptions and behaviors over time (e.g., Cunningham et al., 2004; Forbes et al., 2012).

When asked to take the perspective of others, fMRI research suggests that similar others evoke activation in similar regions of medial prefrontal cortex (mPFC) that are integral for self-oriented processing (Mitchell et al., 2005). This suggests that when individuals are asked to infer the attitudes and attributes of similar others, they literally use the same parts of their brain that they use to infer their own attitudes and attributes. Conversely, inferring attitudes and attributes of

dissimilar others, for example, outgroup members, evokes activity in a different region of mPFC, possibly a region involved in storage of social semantic information (e.g., stereotypes) that is retrieved when individuals are asked to predict what novel outgroup members think and feel. Importantly, fMRI research has also revealed that these perceptions, and the neural activity that instantiates them, are flexible and can be altered with simple recategorization procedures like those utilized in minimal group paradigms (Van Bavel et al., 2008).

Another fMRI-based approach that has been utilized to inform our understanding of the neural correlates underlying dyadic interactions is referred to as hyperscanning. Hyperscanning involves placing two or more individuals in separate scanners and having them interact via an intercom system or even on-line from different locations. Each individual's BOLD signal is recorded in response to stimuli of interest or during various aspects of the interaction. While this approach has understandably been less utilized due to sheer cost and limitations in infrastructure and resources, hyperscanning studies have revealed that individuals' neural responses are highly attuned to one another when they engage in activities like playing economic games with one another or watching movies together (e.g., Hasson, Nir, Levy, Fuhrmann, & Malach, 2004; Montague et al., 2002). For instance, Hasson et al. (2004) had five participants freely watch a movie together while functional images were obtained from each individual. Results revealed large-scale synchronization between participants within visual, auditory, and association cortices, including during emotionally arousing scenes. That is, neural activity elicited in these regions during these scenes within each participant was correlated across participants.

While fMRI is an integral tool for understanding neural function, it does have certain limitations that are important to consider. One obvious limitation is poor temporal resolution. However, employing event-related designs that can account for the sluggishness of the BOLD response, as well as recent advances in multiband imaging, help alleviate this concern substantially. Another issue concerning fMRI is whether increases in BOLD activation index increases in excitatory neurons or inhibitory interneurons (i.e., the "gas" and "breaks" of the brain respectively). While it is typically assumed that increases in BOLD signal reflect increased activity or processing in a given neural region (i.e., greater excitatory neuron activity), it is not entirely possible to determine this with current technology. Nevertheless, as technology advances and magnets get stronger (i.e., have greater Tesla values) it should be possible to not only see which regions are active, but to see which layers of cortex are active as well (and thus whether excitatory neurons or inhibitory neurons are more active given their differential representation in different layers of cortex). As analytic approaches to understanding neural function become increasingly complex, researchers have also become interested in not only regional activity but how regions interact with one another to form networks. As such, it's worth questioning whether it is better to index these network interactions via the BOLD response or via the actual units of communication in the brain: neurotransmitters, electric signals, and subsequent neural oscillations. One solution for this again lies with technological advancements as it is now possible to assess the BOLD response in conjunction with both EEG and radioactively labeled molecules injected in the bloodstream that are metabolized in the brain. That is, there are a number of scanners on the planet that combine fMRI with positron emission tomography (PET) that can be used in conjunction with fMRI compatible EEG systems to track, and ultimately associate, most of the relevant neural processes one would need to assess large-scale network interactions.

Another complicated issue facing imagers in all disciplines (although the field of social neuroscience appears to bear the brunt of this criticism) concerns various analytic approaches employed in fMRI research. In 2009, social and affective neuroscientists came under attack for what appeared to be "puzzlingly high" or "voodoo" correlations in social and affective fMRI

studies (Vul, Harris, Winkielman, & Pashler, 2009). Vul et al. (2009) argued that fMRI studies of emotion, personality, and social cognition specifically would often report correlations between brain activation and behavioral measures that exceeded .80. One reason for this occurs when fMRI researchers assess whether correlations exist between any voxel in the brain and their behavioral measure of interest. Given the sheer number of voxels and thus tests conducted, it's possible that researchers detect those regions that by chance contribute the highest levels of signal and/or noise that in turn are correlated with the behavioral measure of interest. If researchers only report the highly significant relationships, then we might expect highly inflated correlations that yield meaningless effect size estimates and scatterplots that appear far more uniform than they would be otherwise.

