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REVIEW ARTICLE

The emerging Frontier of interpersonal communication and neuroscience: scanning the social synapse

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ABSTRACT
Humans are inherently social, driven to communicate and build relationships with one another. The question of how messages between people create shared understanding lies at the core of interpersonal communication. Relatedly, neuroscience scholars are beginning to investigate how dyads, i.e. two socially interacting brains, produce this shared understanding. Here, we argue that interpersonal communication has much to contribute to this rapidly growing area within neuroscience, while also benefiting from adopting neuroscientific approaches. We illustrate what such research looks like using reactance as a case example. While we are optimistic that neuroscientific research into interpersonal communication processes will grow and yield new insights into communication processes, we will also discuss challenges and potential misunderstandings that researchers may encounter.

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Interpersonal communication is central to our lives as humans (Berger et al., 2016). Interpersonal communication allows for the development and maintenance of relationships (Canary & Yum, 2015; Dindia, 2003), and having healthy relationships is crucial for many positive physical, psychological, and personal outcomes (e.g. Gerstorf et al., 2016; Valtorta et al., 2016; Whisman, 2013). But what are the mechanisms behind these powerful phenomena? How does one person's message influence the other partner, and how does this ultimately lead to friendship, love, or bonding; or, if things go awry: shame, guilt, and loneliness?

In this article, we suggest a new approach to answer these questions. Specifically, we argue that the time is ripe for interpersonal communication scholars to embrace and engage with neuroscientific approaches, and for neuroscientists to embrace and engage with interpersonal communication theory. Our general message is a positive one: We believe that the study of interpersonal communication can contribute significantly to the ongoing scientific success of human neuroscience, and that in return, the study of interpersonal communication itself stands to benefit markedly from the field of neuroscience.

Many interpersonal communication theories invoke mental processes that are not directly observable (e.g. relational turbulence theory, Solomon et al., 2016; the theory of motivated information management, Afifi & Weiner, 2004; or the cognitive-emotional theory of esteem support messages, Holmstrom & Burleson, 2011), and neuroscience offers methods to observe neural processes in real time, without interruption, and to tap into systems that are detached from the language system and thus difficult to report verbally (e.g. Cacioppo et al., 2007; Huettel, 2008). Neuroscience has already promoted significant theoretical advances in research on cognitive processes and has now begun to

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decipher processes that are relevant to interpersonal communication (e.g. Huskey et al., 2020; Schmälzle & Meshi, 2020; Ward, 2015). In turn, interpersonal communication theories provide a much-needed framework for making sense of what occurs in the brain during social interaction. Overall, the disciplines of interpersonal communication and neuroscience have complementary strengths that can be combined to improve the description, explanation, and prediction of interpersonal communication processes.

Interpersonal topics are widely viewed as very important in neuroscience (Cacioppo & Berntson, 2005) but insufficiently understood, and a sustained interdisciplinary dialogue has not emerged between interpersonal communication and neuroscience. To make a case for pursuing such a dialogue, we will begin with introductions to interpersonal communication and cognitive neuroscience – considered separately. We will then provide an overview of recent interpersonal neuroscience research and discuss the current gaps in neuroscience scholarship that interpersonal theories could fill. Next, we describe the current state of neuroscience methods used to study the neural basis of cognitive and affective processes, and how such methods may benefit interpersonal communication research, both theoretically and methodologically. Using the phenomenon of reactance as a case example, we will illustrate how interpersonal scholars can engage with a neuroscientific approach. While we are optimistic that this work will grow and yield new insights into core communication mechanisms, we will also discuss challenges and potential misunderstandings that researchers may encounter. Our main conclusion is that topics that fall squarely into the domain of interpersonal communication hold the greatest potential for a truly social, that is *interpersonal* neuroscience, and that the disciplines of interpersonal communication and neuroscience should engage in more dialogue to build a mutually beneficial relationship.

What do we mean by interpersonal communication?

Humans are naturally social (Crespi, 2001). The need to belong is a fundamental evolutionary force that motivates connection with others (Baumeister & Leary, 1995). It is therefore unsurprising that the field of interpersonal communication is central within the broader communication discipline (Barnett & Danowski, 1992). According to the Handbook of Communication Science, interpersonal communication can be defined as 'a complex, situated social process in which people who have established a communicative relationship exchange messages in an effort to generate shared meanings and accomplish social goals' (Berger et al., 2010, p. 6). This definition suggests a message-centered approach to interpersonal communication, prompting us to think about social interactions as back-and-forth exchanges in which interactants produce and interpret one another's messages (Burleson, 2010). Accordingly, the mission of interpersonal communication research is to describe, explain, and predict how and to what effects individuals communicate with each other by focusing on fundamental communication processes, structures, functions, and contexts (Burleson, 2010).

What do we mean by Neuroscience?

