Persuasion, Influence and Value:

Perspectives from communication and social neuroscience

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Abstract

Opportunities to persuade and be persuaded are ubiquitous. What determines whether influence spreads and takes hold? This review provides an overview of evidence for the central role of subjective valuation in persuasion and social influence, for both propagators and receivers of influence. We first review evidence that decisions to communicate information are determined by the subjective value a communicator expects from sharing. We next review evidence that the effects of social influence and persuasion on receivers, in turn, arise from changes in the receiver's subjective valuation of objects, ideas and behaviors. We then review evidence for self-related and social considerations as two key inputs to the value calculation in both communicators and receivers. Finally, we highlight biological coupling between communicators and receivers as a mechanism through which perceptions of value can be transmitted.

Keywords: Persuasion, social influence, communication, value, neuroscience, fMRI

Persuasion, Influence and Value

1. Introduction

People's preferences and behaviors are strongly influenced by others. A daughter encourages her parent to stop smoking. A coach shares an inspirational news article to raise team morale. A person, let's call her Emily, is more likely to take the stairs to her fifth-floor office if she is with her sporty colleague, let's call her Christin, than if she is with colleagues who prefer the elevator. Knowing that Emily respects Christin's healthy lifestyle would also increase Christin's willingness to actively encourage Emily since she can expect Emily to think more positively of her and respond with appreciation rather than rejection. In parallel, knowing that Christin likes taking the stairs might make the personal health and social benefits of stair taking more salient to Emily than the ease of taking the elevator.

In this review, we argue that the diverse set of thought processes that determine what information communicators share (e.g., facts about smoking, an inspirational news article, encouragement to take the stairs) and whether receivers are influenced (e.g., to quit smoking, to train harder for a sport, to take the stairs) do so via a common pathway, namely subjective value maximization. Valuation involves explicitly and implicitly weighing perceived costs and benefits to derive the value of choices or actions and has been conceptualized as a motivating force for action (Bartra et al. 2013, Levy & Glimcher 2012). In other words, people make choices to maximize the value they expect from their actions. Within this review, we examine the role of this broad class of value calculations in decisions to share information (2.1) and susceptibility to influence in information receivers (2.2). Among multiple person-level, social and environmental factors, we highlight self-relevance (3.1) and social-relevance (3.2) as inputs to the value computation, and neural coupling (4) as a process through which subjective value may be transmitted between communicators and receivers (see Figure 1).

Our argument is grounded in social science research on active forms of persuasion (e.g., trying to convince a loved one to quit smoking; being persuaded by a public service announcement; for a review see Albarracin, this issue), more passive forms of social influence (e.g., taking the stairs because others are doing it; for a review see Cialdini & Goldstein 2004) and interpersonal contagion (e.g., sharing an inspiring news article; for a review see Berger 2014). Core aspects of prior theories in each of these domains have implicitly focused on people's attempts to maximize subjective value when making decisions about sharing information or being influenced. We highlight these elements and explicitly conceptualize each as forms of a more general class of value-based decision making. This conceptualization creates a bridge across prior theories, as well as a concrete link to the previously disconnected literature on neuroscientific underpinnings of subjective valuation, which has served as a guiding force to understand a more general set of choices and actions in other domains.

Recent findings in neuroscience provide insights into how the brain calculates and represents subjective value, in service of decision making (see Bartra et al. 2013, Clithero & Rangel 2014, Levy & Glimcher 2012). This neural perspective suggests that brain systems that calculate subjective value represent a "final common pathway" or "common currency" through which different decision alternatives (e.g., sharing one piece of information or another; taking the stairs or the elevator) can be reconciled, prioritized and realized in behavior and preferences (Bartra et al. 2013, Kable & Glimcher 2009). As such, conceptualizing persuasion and social influence in terms of value-based decision making complements and extends prior theorizing in fruitful ways.