Another possibility for exceedingly high correlations occurs if fMRI researchers find a specific region of the brain where activation differs between conditions in the entire sample, isolate activation in that region of the brain (termed region of interest or ROI analyses), and then assess whether correlations exist between activation in the ROI and a behavioral measure of interest. This "double dipping" will often yield a significant relationship between neural activation and a behavioral measure simply because of preexisting differences in neural activity inherent between the conditions of interest (Kriegeskorte, Simmons, Bellgowan, & Baker, 2009). That is, significant correlations could ultimately be the result of nonindependent analyses.

Solutions for these issues are difficult given the number of tests required by fMRI analyses and myriad ways researchers can probe for relationships. Nevertheless, they do exist. One obvious solution is to base ROI analyses exclusively on a priori hypotheses. This approach is increasingly feasible given recent technological advances that allow researchers to conduct instantaneous meta-analyses among thousands of fMRI studies that identify neural regions commonly implicated in psychological phenomena of interest (e.g., via neurosynth.org). Another possible solution is to probe for correlations between voxels and behavioral measures of interest on a subset of data, or via a pilot study, and then test whether these relationships exist in the untested, that is, independent, sample data or follow-up study. Preregistration of hypotheses and analytic strategies could also help, as journals such as *Cortex* currently allow for. Of course, there is never a substitute for replication, larger sample sizes, and utilizing sensible analytic strategies whose strengths and shortcomings are well established in the literature and that are most appropriate for a given research question. Ultimately it is becoming increasingly clear that researchers need to establish standards of operation for the field that many will willingly comply with.

Despite these issues, future research will undoubtedly incorporate more sophisticated methodological and data analytic approaches to better understand just how in tune individuals' brains are with one another. Of particular interest to intergroup processes will be identifying the conditions under which this synchronization is present, as well as the conditions under which it is not. While advances in hyperscanning provide more external validity for findings associated with intergroup processes, it should be noted that fMRI studies are inherently less externally valid given the aberrant and novel situations that the fMRI methodology requires (i.e., placing individuals in a small tube that elicits really loud noises). The next neuroscience methodology discussed, EEG, helps address this concern but, as we'll see, carries its own issues with it as well.

Electroencephalography

EEG recordings represent the oldest form of neuroimaging. EEG is the assessment of voltage fluctuations in large-scale, synchronous neural activity that manifest at the scalp (Buzsaki, 2006; Kappenman & Luck, 2011). While still not clearly understood, the EEG signal recorded at the scalp likely stems from a large-scale summation of postsynaptic potentials in cortical pyramidal cells in multiple generators (i.e., different regions in the brain) that are influenced by subcortical regions

like the thalamus and hippocampus, which have extensive connections with cortical neurons (Buzsaki, 2006; Kappenman & Luck, 2011). Raw EEG signal contains both a time and frequency (i.e., the number of oscillations or sine wave peaks per second) domain, meaning the EEG signal contains valuable information pertinent to the time at which dynamic neural processes unfold as well as the extent to which different populations of neurons oscillate in unison with one another both locally and over longer distances. The temporal resolution of EEG is what really sets it apart from other neuroimaging techniques, however, as samples of neural activity can be collected as often as every 5 ms (contrasted with seconds when dealing with fMRI, although recent advances in multiband imaging have narrowed that gap). Furthermore, advances in EEG signal processing provide a means to directly assess large-scale neuronal interactions across large areas of cortex on the order of milliseconds. This provides researchers with exciting possibilities to better model the inherent complexity involved in the neural interactions between multiple brain regions that likely instantiate a given social cognitive construct or process of interest.