Neuroscience is concerned with the structure and function of the nervous system, particularly the brain. The brain is the biological organ of the mind and as such the ultimate sender and receiver of all communication (Gazzaniga et al., 2013; Watson & Breedlove, 2012). We note that while this paper focuses mainly on neuroimaging, similar arguments also apply to psychophysiological measures of central and peripheral nervous responses, which have already been adopted in domains like political communication (Coronel & Sweitzer, 2018), health communication (Bailey et al., 2018; Hohman et al., 2017), media psychology (Clayton et al., 2019b; Lang et al., 2009), and within interpersonal contexts such as deception or economic decision making (e.g. Van't Wout et al., 2006; Wang et al., 2010).

The advent of technology to measure brain activity in living humans, called functional neuroimaging, makes it possible to examine the neural basis of cognitive processes (Biasiucci et al., 2019; Hari

& Puce, 2017; Huettel, 2008; Toga & Mazziotta, 2002). These advances have led to the emergence of cognitive neuroscience, an interdisciplinary field that studies the neural basis of cognitive functions (e.g. vision, audition, memory, attention, emotion; Poeppel et al., 2020). The details of how brain activity relates to specific thoughts and feelings are beyond the scope of this article but have been discussed in previous communication articles (e.g. Schmälzle & Meshi, 2020; Weber et al., 2015b). As the term neuroimaging suggests, these methods produce images of brain activity. In the case of EEG (electroencephalogram), one can record the electrical signals of large groups of neurons by placing sensors on a participant's head and visualizing the changes prompted by various stimuli or tasks. In the case of fMRI (functional magnetic resonance imaging), changes in regional brain activity can be captured and visualized by an MRI machine, also called a brain-scanner. Many other techniques exist, but the basic principles of measurement are similar: they record functional brain activity, that is, they enable researchers to study the brain in action (Newman, 2018; Raichle, 2009).

Regardless of the specific method used, whether EEG, fMRI, or psychophysiology, the basic procedure to study nervous system responses during communication is rather simple: First, the researchers must create a situation to evoke the phenomenon they want to study. For example, if the goal is to study visual perception, images must be presented in a controlled manner, or words or text if the research is about language. If, on the other hand, the goal were to study the perception and evaluation of compliments or insults, respectively, then one could present messages that elicit these phenomena. Second, researchers must record and analyze the physiological reactions to identify how they relate to the eliciting stimuli and tasks, or to subsequent behavior. This procedure illustrates the general principles of a neuroimaging approach: A mental process of interest is manipulated and the effect of this manipulation on neurophysiological activity is measured. This approach, sometimes called brain-mapping, has been carried out for numerous processes, yielding a growing database of the relationships between mental phenomena and nervous system function.[1]

Beyond brain-mapping approaches, which treat the brain-activity as the dependent variable, the brain-as-predictor approach uses neuroimaging data to predict subsequent outcomes, such as whether a person will like or share a message (Falk et al., 2015). For example, in studying trustworthiness impressions, one could test how brain responses to trustworthy/untrustworthy-looking individuals predict trust behavior during gameplay among players (e.g. during dilemma tasks, Krueger & Meyer-Lindenberg, 2019).

Current developments: studying multiple brains

Over the past two decades, functional neuroimaging has provided many new insights into the neural basis of mental phenomena, including various social topics such as social rejection, social comparison, and social support, to name but a few (Dvash et al., 2010; Eisenberger et al., 2007; Meshi et al., 2013; Slavich et al., 2010; Wagner et al., 2016). Due to methodological constraints of the new technologies, however, early cognitive neuroscientists were required to conduct their studies one-brain-at-a-time and under highly controlled and rather artificial laboratory conditions. These requirements rendered most cognitive neuroscience research distinctly non-social and thereby non-interpersonal. However, this is about to change as recent technological advances offer new ways to address this gap by investigating social interaction in the brain (for review, Hari & Kujala, 2009; Hasson et al., 2012; Wheatley et al., 2019).

As of 2020, a handful of studies have begun to investigate the simultaneous brain activity of multiple individuals engaged in dyadic conversations or other kinds of social interaction (Anders et al., 2011; Kuhlen et al., 2012; Liu et al., 2017; Liu et al., 2018; Montague et al., 2002). A method termed hyperscanning, or multi-brain imaging, can be used to record brain activity while two (or more) participants interact (Montague et al., 2002). Methodologically, this requires multiple fMRI machines or EEG caps to simultaneously capture brain activity data from both sides of this 'social synapse'. The neural responses from the brain of the sender, the receiver, or both, can then be linked to message factors, receiver impressions, or communication outcomes. An illustration of such dyadic approaches to neural measurement can be found in Figure 1.