There are several other advantages to linking psychological and economic models of persuasion, social influence, and successful communication more broadly to neural models of value-based decision making. First, neural models offer a specific way to quantify the relationship between inputs to the subjective value calculation, and the resulting decisions and actions. For example, expectancy-value models of behavior change (Fishbein & Ajzen 2011) suggest that the overall probability of choosing a particular option is determined by the average value of the expected consequences of each choice weighted by their likelihood of occurrence. For instance, Emily will be more likely to take the stairs if she believes that the chances of a positive outcome such as bonding with Christin or positive downstream health effects are highly probable results of taking the stairs. In contrast, she will be unlikely to take the stairs if she expects the result to be arriving late and sweaty at a meeting on the 5^{th} floor.

Given the wide range of dimensions that inform the expected costs and benefits, it can be difficult for individuals to self-report on the exact process that lead to their choices. To this end, neuroimaging provides a method to simultaneously measure and quantify a wide range of possible input dimensions to the subjective value calculation. Measurement occurs in real time as people are exposed to different information, and without requiring the participant to consciously reflect on the processes that are contributing to his or her decisions, preferences or actions. Thereby, this neural evidence is agnostic to whether or not the processes in question are consciously accessible to the participant (Lieberman 2007); this is important because as with many fundamental processes (Krumpal 2011, Wilson & Nisbett 1978, Wilson & Schooler 1991), motivations to share (Barasch & Berger 2014), and to update attitudes and behaviors in response to persuasion and social influence (Cialdini & Goldstein 2004) often occur automatically, outside of conscious awareness. Within this context, we will refer to "communicators" who may intentionally seek to persuade (e.g., trying to convince a parent to quit smoking), may share without explicitly identifying persuasion as a motive (e.g., sending an inspirational news article), or may influence others indirectly through actions (e.g., turning toward the door to the stairs out of habit without thinking about influencing a colleague). In parallel, we will refer to "receivers" who may or may not be consciously aware of the communicator's influence on them (e.g., actively considering the merits of an argument vs. following a colleague up the stairs without explicitly thinking about it).

2. The role of valuation in communication, persuasion and social influence

Decisions to communicate and to conform to the influence of others each centrally involve subjective valuation. Within the brain, activity within the ventromedial prefrontal cortex (VMPFC) and ventral striatum (VS) integrates multiple different inputs from other parts of the brain into a "common value signal". This offers a means for comparison between different choices on a common scale which informs corresponding actions (see Figure 1). Importantly, this common value signal is not specific to one category of stimuli or choices, and scales reliably with how much a person values a wide range of stimuli including both primary (e.g., food, sex) and secondary (e.g., financial) rewards (Bartra et al. 2013, Chib et al. 2009, Levy & Glimcher 2012, McNamee et al. 2013). By putting the universe of inputs on a common scale, the brain can make choices about which alternatives are subjectively more valuable in a given context (e.g., whether take the stairs or the elevator; whether to eat an apple or a chocolate bar; whether to share or not share a piece of information).

The value signal also accounts for past experiences to guide future behavior through the process of reinforcement learning. To do so, the brain computes a "reward prediction error" (Schultz 2006) tracking the difference between a person's expected outcome (e.g., reward) and actual outcomes of actions. When an action produces higher than expected rewards, it is seen as more valuable and reinforced, whereas when an action produces less reward (or more punishment or conflict) than expected, it is devalued, and that also correspondingly guides future action. A similar principle guides social learning from the behaviors and outcomes observed in others. In both cases, choices with higher than expected (experienced or observed) rewards are more likely to be chosen in the future, whereas choices with lower than expected (experienced or observed) rewards are less likely to be chosen in the future.

One form of reward that may be especially relevant in the communication context comes from anticipated and received social approval. Because social connection is fundamental to human survival (Baumeister & Leary 1995, Lieberman & Eisenberger 2009) it makes sense that the brain would reinforce successful communication strategies and conformity to group norms as an end in itself, to the extent that they result in better coordination and stronger bonds between people (i.e., conforming helps me fit in with my friends). Within this framework, we conceptualize decisions to share information as attempting to maximize the expected value to the communicator, with particular attention to anticipated social rewards. This could be informed by the communicator's own past experiences sharing or through observing the consequences when others share. In parallel, we conceptualize both persuasion and social influence as inputs to value-based decision making in receivers, wherein the actions and recommendations of others provide broader information about the value of ideas, objects and behaviors to the receiver (i.e., if my friend likes it, it may have value to me), in addition to the social value of conformity and social connection described above.