Raw EEG signal is typically averaged over chunks of time and analyzed with respect to specific stimuli or events of interest. To this end, event-related potentials (ERPs) are by far the dominant approach used to analyze continuous EEG activity with respect to psychological processes. In a typical ERP paradigm, stimuli of interest are presented to participants many times over (e.g., at least 20 times) in hopes of optimizing the ability to extract signals of interest from spontaneous neural activity that may or may not be associated with said signals. Epochs (or chunks of time) are then averaged together, artifacts (e.g., eye blinks and muscle activity) are removed and the signal is filtered (e.g., any activity with frequencies below .5 Hz or above 30 Hz is removed). Then the new average waveforms in an experimental condition are averaged together with other subjects in the same condition to create a grand average waveform that is compared to the grand average waveform from a control condition. Peaks, which can be positive or negative in valence, observed at different points in time in different areas of the scalp have been mapped onto different psychological processes, particularly those relevant to basic perceptual processes, attention, memory, or emotion. The amplitudes of these peaks are operationalized with respect to whether they are positive or negative in valence and what point in time they occur. For example, a positive potential occurring approximately 100 ms after a response would be referred to as P100 (but note that *the* P100 refers to a positive potential that occurs approximately 100 ms poststimulus in occipital and parietal channels). A negative potential during this same time period would be referred to as N100. The peak of an amplitude, area under the curve, or average microvolts over a given time span are often used as ways to quantify ERPs. These values are used as an index of an increase or decrease in a psychological process of interest, with the assumption being that neural activity within regions of the brain involved in said process changes and engenders the change in signal accordingly.

ERPs themselves are ultimately comprised of both increases in power, that is, the extent to which populations of neurons fire in synchrony at specific frequencies in multiple neural generators across the brain, and phase-resetting dynamics, that is, the extent to which populations of neurons that fire in phase with one another reset their oscillations in response to stimuli of interest (Trujillo & Allen, 2007). Thus, as opposed to fMRI, it's difficult to isolate where in the brain given potentials are stemming from, and it's quite difficult to isolate what precise regions of the brain are contributing to a given psychological process. Nevertheless, decades of corroborating research have identified many ERP components that are reliable predictors of given psychological phenomenon (e.g., the P100 and perception or error-related negativity and conflict detection). This provides researchers with the ability to reliably and noninvasively monitor both implicit and explicit psychological phenomena of interest, on-line, or while individuals complete a given task.

It is important to note, however, that continuous EEG activity through which ERPs are obtained contains a wealth of information that is ultimately discarded during preprocessing stages of ERP analyses. Part of this is intentional, as the brain is quite noisy; among other things the brain is constantly engaged in (a) spontaneous, intrinsic processes that are orthogonal to the environment, (b) preparatory and anticipatory processes that are associated with experimental manipulations and attempts to predict future outcomes, and finally (c) activity that is specific to experimental stimuli of interest (Cohen, 2013; Kappenman & Luck, 2011). Inherent in this process is a focus on the time domain that comes at the expense of the frequency domain. This is unfortunate as many argue that much can be gleaned from analyses of neural oscillatory activity, including power, the extent to which neurons in different neural regions communicate with one another (termed phase locking, which is a measure of the extent to which neurons in different regions of the brain fire at the same point in time and angle, or in phase, at specific frequencies), and possibly whether excitatory neurons or inhibitory interneurons are more or less active (Buzsaki, 2006). Thus it has been deemed increasingly important to conduct time-frequency analyses in addition to ERP analyses in hopes of more fully understanding the nature of the brain (Makeig & Onton, 2011). Indeed, time-frequency analyses provide a more comprehensive assessment of neural activity that may instantiate both neural function and psychological processes in general (Cohen, 2013).