Figure 1. Examples of how dyadic or multi-brain neuroimaging can be used to study brain responses on both sides of the sender-receiver system (top figure modeled after Stephens et al., 2010, bottom figure from Goldstein et al., 2018). Findings to date suggest that shared processes between two individuals' brains reflect similar psychological meaning (e.g. similar interpretations or similar knowledge; Honey et al., 2012; Stolk et al., 2016) and can predict successful message

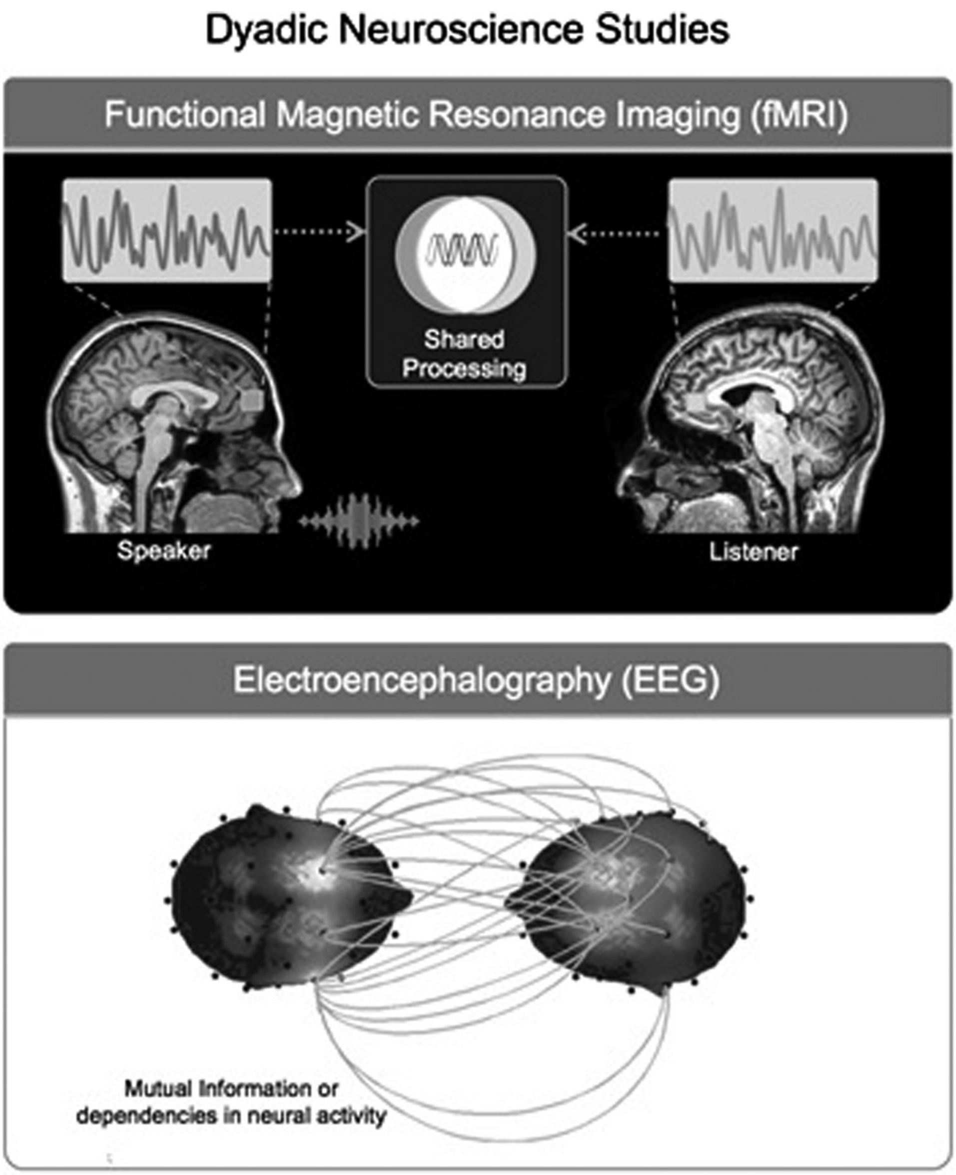

Figure 1. Examples of how dyadic neuroimaging can be used to study brain responses on both sides of the sender-receiver system (top figure modeled after Stephens et al., 2010, bottom figure from Goldstein et al., 2018). Findings to date suggest that shared processes between two individuals' brains predicts communication success (Hasson & Frith, 2016; Redcay & Schilbach, 2019), and similar psychological meaning (e.g. similar interpretations or similar knowledge) reflects more similar brain activity (Stolk et al., 2016).

transmission (Hasson & Frith, 2016; Redcay & Schilbach, 2019). While we focus here on multi-brain studies, the same principles apply to multi-person psychophysiological and multi-body behavioral studies (e.g. Bente & Novotny, 2020; Dumas et al., 2014).

To provide some examples, a recent study investigated how dyads update their beliefs and cooperates in the prisoner's dilemma game (Zhang et al., 2019). Another area is brain-to-brain synchrony between parents and children (Piazza et al., 2018), where recent results suggest that parental stress results in a reduced correlation between parent–child brain and poorer dyadic interactions (Azhari et al., 2019). Other areas that are being explored are, for instance, teacher-to-student and student-to-student communication in classrooms, collective audience responses, and other joint tasks (Babiloni & Astolfi, 2014; Dikker et al., 2017; Dumas et al., 2010; Imhof et al., 2020; Schmälzle et al., 2015; Schmälzle & Grall, 2020). Across these studies, a general finding is that brain activity in regions associated with social cognition and particularly the temporal alignment of this activity between interactants, is related to understanding and collaboration (e.g. Hasson & Frith, 2016; Xie et al., 2020). Although many questions remain unanswered, this research demonstrates that it is now possible to measure the brain activities involved in message production and reception during ongoing social interaction over time and without overt questioning.