As reviewed in greater detail below, core theories of persuasion, social influence and behavior change have incorporated ideas about subjective valuation and value maximization under different names, highlighting, among others, beliefs about the consequences of behavior for oneself or self-interest (Darke & Chaiken 2005, Fishbein & Ajzen 2011, Johnson et al. 2004, O'Keefe 2012). In parallel, neural systems that are key to computing subjective value are robustly observed across studies of sharing, persuasion and social influence. Decisions to share information, as well as successfully persuading or influencing others, involve increased activity in the brain's value system (Baek et al. in press, Falk et al. 2013, Scholz et al. in press), and some have argued that humans may find intrinsic reward or positive value in sharing information with others (Falk et al. 2013, Tamir & Mitchell 2012). On the receiving end, social influence from peers (Campbell-Meiklejohn et al. 2010, Cascio et al. 2015, Klucharev et al. 2009, 2011; Nook & Zaki 2015, Welborn et al. 2016, Zaki et al. 2011) and media (Chua et al. 2011, Falk et al. 2012a, 2013, 2016) changes the value that receivers ascribe to objects and actions.

Consistent with social learning theory (Bandura 2001) and theories of embodied social cognition (Semin & Cacioppo 2008), recent evidence also suggests that synchronization between communicators and receivers is a key component of successful persuasion and social influence, beyond the brain activity observed in either party alone (Scholz et al. in press, Stephens et al. 2010). Social learning or using social information to update one's own preferences and actions is an efficient mode of learning (Bandura 2001), with conformity to group norms as a central, valued commodity which promotes approaching positive social outcomes (Cialdini & Goldstein 2004) and avoiding negative social sanctions (Fehr & Fischbacher 2004). Likewise, conformity and mirroring of others can promote positive relationships with others (Cacioppo & Cacioppo 2012), in part by activating social-cognitive and value systems in the person being mirrored (Cacioppo et al. 2014).

2.1 Communicator's perspective

People share when they believe that information is valuable to the receiver (Barasch &

Berger 2014, Berger & Milkman 2010, Reeck et al. 2016), valuable to the way that others will see them (Lampel & Bhalla 2007), or valuable for the relationship between the sharer and receiver (Clark & Kashima 2007). Berger (2014) argues that sharing is motivated by five key factors: impression management, emotion regulation, information acquisition, social bonding, and persuading others (Barasch & Berger 2014). Each of these motives can be conceptualized as being valuable to the sharer as these motivations correspond to central human goals of holding a positive image of the self and maintaining positive social relationships (Baumeister & Leary 1995, Mezulis et al. 2004, Taylor 2006, Taylor & Brown 1988).

Neural evidence also suggests that sharing recruits the value system, and may offer a parsimonious way of quantifying and comparing various motives. In this view, opportunities to fulfill one or multiple motivations associated with sharing could each increase the value of sharing information, either alone or in concert. These inputs could be weighed using the same context dependent neural machinery (Cox & Kable 2014) that compares value in other domains (e.g., purchase decisions; mate selection) and increase the "value signal" associated with sharing a given piece of information over others, or over not sharing at all. Empirical evidence supports this view. For example, ideas that end up being shared most successfully increase activity in the brain's value system when potential sharers are first exposed to them (Baek et al. in press, Falk et al. 2013, Scholz et al. 2017). More broadly, participants are willing to pay more money to share information than to answer trivia, and the act of sharing also increases activity in the brain's value system (Tamir et al. 2015).