EEG studies have provided valuable insight into intergroup processes and basic intergroup perceptual processes specifically. For instance, research on a component referred to as the N170, which may reflect activity in the fusiform face area (a region of the brain involved in basic face perception processes; Cunningham, van Bavel, Arbuckle, Packer, & Waggoner, 2012; Herrmann, Ehlis, Muehlberger, & Fallgatter, 2005), indicates that face perceptual processes are dynamic, flexible, and particularly sensitive to ingroup status and individual differences in bias (Cunningham et al., 2012; Freeman, Ambady, Midgley, & Holcomb, 2011; Ito & Urland, 2005; Ofan, Rubin, & Amodio, 2011; Ratner & Amodio, 2013). Examining neural activity in regions involved in the mirror neuron system—that is, a collection of regions that are involved when executing actions and viewing the actions of others—via EEG also provides insight into the extent to which individuals perceive others as similar or as someone they identify with at a fundamental level. For instance, Gutsell and Inzlicht (2010) examined individuals' oscillatory activity over motor cortex (a key region in the mirror neuron system), in the alpha frequency band (which is referred to as mu when discussing activity in this frequency band in motor cortex specifically), while they viewed ethnic ingroup and outgroup members perform different actions, or performed the actions themselves. Findings revealed that individuals elicited increased activity over motor cortex when performing an action or watching an ethnic ingroup member perform the action. When viewing ethnic outgroup members perform the action, however, this increase in motor cortex, that is, mirror neuron, activity, was less evident. Furthermore, this effect was exacerbated among individuals who were more explicitly prejudiced. Thus the distinction between ingroup and outgroup, and the exacerbation of this distinction via top-down prejudiced beliefs, appears to manifest even within a neural network that arguably has served as the foundation of social interaction and learning over the course of our species' evolution.

Hyperscanning-like approaches have also been employed using EEG methodologies, but with much greater external validity given the ability to assess EEG on-line while individuals interact face-to-face with one another. For instance, Dumas, Nadel, Soussignan, Martinerie, and Garnero (2010) had two individuals interact with one another while continuous EEG activity was recorded simultaneously from both individuals. In each session, one participant was assigned to be the model of a given behavior (hand movements) and one was assigned to be the imitator. Results revealed that states of interactional synchrony

(when imitators were imitating models' behavior) were associated with increased synchrony in the alpha (or mu) frequency band over right centroparietal regions, likely reflecting activity from the mirror neuron system. These findings mirrored those from previous studies (e.g., Tognoli, Lagarde, DeGuzman, & Kelso, 2007).

Highlighting the potential for EEG in informing our understanding of both neural synchrony processes in dyadic interactions as well as how interactions between neural networks modulate these processes, Astolfi et al. (2010) recorded continuous EEG activity simultaneously in four partners (two of which were on the same team) while they played a card game with one another. Modeling neural activity in regions of interest, including anterior cingulate cortex (ACC) and dorsolateral prefrontal cortex (DLPFC), and then conducting both Granger causality analyses and graph theoretical analyses to model network activity within each partner, findings revealed two fascinating events: (a) functional connectivity within individuals' regions of interest were only associated with their teammates, that is, individuals did not exhibit any kind of neural network synchrony between members on the opposing team, and (b) Activity in one teammate's DLPFC on one trial of the game predicted activity in the other teammate's ACC on the next trial while playing the card game together. As these two regions have been implicated in more top-down (DLPFC) and bottom-up (ACC) executive function and attentional processing, these findings hint at an intriguing and intimate relationship between one individual's initial attempt to relay a given thought or strategy to their partner who must ultimately interpret what idea their partner is trying to convey.

While EEG provides provocative and boundless potential for researchers it certainly comes with its own set of liabilities. The biggest issue with EEG methodology is its poor spatial resolution. The spatial resolution of EEG pales in comparison to fMRI and given the inverse problem, that is, the fact that there is so much information that comes from the brain, from medial temporal regions onward and outward towards the outer limits of cortex, almost an infinite number of solutions can be derived when trying to ascertain where specific neural generators stem from (Cohen, 2013). One can think of it as throwing millions of pebbles into a pond and trying to isolate a specific ripple associated with a specific pebble. Nevertheless, advances in source localization analyses provide some hope for circumventing this issue. Indeed, it is possible to reliably isolate signals stemming from neural generators that are closer to the scalp, particularly when high-density arrays are utilized, researchers account for such factors as scalp thickness and age of the participant and one has a priori hypotheses based on either past fMRI studies or combined EEG/fMRI studies (Grech et al., 2008).

In sum, as evidenced by Astolfi et al. (2010), EEG has arguably the greatest potential for informing the complex relationship between intergroup interactions and the neural processes that both instantiate and modulate them. EEG systems have become portable and wireless as well, allowing for greater external validity in addition to real-time monitoring of neural and psychological processes during multipartner interactions. Nevertheless, the poor spatial resolution of EEG does place a ceiling on this potential, at least for the time being. Perhaps the optimal compromise are studies that employ a combined EEG and fMRI approach, but this still involves obtaining neural estimates from individuals in conditions with suboptimal external validity (i.e., in a small tube inside a giant magnet).