The current gap between neuroscience and interpersonal communication research

Innovative research has demonstrated that it is possible to (a) record neural data from multiple participants and (b) use these data to gain insights into the hidden processes of social interaction within the brain and body, including many topics that border on the interpersonal domain. These multi-brain neuroimaging studies provide initial neural evidence for the processes that bring about interpersonal communication, but they leave countless questions to be explored from a communication perspective. For example, one key topic that has so far received limited attention from neuroscience is how interpersonal contexts like similarity, social ties, or perceived social support between subjects' shape participants' interactions. Similarly, very little attention has been given to the actual content of the messages that are being exchanged. These are only two immediately identifiable gaps for which interpersonal communication scholars are urgently needed to contribute as neuroscientific approaches emerge. Most critically, theories from interpersonal communication are currently rarely utilized in multi-brain or multi-person studies (for exceptions, see Bente & Novotny, 2020; Dulleck et al., 2014; Feldman, 2017) and interpersonal communication theory is rarely discussed in standard textbooks in social neuroscience. As a result, the use of interpersonal communication theory in neuroscience research is underdeveloped, and most existing multi-brain studies remain rather exploratory in nature. This void represents a unique opportunity for interpersonal scholars to integrate theoretical frameworks with new methods of research, thereby furthering theoretical understanding of the mental processes that unfold within communicating individuals.

While interpersonal communication theory is crucial for studying how peoples' brains respond during interaction, a combined interpersonal and neuroscience approach also promises to advance interpersonal communication theory. Neuroscientific measures are clearly well suited to examine the brain basis of psychological processes, which loom large in interpersonal communication. However, beyond merely aiding measurement, neuroscience also promotes theoretical advances by improving explication of concepts, refinement of existing theories, or by adjudicating between competing ones (Mather et al., 2013). For instance, cognitive neuroscience has significantly advanced our understanding of coarse psychological categories like emotion, memory, attention, or theory-of-mind, which have each been parsed into more specific components whose neural basis is increasingly known (e.g. Henke, 2010; Chun et al., 2011 ; Schaafsma et al., 2015). Similarly, neuroscientific insights on semantic memory and language comprehension (Chen et al., 2017; Huth et al., 2016; Pickering & Garrod, 2004) are highly relevant for communication scholars who are concerned with the general question of how humans 'exchange messages in an effort to generate shared meanings' (Berger et al., 2010, p. 6; also see Abel, 1948; McCroskey & Richmond, 1995).

Although issues of meaning, understanding, and comprehension are central to the mission of the communication discipline, our theoretical grasp of them has remained incomplete. In fact, the question of how messages get their meanings and what meaning actually is (also known as the symbolic-grounding problem; Barsalou, 2008; Harnad, 1990), remains unsettled, but emerging work in neuroscience is promising (e.g. Hasson et al., 2012).

The claim that there is a need for research on how we understand the meaning of messages also resonates well with a recent paper by Gasiorek and Aune (2019), who argue that 'interpersonal understanding' has been treated only as a primitive term and that questions like how conversation partners understand or comprehend the content of each other's message have become less commonly studied. But what would research on interpersonal understanding look like if approached from a perspective that combines interpersonal theory and neuroscientific methods? In our view, the levels-of-explanation framework (Cacioppo et al., 2000; Churchland & Sejnowski, 2016; Wilson, 1999) provides a useful way to think about how interpersonal communication and neuroscience are related and why these fields should become more integrated to advance science. According to this framework, illustrated in Figure 2, scientific phenomena can be organized into multiple, interconnected vertical levels. Effects at one level result in effects at another level. For example, drug-evoked changes at the neuronal level produce predictable changes in affective brain circuits, which shift the individual's mood and influence their overt behavior in interpersonal interactions. This causal sequence of drug-evoked changes to the brain is widely known, and the fine details of the involved mechanisms are increasingly understood (Berridge, 2018, 2019). When it comes to