2.2 Receiver's perspective

Theory and evidence support a key role of valuation in being socially influenced or persuaded. When incoming information changes the receiver's perceived value of ideas and actions, the receiver is more likely to update their views or behaviors to be consistent with the message based on that value signal. For example, expectancy value theories of persuasion and behavior change suggest that people's expectations of what will happen if they act and their evaluation of the expected outcome determine in part whether and what action is taken (Fishbein & Ajzen 2011). Studies of argument quality similarly suggest people are persuaded less by facts and more by subjective value: "the persuasive impact of argument quality, as it has been operationalized, is much less about logic than it is about valence. That is, persuasion is more about suggesting good rather than bad *consequences* (valence) for the message recipient than it is about creating impeccably logical -- a.k.a. truthful or likely-- arguments." (Johnson et al. 2004). O'Keefe (2012) further highlights that a wide range of message effects that have traditionally been studied separately (e.g., gain vs. loss frames; individualistic vs. collectivistic frames; prevention vs. promotion focused appeals; fear appeals) all draw a connection between taking a specific action and a subjectively valuable outcome or consequence (consequence-based arguments). At their core, these theories align with subjective expected utility models, which are central to a broad set of economic decision models (Samuelson 1937, Savage Leonard 1954, Von Neumann & Morgenstern 1944). Likewise, behavioral and neuroeconomic theories of decision making assume that actors make decisions to maximize subjective value (Camerer et al. 2005, Levy & Glimcher 2012).

As such, conceptualizing persuasion in terms of value to the actor bridges psychological and economic perspectives on persuasion, influence and behavior change. In particular, although psychologists typically do not assume that people know their preferences nor that these preferences are stable, theories in both disciplines have considered ways in which people assign value to ideas and act accordingly, with psychologists perhaps placing greater emphasis on contextual factors (e.g., social norms, framing, attributes of the communicator, self-relevance in a specific context, etc.) as inputs to the value computation. In other words, the value assigned to a particular choice or action is subjective, and takes into account a wide range of features that depend on the individual and social context. Likewise, neural evidence highlights a key role of valuation in conformity to social influence induced by perceived social norms and by persuasive messaging, and offers a specific and quantifiable signal tracking the process.

2.2.1 Social influence and value in the brain.

Neural evidence supports the idea that conforming to social influence implicates the brain's value system. First, one set of studies points to the involvement of the brain's value system in tracking divergence vs. consensus with group opinion; rather than tracking the value of the stimulus in isolation, some evidence suggests that the brain initially tracks convergence and divergence with group opinion as an end in itself. In these studies, a participant's brain activity is monitored during exposure to information about others' preference ratings that either agree or disagree with an earlier rating made by the participant. Activity is typically higher in the value system during consensus with others' opinions than when participant opinions diverge from the group (c.f. Cascio et al. 2015). For example, in one early study Klucharev and colleagues argued that social influence exerted by learning normative information (in this case, the preferences of others) encourages and reinforces certain preferences and behaviors, while discouraging others (Klucharev et al. 2009). Their core argument is that conformity to social norms (i.e., updating ratings to align with group norms) is driven by similar valuation processes to the type of reinforcement learning that guides motivated behaviors more generally. In this study, participants rated the attractiveness of female faces and then received feedback about peer perceptions of the same faces. Later, the participants re-rated the attractiveness of the faces. The team focused on brain systems known to track value within the brain's ventral striatum and the complementary capacity to detect conflict within parts of medial frontal cortex. When participants' beliefs about the attractiveness of female faces deviated from (experimentally manipulated) opinions of others, such deviations from the social norm correspondingly produced decreases in brain regions tracking value and increases in brain regions tracking conflict (Klucharev et al. 2009). The magnitude of this signal was associated with participants updating their own ratings of facial attractiveness to conform to peer norms. In a second sample, the authors showed that the effects were stronger when participants believed that the group ratings were made by other people, compared to when participants believed ratings were made by a computer, suggesting that conformity may be a form of reinforced *social* learning. In their example focused on facial attractiveness, deviations from the social norm triggered a "prediction error" tracking the difference between a person's expected outcome (alignment with social norms may lead to social rewards) and actual outcomes (i.e., misalignment with the group) and caused participants to update their valuation of the faces.

Other teams have also found evidence consistent with the idea that the brain monitors social cues that indicate alignment and misalignment with group opinions during peer feedback, and track these within brain systems associated with conflict monitoring and value (Berns et al. 2005, Tomlin et al. 2013). For example, agreement (vs. disagreement) with expert opinions about music was associated with increased activity in the brain's valuation system within ventral striatum (Campbell-Meiklejohn et al. 2010, Cascio et al. 2015). Likewise, agreement (vs. disagreement) with peer opinions about food was associated with increased activity in the brain's value system within vMPFC (Nook & Zaki 2015). By contrast, non-conformity to peer opinions has been associated with increased activity in brain regions implicated in salience, arousal and conflict monitoring (Berns et al. 2005, Tomlin et al. 2013), which the authors interpret to indicate the saliency or negative arousal produced by going against peer opinions. This account also fits with the broader argument that conformity is first triggered by detecting divergence from group opinion, and arises as a result of learning in which alignment with group norms and values is reinforced, and deviations produce conflict signals.