Functional Near Infrared Spectroscopy

Another neuroimaging methodology that is used much less extensively in social neuroscience studies is referred to as fNIRS. The exception to this is when more difficult populations are the targets of interest in the investigation (e.g., infants). The fNIRS approach consists of placing something like a headband on top of individuals' heads over brain areas of interest. The headband itself contains both light emitting diodes that elicit light at

near-infrared wavelengths and optical sensors. Essentially, light emitting diodes elicit light beams at near-infrared wavelengths millimeters into cortex (i.e., the very top layers of cortex), which then differentially reflect off of (or are absorbed by) oxygenated and deoxygenated hemoglobin molecules in active areas of cortex. These reflected light waves then travel back to the scalp where optical sensors calculate changes in oxygenated, deoxygenated, and total hemoglobin molecule concentrations (Lloyd-Fox, Blasi, & Elwell, 2010).

fNIRS is similar to fMRI in that it measures the hemodynamic response, however it differs from fMRI in that it (a) provides an estimate for oxygenated, deoxygenated, and total hemoglobin concentrations, (b) has much better temporal resolution, allowing for real-time assessment of the hemodynamic response (upwards of 10 Hz), (c) it's highly mobile, (d) it does not require subjects to sit in small, enclosed, and noisy environments (i.e., subjects can be seated in normal positions) and (e) it is much less expensive compared to fMRI research (Ding, Fu, & Lee, 2014). fNIRS does not, however, provide remotely comparable degrees of spatial resolution compared to fMRI. Whereas fNIRS' spatial resolution is more akin to EEG, its temporal resolution is not. Furthermore, it faces the same concerns as fMRI in that it doesn't serve as a direct index of neural activity. Finally, in light of current fNIRS technology, it would be particularly difficult to assess large-scale neuronal interactions across large swaths of cortex in the way EEG and fMRI allows for (Lloyd-Fox et al., 2010). So the fNIRS approach ultimately represents an interesting middle ground between fMRI and EEG methodologies (although in the end it is far more similar to fMRI given its index of the hemodynamic response) that can be a suitable compromise when questions of interest revolve around more difficult populations.

Regarding intergroup processes, much less research has been done with fNIRS but the approach has been effectively used to better understand elements of dyadic interactions. Suda et al. (2010) recorded fNIRS activity from one participant while they conversed with an interviewer (sitting face-to-face with the interviewer). Findings revealed that conversing with others elicited increased activity in frontopolar cortex and superior temporal regions, two regions that have been identified as integral for higher order social cognitive processing. Cui, Bryant, and Reiss (2012) employed an fNIRS-based hyperscanning approach to examine neural synchrony between two partners sitting side by side while they played a cooperation game on computers. Results revealed that increased coherence between partners' right superior frontal cortices was evident on trials in which partners cooperated but not on trials where they competed with one another. Furthermore, better cooperation performance was evident to the extent partners exhibited synchrony between these neural regions.

Overall, fNIRS represents an underutilized, undervalued approach to informing our understanding of the neural correlates and psychological mechanisms involved in intergroup interactions, as well as the field of social neuroscience in general. It is almost completely noninvasive, highly mobile, takes little time to set up, and appears robust to external influences, that is, artifacts that could distort signal. All of these factors are ideal with respect to dyadic interactions and desires for more external validity. As the study by Cui et al. (2012) indicates, it is fairly fast and easy to place two individuals in front of one another and track their neural activity while interactions unfold. Findings from fNIRS studies are also highly compatible with fMRI studies given their common assessment of the hemodynamic response in neural regions of interest (i.e., findings from fNIRS can be directly associated with findings from fMRI studies) but for a fraction of the cost. Whether these advantages are recognized and utilized in intergroup studies in the future will likely depend on methodological advancements and recognition for the approach, but it will also depend on researchers' specific questions and interest in brain regions close to the cortical surface.