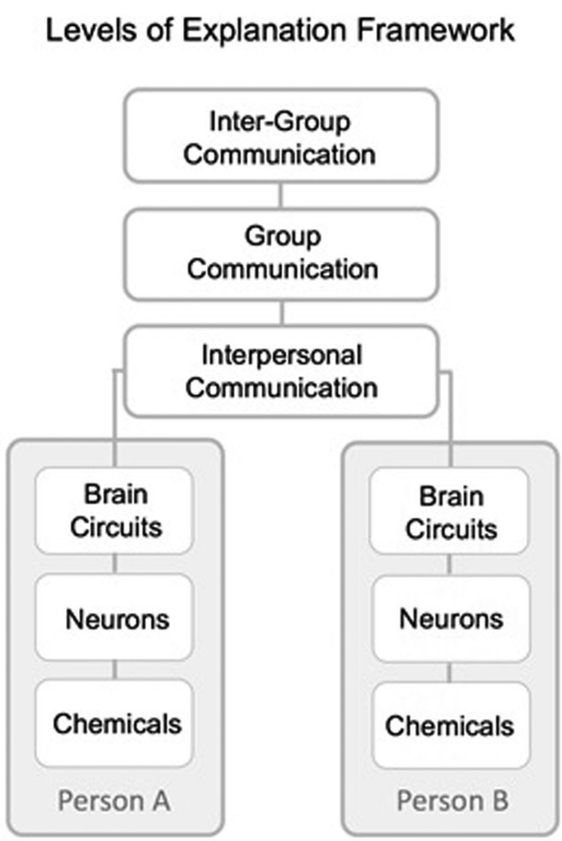

Figure 2. Levels of explanation framework. Each level is interconnected to the other levels so changes at one level affect the other levels. Therefore, studying phenomena at one level improves our understanding of phenomena at another level.

'interpersonal understanding' and the 'generation of shared meanings', however, a similar understanding of mechanisms operating across levels is lacking.

Figure 2. Levels of explanation framework. Each level is interconnected to the other levels so changes at one level affect the other levels. Therefore, studying phenomena at one level improves our understanding of phenomena at another level. To avoid potential misunderstanding here, we emphasize that the goal of studying interpersonal phenomena from a neural perspective is not to explain interpersonal factors away through reduction onto biology. Rather, the goal is to increase scientific understanding of topic areas that quite obviously depend on an intricate interplay between levels but have not yet received the attention they deserve in communication.

It is clear that what we commonly assume to be understanding[2] between people requires that a person must correctly analyze and comprehend the content of messages to accurately infer the other person's intent (Burleson, 2010). Neurolinguistic theories, for instance, the interactive alignment model of dialogue (Garrod & Pickering, 2004), have begun to incorporate such multi-level linkages between the social, interpersonal level of analysis and lower levels. As cognitive neuroscience promotes new insights into the mechanisms of social cognition, semantic memory, and comprehension in working memory, it becomes possible to start connecting the interpersonal and neural levels and unpack the inner workings of interpersonal understanding. Several innovative multi-brain and multi-person studies have already begun to study this issue (e.g. Richardson et al., 2007). For instance, recent work has examined how the brains of message senders and receivers become aligned during dialogue, and that the strength of this brain coupling is related to receivers' comprehension (Stephens et al., 2010). The research introduced in the section on multi-brain studies if of a similar kind.

Together, new methods for recording live data from interacting human brains have unique potential to elucidate core interpersonal communication processes between levels. However, to involve a social analogy: 'data without theory are like a baby without a parent, their life expectancy is low' (Gigerenzer, 1998). Indeed, there is a real danger that the advancements of neuroscience remain decoupled from theorizing in interpersonal communication. Just like interpersonal scholars tend to know little about the brain, neuroscientists tend to have limited knowledge of interpersonal communication theory – at least not beyond their own intuitive lay-theories. We therefore provide an example of how existing interpersonal theorizing can be connected to neuroscience research.

An example of an interpersonal neuroscience approach in action: reactance and politeness theory

To apply some of that theory: There is a reason why we didn't start this article commanding you that 'From now on, you must use neuroimaging to examine communication and nothing else'. The reason we did not use such phrasing is the phenomenon of reactance. Reactance occurs when threats to freedom are perceived. When people perceive such threats, they tend to attempt to restore freedom directly or indirectly (Brehm & Brehm, 1981). This is why social interactions involving attempts at social influence frequently incur reactance (Brehm, 1966). Take for example a newly married couple discussing their now-shared finances. A partner may experience reactance if their spouse insists that their coffee budget be reduced to accommodate a new home budget. On the subjective or experiential level, reactance is related to anger and message rejection, and reactance may manifest behaviorally by the partner spending more money on coffee instead of less. In sum, reactance processes are pertinent in determining message reception and ultimately, persuasiveness (Miller et al., 2007).

Research on reactance in interpersonal communication began as scientists noticed that some influence messages elicited the opposite outcome of the one being encouraged (Worchel & Brehm, 1970), or people rated the behavior being threatened as more attractive (Hammock & Brehm, 1966). Subsequent research investigated what it is about messages that elicit reactance and how reactance can be reduced. Freedom-threatening messages can be made less reactive by, for example, using politeness strategies (Brown & Levinson, 1978, 1987). Politeness strategies, which were developed in sociolinguistics and are based on Brown et al.'s (1987) politeness theory, attempt to minimize threat to positive and negative face by changing how messages are phrased. Positive face is related to the need for approval, whereas negative face is related to the need for autonomy and freedom. To minimize harm to positive face when making requests, senders may use positive politeness strategies such as compliments in their messages (e.g. in the case of the newlyweds discussed above: 'Honey, I know that if we had a house, you'd be great at fixing it up. What if we tried to cut back on our coffee budget to save for our first home?') This message also is phrased such to minimize threat to negative face; by making the request a question, the recipient is given freedom to accept or reject the suggestion. A message with neither of these politeness strategies is predicted to be more likely to induce reactance (e.g. 'You need to stop spending so much money on coffee!')