A brain stimulation study offered further evidence for a causal role of the conflict monitoring component of reinforcement learning in conformity (Klucharev et al. 2011). Similar to the team's earlier fMRI study of conformity, participants rated the attractiveness of female faces before learning about peer perceptions of the same faces; however, in this study, one group of participants made their initial ratings and received peer feedback while undergoing brain stimulation (transcranial magnetic stimulation; TMS) to decrease activity within part of the posterior medial frontal cortex implicated in conflict detection. Other participants completed the task under TMS within a control region, or sham stimulation that did not alter brain activity but involved similar procedures to the other groups. When participants later provided their final face ratings, those whose neural conflict monitoring activity was downregulated during peer feedback showed significantly lower rates of conformity to peer feedback compared to the control and sham stimulation groups. Consistent with an account of conformity that emphasizes monitoring for potential conflicts with social referents, this study provides stronger causal evidence for the role of reinforcement learning in conformity.

A complementary study using pharmacology also suggests that modulating neurochemicals such as dopamine involved in reinforcement learning within the brain's value system can alter people's tendency to conform. Here, methylphenidate (MPH), an indirect dopamine agonist, increased the value of conformity and resulting tendency for subjects to conform to the judgments of others (Campbell-Meiklejohn et al. 2012).

A second group of studies examine brain activity following social influence, typically as participants re-rate stimuli following exposure to others' opinions. In these studies, greater activity in the value system tracks stimuli that were more positively (vs. negatively) rated by peers, and may more closely parallel participants' final valuation of the stimulus itself, rather than the social value of fitting in. This relationship has been found for stimuli such as abstract symbols (Mason et al. 2009), faces (Zaki et al. 2011), celebrity endorsed consumer products (Klucharev et al. 2008), and foods (Nook & Zaki 2015).

Consistent with the idea that that the value system tracks alignment with group opinions during initial exposure to social feedback (i.e., greater value-related activity for agreement than disagreement during feedback), and valence of group opinions during final ratings (i.e., greater value-related activity for stimuli rated more highly by the group), Nook and Zaki (2015) examined brain activity during both initial exposure to peer feedback about food preferences, and during participants' subsequent ratings of foods. Disentangling the valence of peer opinions from the value of consensus during initial peer feedback, they found that during initial exposure to peer opinions, activity in the value system was greatest when participant opinions aligned with peer opinions, and was relatively lower when peer ratings were either higher or lower than the participant's. In later ratings, however, they observed higher behavioral ratings, as well as greater activity within VMPFC to foods that peers had earlier rated higher vs. lower.

This is not universally the case, with some studies reporting greater (rather than less) activity in parts of the value system during exposure to divergent peer opinions (Cascio et al. 2015, Welborn et al. 2016); notably both of these studies focused on adolescents, raising the question of whether there may be developmental changes in the relationship between activity in the value system and social influence. More broadly, questions remain about the extent to which value-related activity tracks the value of conformity (i.e., aligning with the group opinion), the valence of the group opinion (i.e., increasing for stimuli that are more highly valued by the group), or an interaction that accounts for these factors in addition to a participant's starting and/or final valuation. In addition, different parts of the value system (e.g., VS, VMPFC) are highlighted in different investigations. As such, additional research is needed to understand the temporal dynamics of these effects and conditions under which different parts of the value system are most influential. Critically, studies have differentially focused on brain activity during initial preference ratings, peer feedback and/or final preference ratings, and have not consistently ordered participant preference ratings and feedback relative to one another. In addition, these phases have been grouped together differently across studies (e.g., grouping preference ratings and peer feedback together before the scan vs. grouping peer feedback and final ratings together during the scan vs. delivering peer influence during the scan and collecting final ratings after). Despite these methodological differences, common patterns across these studies are consistent with the idea that in adults, the brain's value system tracks deviations and promotes conformity when social norm feedback is initially presented (i.e., during a learning phase), and may subsequently track the updated value of the stimulus (i.e., liking after a participant's attitude reflects the norm).