Transcranial Magentic Stimulation

TMS is a noninvasive brain stimulation method that has gained popularity over the past decade as a means to create interference, or a "virtual lesion," in cortical brain regions closer to the scalp (Reis et al., 2008; Walsh & Cowey, 2000). This approach is appealing because it affords the possibility of examining possible cause–effect relationships between activity within a specific neural region and behaviors of interest. TMS relies on Faraday's principle of electromagnetism, that is, when an electrical current is passed through one coil it produces a magnetic field that causes a current to flow in a second coil; in this case the second coil is the brain and the induced electric field promotes neuronal activity that ultimately engenders disorder or noise in a neural region involved in a specific cognitive task (Walsh & Cowey, 2000). The temporal and spatial resolution of TMS is more difficult to ascertain in relation to fMRI and EEG because repetitive TMS pulses (termed rTMS) instantaneously affect many neurons within a given region that then recover at different rates. Nevertheless spatial and temporal resolution appears to be on the order of a few millimeters and tens to hundreds of milliseconds respectively (Walsh & Cowey, 2000). One interesting way of utilizing TMS methodologies of late has been to examine them with respect to EEG and fMRI, that is, by employing virtual lesions in individuals and then assessing how these lesions alter oscillatory and functional network neural processes indexed by EEG and fMRI (Ruff, Driver, & Bestmann, 2009; Thut & Miniussi, 2009).

Another popular use of TMS is in assessing motor cortical activity via motor-evoked potentials (MEP). In a typical experiment, the TMS coil is positioned directly over individuals' motor cortex and electrodes are placed over the abductor pollicis brevis (APB; a muscle extending from the thumb) on an individual's hand. TMS pulses are then delivered to the motor cortex during time points of interest. Neural activity engendered by the TMS pulse is then relayed via motor neurons to the contralateral side of the body (i.e., the opposite side of the body in relation to the hemisphere where the TMS pulses are delivered) which then causes the APB muscle to contract. This contraction comprises the MEP. Importantly, the degree to which the motor cortex is active in a given moment is directly reflected in the amplitude of the MEP such that greater motor cortex activity results in larger MEP amplitudes. Given that the motor cortex is involved in planned actions/movements, the mirror neuron system, and even reward processing, this approach provides an intriguing way to examine neural processes associated with important cognitive and social phenomena almost instantaneously. This includes the extent to which individuals are more attentive to or receptive of others (see the discussion of Obhi, Hogeveen, & Pascual-Leone, 2011, in the following lines).

Specific to intergroup relations and group processes, the crux of social neuroscience studies that employ TMS methodologies reveal that medial and lateral frontal cortex are particularly important for self and higher order social processing. For instance, Kwan et al. (2007) administered TMS to medial frontal cortex and then asked individuals to rate themselves on a number of desirable and undesirable traits compared to their best friend. Findings revealed that disrupting local activity in medial frontal cortex reduced the degree to which participants rated themselves more positively than their best friend (i.e., were less likely to self-enhance) compared to a sham and other lesion conditions (groups that had TMS administered to parts of the brain not thought to be involved in self-oriented processing). Knoch, Schneider, Schunk, Hohmann, and Fehr (2009) found that disrupting individuals' lateral prefrontal cortex via TMS diminished their ability to act in a reputable manner during a trust game despite demonstrating a knowledge of how they should behave (i.e., in a reputable manner).

Demonstrating the potential for informing our understanding of mirror neurons and intergroup processes via the MEP approach just described, Obhi et al. (2011) primed individuals with independent- or interdependent-related words and

then examined mirror neuron activity via MEPs elicited while individuals viewed novel others perform motor actions (e.g., squeezing a ball). They hypothesized that priming an interdependent schema would cause individuals to be more attuned to others and would thus yield greater mirror neuron activity when viewing others' behaviors. Results supported their predictions as individuals primed with interdependent words evoked greater MEPs in response to others' actions compared to those primed with independent words. Such studies provide novel insight into the complex interactions between group and self-based schemas, neural regions involved in executive function, self-processing and the mirror neuron system, and how these processes interact to guide perception and behavior accordingly.

Thus as a methodology TMS appears to have no problem yielding provocative findings. It represents one of the only ways to study causal relationships between neural function, cognition, and behavior. Nevertheless, the suboptimal spatial and temporal resolution that TMS yields requires results to always be interpreted with caution. The degree to which TMS can provide insight into large scale neural network dynamics is also questionable at best. Similar to all methodologies discussed thus far, however, these limitations are currently being addressed by combining methodologies, for example, combined EEG-TMS studies and fMRI-TMS studies are becoming increasingly common.