Although numerous findings document the importance of the phenomenon, measuring reactance has been a subject of debate since the inception of reactance theory (Brehm, 1966; Brehm & Brehm, 1981; Quick & Stephenson, 2008; Ratcliff, 2019). Indeed, the challenge of measuring reactance was first noted by Jack Brehm, the originator of reactance theory. Work by Dillard and Shen (2005) led to the intertwined model, which conceptualizes reactance as a latent factor with indicators for self-reported negative cognition (measured via a thought-listing task) and anger (measured via state anger scales) in equal weight. This factor-analytic approach provides one robust way to assess reactance as a latent construct, yet several measurement challenges remain. First, the method is time-consuming and requires effort, both on the part of the participant (in thought-listing) as well as the researcher (in coding and counting participant cognitions). Second, issues of measurement reactivity and order effects arise when participants are asked to reflect about their cognitive and emotional responses, respectively (Rains, 2013). Third, although the method captures how reactance manifests in subjective experience, the factor-analytic approach cannot reveal the rapid and nuanced changes in affect and cognition, which are likely to occur within split-seconds in response to specific words like 'ought,' 'must,' and 'need' (Miller et al., 2007; Quick & Stephenson, 2008), or variations in tone. Fourth, the process of reactance may differ depending on contextual features or individual differences that are not captured by current measures. For example, research indicates that threats to freedom, while causing anger, may not lead to counterarguing, particularly when the threat to freedom occurs at the end of a message (Ratcliff, 2019). In sum, although advances have been made in conceptualizing and measuring reactance, important challenges remain, particularly in measuring the process of reactance.

Over the past decade, several studies have followed a call by Quick and Stephenson (2008) to examine how reactance is affected by message features, explore its underlying mechanisms, and link reactance to outcomes. In a meta-analytic review of existing studies (Rains, 2013), the intertwined model has received support and continues to be the most prominent approach to measure reactance (e.g. Ratcliff, 2019; Rosenberg & Siegel, 2018; Steindl et al., 2015). Psychophysiological studies have also begun to examine reactance in the context of health campaign messages (e.g. Clayton et al., 2019a). For instance, when anti-smoking campaign messages were presented to non-smokers, participants had less heart rate deceleration over time, greater anger and counterarguing, and poorer performance on memory measures when messages contained freedom threats and smoking cues (Clayton et al., 2019b).

Beyond mass media health communication, the study of reactance also continues to be fruitful ground for interpersonal researchers. For instance, Smith et al. (2016) studied how parole officers' communication style affects reactance and influences the likelihood of parolees abstaining from drinking, and Tian et al. (2020) examined reactance as a mediator of the relationship between support message quality and message outcomes. Overall, reactance has attracted and continues to attract considerable interest in communication science, resulting in increased understanding of its elicitors, mechanisms, and outcomes. We believe that neuroimaging can complement existing approaches to measure reactance and ultimately help resolve conceptual ambiguities.

The potential of neuroscientific measures to assess reactance as it occurs

Despite the progress discussed above, reactance measurement remains challenging, as Ratcliff (2019) emphasizes in her recent review of the communication literature on reactance. In fact, Ratcliff explicitly advocates for neuroscientific measures of reactance such as fMRI and EEG, either alone or in combination with other measurement approaches: 'For the study of reactance, measuring [neural] responses during message exposure might aid investigation of the temporal nature of reactance, help to delineate boundaries between elements of the process (and associated measures), or clarify whether the intervening response manifests differently in different people or contexts' (p. 19).

Interestingly, there exists some work that examines related issues from a neural perspective. Specifically, research on mass media health messages has focused on topics like counterarguing and negative affect, which are both related to reactance. Recent work using fMRI, for instance, has suggested brain regions associated with counterarguing, a process assumed to be a cognitive aspect of reactance, in response to persuasive messaging (Coronel et al., 2019; Weber et al., 2015a). Other work using EEG points to extremely rapid brain responses during message rejection (Van Berkum et al., 2009). Though none of these studies were executed in the interpersonal domain, but instead in the context of persuasive health messages (Weber et al., 2015a) or moral statements (Van Berkum et al., 2009), it seems clear that these measures have promise for studying the mechanisms of message rejection and provide a roadmap for assessing reactance as it arises.

Specifically, the high temporal precision of EEG, which ranges on the order of milliseconds, could make it possible to capture even fleeting instances of reactance during ongoing conversations, and to relate them back to eliciting message features. Although a full discussion of the extant EEG literature is beyond the scope of this article (e.g. Luck, 2014), we can refer to a number of EEG-effects that provide predictions for how reactance-eliciting messages would be processed, or how EEG-correlates of reactance could be studied: For instance, event-related potential (ERP) studies point to several components, such as the P300 and N400, which are related to improbable events or words that violate semantic expectancy (Luck & Knappenman, 2011). Especially in neurolinguistics, it is common to present individual words at a fast pace and measure electrocortical responses to derive ERPs (e.g. 'he-takes-his-coffee-with-milk-and-[conditionA: sugar; conditionB: socks]'). By comparing differential responses between the expected sentence endings and the surprising one, neurocognitive differences that occur within 500 ms of word processing can be revealed. Conceiving similar paradigms to study reactance seems possible considering that the above-mentioned study by Van Berkum et al. (2009), applied the paradigm to study morality by using clashing/non-clashing moral statements (e.g. 'I think euthanasia is an [acceptable/ unacceptable] course of action.'). Moreover, the rise of methods to study brain responses to continuous speech, as opposed to the rather artificial one-word-at-a-time ERP presentation, gives hope that EEG studies will become far more naturalistic and thus more adept to study interpersonal phenomena (e.g. Anderson et al., 2018). In sum, the high temporal resolution of EEG measures is beneficial for measuring reactance effects, which can be triggered rapidly and by single utterances. Additionally, the tight link between EEG effects and neuromodulatory systems is critical for studying the modulation of attention and the orchestration of emotional and cognitive responses during reactance (Nieuwenhuis et al., 2005).

FMRI, in turn, provides us with an opportunity to identify brain regions involved in reactance. Although again, a full treatment of the relevant fMRI literature is beyond the scope of the article (e.g. Huettel, 2008), we can expect that statements that trigger reactance should recruit the so-called saliency network, a network of regions including the anterior cingulate cortex, the anterior insulae, as well as subcortical structures, which has often been linked to appraisal processes (Chen et al., 2016; Etkin et al., 2011). Several fMRI studies also point to the dorsolateral prefrontal cortex (DLPFC) as a region associated with effortful cognitive processes and particularly counterarguing (Coronel et al., 2019; Weber et al., 2015a). Beyond these predictions of regional effects associated with reactance, predictions could also be made regarding multivariate (multi-region) patterns of brain activity and brain network effects associated with reactance (for introductions see Huskey et al., 2017).

Lastly, aside from these candidate EEG and fMRI effects based on prior research, the neuroscience literature also provides numerous examples how one can identify brain activity differences associated with a variable of interest in a more data-driven fashion. For instance, by comparing initial brain responses to messages that are subsequently remembered vs. forgotten, one can reversely identify differences associated with memory encoding (Wagner et al., 1998). The same strategy could be used to identify 'when' and 'where' the neural processing of messages that provoke reactance parts ways from those that do not.

Taken together, a researcher may benefit from this approach if they were interested in obtaining a temporal and unobtrusive measure of reactance in an interpersonal interaction, for example, in bringing dyads into a lab and asking one to provide the other with advice to elicit possible threats to freedom. Self-report, video playback, and EEG or fMRI data collected during and after the interaction could then be used to understand the phenomenon of reactance-in-conversation. Furthermore, if we recall the above mentioned work on multi-brain-imaging (or hyperscanning) during dyadic communication, one might possibly begin to study how a partner's message triggers reactance in the other partner, which may in turn lead to a response that itself contains reactance-eliciting features (e.g. tone, face-threatening content, etc.).

Another promising strategy is to combine neuroimaging and self-report measures to predict outcomes, such as forecasting whether individuals will engage in reactant behavior (Falk et al., 2011; Falk et al., 2012). In sum, the reactance phenomenon provides a good example of how neuroscience and interpersonal communication science, when used together, offer more than the sum of their parts.

The potential of neuroscience to make theoretical contributions to interpersonal communication

The previous section highlighted mainly the methodological potential of neural measures for capturing reactance as it occurs. However, the potential of neuroscience to contribute to interpersonal theory itself should not be overlooked (e.g. Mather et al., 2013) – for reactance and beyond. For example, the reactance literature discusses the emotional and cognitive aspects of the phenomenon, whereby the emotional component consists largely of anger and the cognitive component of negative cognitions (Dillard & Shen, 2005). Yet this raises theoretical questions regarding how such a cognitive-emotional alloy is formed and how cognitive and emotional phenomena can be distinguished in the first place (e.g. Duncan & Barrett, 2007; Pessoa, 2013). Neuroscientific theories inform the conceptualization of cognitive and emotional processes (e.g. Adolphs & Anderson, 2018) and neuroimaging methods are suited to decipher the temporal sequence in which specific responses are elicited. For example, classical appraisal theories (e.g. Lazarus, 1991; Scherer, 1999) suggest that messages must first undergo cognitive-semantic analysis and be evaluated before anger can emerge. Neuroscience has already helped elucidate such rapid evaluation processes in the domains of attitudes and appraisals (e.g. Cacioppo et al., 1996; Schupp et al., 2006; Van Berkum et al., 2009). As such, antecedent brain differences associated with reactance-evoking messages could be investigated with ERP methods that have key features relevant for theoretical research into the component processes of reactance such as processing speed, level of automaticity, relationship to subjective report, and so forth (e.g. Schmälzle et al., 2011; Moors & De Houwer, 2006). Used this way, neuroscience provides more than just a method, but it represents a theoretical contribution that advances understanding of the phenomenon (also see Mather et al., 2013).