Genetics

Moving away from more temporally and spatially precise indices of neural function, the field of genetics has grown immensely in popularity in recent years as a methodological approach to understanding intergroup processes/dyadic interactions. Indeed, advances in DNA extraction and gene isolation methods have led to a dramatic increase in the number of social neuroscience studies that include genetic variables. These advances, stemming largely from the genome project funded through the National Institutes of Health in the early 2000s, have provided researchers with the ability to conduct large-scale genetic analyses that are relatively easy and affordable. Genetic samples are typically collected via blood samples or cheek swabs and can either be frozen or stored in dry climates at room temperature. Laboratories that have the capacity to perform polymerase chain reactions (PCR), the technique used to sequence the genome, can then be hired to sequence researchers' genes of interest, or of course researchers can sequence the genes themselves if they are willing and able. Given this, our understanding of how single nucleotide polymorphisms (SNPs), or common variations in the DNA code in a given gene, modulate both neural function and cognitive processes has increased dramatically in recent years.

For instance, the brain-derived neurotrophic factor (BDNF) gene plays an integral role in the promotion of neuroplasticity in the brain, being linked to the regulation of synaptic connections (Huang & Reichardt, 2001), neural growth (Binder & Scharfman, 2004; Leibrock et al., 1989), and synaptic plasticity (Lu, 2003; McAllister, Lo, & Katz, 1995). Specifically, BDNF is involved in the apoptotic process, or programmed cell death, of neurons in the brain. Apoptosis is a normal and necessary function of cellular maintenance (including neurons), and without it neural assemblies within a given region of the brain would cease to function properly (Krueger et al., 2011). Among normal populations, the BDNF gene can contain a SNP on codon 66 of the gene that codes for a valine-valine (Val-Val) amino acid pair. This Val-Val pair, in turn, has been associated with better neural plasticity and connectivity between different brain regions, including increased gray matter volume and neural growth within prefrontal cortex (Dempster et al., 2005; Egan et al., 2003; Hariri et al., 2003; Ho et al., 2006; Tan et al., 2005). As such, the Val-Val SNP has been associated with enhanced global cognitive functions such as general intelligence (Barbey et al., 2014), memory (Egan et al., 2003), and more efficacious extinction of fear-conditioned responses (Soliman et al., 2010), presumably because the neural regions thought to underlie these processes are better

connected with one another. Conversely, another variant of the BDNF gene codes for the amino acid methionine (Met) in place of one or both of the valine molecules (known as Met-Val and Met-Met respectively) on codon 66 of the gene. These SNPs appear to interfere with neural apoptotic processes in healthy populations and have thus been associated with impairments in episodic and working memory and executive function (Rybakowski, Borkowska, Czerski, Skibinska, & Hauser, 2003; Rybakowski, Borkowska, Skibinska, & Hauser, 2006).

In one interesting example of the role different BDNF SNPs may play in the expression of intergroup bias, Forbes et al. (2012) found that lesion patients with varied degrees of intact medial and lateral PFC regions and BDNF SNPs behaved differently on measures of implicit and explicit gender bias. Patients with Met-Val SNPs, which actually provide recuperative advantages in damaged brains, exhibited less implicit bias when more of their orbitofrontal cortex (OFC) was intact and less explicit bias when more of their DLPFC was intact compared with Val-Val patients with comparable lesions and those with large OFC and DLPFC lesions. This relationship didn't exist in other PFC regions. These results identify causal roles for OFC and DLPFC in the inhibition of implicit and explicit bias respectively and also suggest that neuroplasticity *within* these regions modulate individuals' ability to inhibit psychometrically orthogonal forms of bias. Findings also suggest that genetic SNPs that modulate neural plasticity may provide a mechanism for individual differences in the expression of bias and the representation and expression of social knowledge.