Neuroscientific approaches may also be used to decipher different kinds of self-relevant emotions that face threats associated with reactance may evoke, such as shame, guilt, and embarrassment (e.g. Bastin et al., 2016; Gilead et al., 2016). For example, neuroimaging methods may shed light on the relationships between these emotions and the types of messages that elicit them. Being able to assess self-conscious emotions using neuroimaging methods is particularly useful due to inconsistencies and difficulty in their measurement, caused in no small part by peoples' general inability to readily distinguish between shame, guilt, and embarrassment (Tangney & Dearing, 2002). Another important reason to identify better ways to assess self-conscious emotions is their unique consequences. Shame in particular may be associated with reactance. Shame is especially pernicious because it raises cortisol levels to a greater extent than other emotions (Dickerson et al., 2004), induces greater feelings of isolation and inferiority (Tangney et al., 1996), and may lead people to lash out at others in anger (Tangney & Dearing, 2002). Again, a neural approach has potential to promote theory-method synergy (Greenwald, 2012) for research on the causes, mechanisms, and consequences of reactance.

Beyond reactance and associated concepts, theoretical constructs in the interpersonal communication literature that may be better understood via neuroscientific methods include perspective-taking (Schaafsma et al., 2015), active listening (Kawamichi et al., 2015), empathy (Marsh, 2019), and the appraisal process (Sander et al., 2005), among many others (see Huskey et al., 2020). In fact, all interpersonal theories that make claims about mental processes (e.g. emotional or cognitive processes, inferences, evaluations, semantic knowledge and procedural social skills) may benefit from incorporating neural measures or aligning their theories with recent cognitive neuroscience theories.

Like any method, methodological limitations of neuroimaging remain (e.g. Schmälzle & Meshi, 2020; Turner et al., 2018). Researchers should be aware that neuroimaging is correlational by nature[3], that is, such methods do not alter neural activity. Interpersonal scholars should be aware of these limitations because it will help them see neuroscience as a less mystic, more methodological tool for measurement and as a theoretical contribution that helps to better understand the true nature of mental processes core to interpersonal interaction, mental processes which are undeniably contingent on neural activity (Watson & Breedlove, 2012).

Summary and outlook

Together, the fields of neuroscience and interpersonal communication can deepen our understanding of how humans build and maintain relationships; send, interpret, and receive effective messages; and navigate their social worlds. Neuroscience offers a complementary way to approach the explanation of interpersonal communication and neuroscience stands to benefit from incorporating interpersonal communication frameworks and theories. In this manuscript, we provided an overview of how neuroimaging enables researchers to study the neural correlates of mental processes and how this approach could be adopted to examine core interpersonal phenomena. We illustrated this argument by reviewing the emerging literature on interpersonal neuroscience and providing a deeper discussion of how neuroscientific measurements, whether measured from the brains of both sender and recipient, or from the recipient alone, can aid the understanding of reactance. There are many other phenomena for which a similar case could have been made (e.g. on the *positive* side of interpersonal communication: assertiveness, social support, and self-disclosure, on the *dark* side: deception and messages eliciting guilt or shame; Cupach et al., 2009; Socha & Pitts, 2012). The next generation of interpersonal scholars is well-positioned to contribute their expertise on these matters and help social neuroscientists become less reductionistic and more interpersonal. Studying the neural basis of interpersonal communication, the long considered unapproachable topic of neuroscience (Schilbach et al., 2013), is beginning to rapidly grow, and the interpersonal field has a unique chance of being at the center of it.

Notes

1. Interested readers are referred to the website www.neurosynth.org where one can instantly conduct automated meta-analyses on thousands of neuroimaging studies (e.g. examine which brain regions become active during 'self-related cognition,' or 'face perception'(Yarkoni et al., 2011)).

2. Whether understanding between people depends on individual-level mechanisms (reductionist view) or group-level mechanisms (interactionist view) is a philosophical and ongoing debate in cognitive neuroscience (for review see Gallotti & Frith, 2013a and commentary Di Paolo et al., 2013; Gallotti & Frith, 2013b). From a more reductionist view, understanding must obviously occur within the brain of each individual separately, yet from a more interactionist view, the relevant subprocesses within each brain are contingent upon each other because one person's message influences the others' thoughts and emotions, which in turn prompts responses that create interaction-dependent feedback loops.
3. Neuroimaging is inherently correlational, that is it measures neural correlates of mental phenomena, but it does not intervene and alter them. Causal brain stimulation methods do exist, but these are beyond the scope of this article. With these methods, it may become possible to interfere with reactance processes by selectively altering the activity in particular brain regions.

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