Specific to intergroup processes, oxytocin, serotonin, and monoamine oxidase A (MAOA) SNPs have been shown to moderate trust- and bias-oriented behaviors both in the moment and over time. For instance, past research linked different SNPs of the oxytocin receptor gene to more or less trusting behavior during a standard trust game (Krueger et al., 2012) as well as chronic levels of distrust among those with a history of childhood neglect (McQuaid, McInnis, Stead, Matheson, & Anisman, 2013). With respect to intergroup bias, in addition to oxytocin (e.g., De Dreu, Greer, van Kleef, Shalvi, & Handgraaf, 2011), serotonin and MAOA SNPs have also been associated with ethnic bias, aggression, and bias in minimal group paradigms (Cheon, Livingston, Hong, & Chiao, 2013; Schwartz & Beaver, 2011). For instance, in a longitudinal study Schwartz and Beaver (2011) found that one MAOA SNP predicted more aggressive behavior in males (operationalized as number of criminal arrests) to the extent these individuals reported experiencing more prejudice during their life. Such findings highlight the inherent complexity in genetic studies: (a) Many genetic SNPs may influence a specific behavior and (b) myriad environmental factors may interact with different genetic predispositions to moderate the effects of the expression of a given gene on a given behavior.

As such, many rightfully argue that great care should be taken when interpreting findings from social neuroscience studies that include genetic variables (e.g., Ratner & Kubota, 2012). One chief concern is that genetic studies typically require large samples (e.g., 500 individuals or more) in order to adequately represent the sheer diversity of different genetic SNPs in a given population. Furthermore, the genome is so incredibly complex, including genes that can directly or indirectly be involved in transcription of myriad proteins, are dormant or "junk" DNA, or can differentially influence physiological processes in different environmental conditions, that one should always question just exactly how much influence one SNP on one gene might have in any given neural function, cognitive process, or behavior. Nevertheless, findings from genetics studies suggest that genetic SNPs play an integral role in cognition, behavior, and the moderation of intergroup processes. Indeed, in conjunction with environmental factors (both situational and longitudinal), genetic SNPs could one day represent the great moderator of many of the individual differences in intergroup processes and behaviors that social psychologists observe in the laboratory.

Conclusions and Future Directions

The field of social neuroscience is in a nascent stage but it is already making great contributions to the study of group processes and intergroup relations. To the extent we can infer psychological processes from neural function, much of these contributions stem from the ability to track responses to stimuli and others on-line while individuals interact with others on the order of milliseconds. This allows researchers to circumvent self-report measures that may be susceptible to demand characteristics and self-presentation concerns, which is particularly advantageous when dealing with socially sensitive topics. This is particularly true in the study of prejudice, where otherwise egalitarian-minded individuals show evidence of basic fear responses towards outgroup members (Cunningham et al., 2004; Forbes et al., 2012; Phelps et al., 2000) that are difficult to extinguish (Olsson, Ebert, Banaji, & Phelps, 2005), and possibly even comparable to disgust when specific to the disenfranchised or highly stigmatized in our society (Harris & Fiske, 2006). Such neural responses towards others provide a more nuanced account of the cognitive and emotional conflict that may arise whenever individuals encounter novel outgroup members and likely reflect responses that individuals are either unwilling or unable to report or conceptualize (Nisbett & Wilson, 1977).

This review has provided an overview of the tools social neuroscientists have at their disposal and how they work. Each methodology has their advantages, but they also most certainly have their limitations. As such, researchers should always proceed with caution when either utilizing neuroscience methods for their own research or interpreting findings yielded by the different approaches. Future research will undoubtedly yield convergence on different methodologies in more externally valid contexts, for example, studies will (and have been) combining EEG with fMRI, fNIRS, and TMS to optimize temporal and spatial resolution of neural phenomena of interest. The latter approaches also afford the possibility of examining these processes in the context of multiple individuals interacting with one another. Such approaches will be necessary to employ in conjunction with genetic assessments in hopes of more adequately capturing the degree of complexity inherent in brain–mind–body–environment interactions. Of course this complexity is rivaled only by that found in the psychology involved in dynamic interactions between ingroup and outgroups members, meaning social psychologists and neuroscientists have a tough road ahead of them to say the least. Nevertheless, as technology and analytic approaches evolve, so too will our understanding of how brains and genes form the foundation for group processes and intergroup relations.

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