Complementing the within-subject effects described above, several of the studies described above have found that the magnitude of reaction within key regions of interest also tracks with individual differences in sensitivity to social influence (Cascio et al. 2015, Klucharev et al. 2009, Nook & Zaki 2015, Welborn et al. 2016). Additional studies in teens have also found evidence for links between susceptibility to social influence and sensitivity within the value system (Chein et al. 2011) and brain systems tracking conflict and distress of social exclusion (Falk et al. 2014).

2.2.2 Persuasion and value in the brain.

One key component of the brain's valuation system, the ventromedial prefrontal cortex (VMPFC), is consistently implicated in studies of persuasive messaging, such that brain activity in VMPFC in response to persuasive messages has been associated with subsequent message consistent behavior change. These findings are robust across messages about smoking (Falk et al. 2011), physical activity (Falk et al. 2015), and sunscreen use (Falk et al. 2010). For example, in one early study conducted in sunny Los Angeles, participants were scanned using fMRI during exposure to messages about the need to wear sunscreen every day. Activity in VMPFC during exposure to the health messages was associated with increased message-consistent behavior change (i.e., increasing sunscreen use) one week later. Vezich and colleagues (Vezich et al. 2016) replicated these findings and extended them in several important ways. First, the team showed that the association between VMPFC activity during sunscreen message exposure and subsequent behavior change was particularly strong for messages highlighting message value in terms of reasons *why* to use sunscreen (vs. how to use sunscreen). Second, activity in the VMPFC was greater for gain-framed messages rather than loss-framed messages. Further, activity within VMPFC during gain-, but not loss-framed messages was predictive of subsequent message-consistent behavior change. The response in VMPFC to gain-framed messages is consistent with theories of persuasion that emphasize that perceived positive consequences for the message receiver are a key path to persuasion (Fishbein & Ajzen 2011, Johnson et al. 2004, O'Keefe 2012) and also align with psychological and behavioral economic theories suggesting that messages highlighting positive consequences (i.e., gain-framed messages) are particularly effective in encouraging prevention behaviors such as wearing sunscreen (Rothman et al. 2006).

Complementing these findings, Falk and colleagues (2015) sought to determine whether interventions could experimentally alter message-value to the receiver, and hence activity in the value system, and whether this would in turn produce greater behavior change. To do so, the team used self-affirmation, a technique which is known to decrease defensiveness and increase receptivity to health messaging (for a review, see Cohen & Sherman 2014). Consistent with the central role of value in persuasion, participants who were self-affirmed prior to receiving physical activity messages showed greater activity in VMPFC during exposure to the messages, and also went on to change their behavior more over the following month.

Building on this work, Cooper and colleagues (Cooper et al. 2017) sought to determine whether connectivity between VMPFC and VS (i.e., key brain regions implicated in valuation) would predict behavior change. They found that participants who showed greater connectivity between VMPFC and VS during exposure to the physical activity messages also became less sedentary in the following month. Conceptually related results were also observed in smokers exposed to graphic warning messages related to the social and health consequences of smoking. In that context, connectivity within the value system during negative, smoking-relevant images (vs. neutral control images) predicted changes in smoking behavior (Cooper et al. 2017).

Together, these results highlight the role of neural valuation in persuasion and subsequent behavior change. Indeed, a parsimonious explanation for the wide range of message characteristics, study samples and topics that each link activity in the brain's value system with message consistent behavior change, is that subjective valuation acts as a "final common pathway" to persuasion, as in other forms of decision making. This aligns with the view that multiple types of message effects can be unified as consequence-based arguments (O'Keefe

2012), where affecting perceived consequences (and hence the subjective value of decision alternatives) is key to successful influence and behavior change (Fishbein & Ajzen 2011).

Moving beyond individual decisions to the effects of persuasive communications at scale, activity within the value system in relatively small groups of people is also associated with large-scale behaviors in populations. For example, Falk and colleagues (2012) examined brain responses to televised anti-smoking ad campaigns in a group of 28 smokers and, independently, assessed the success of those same ads in increasing the number of calls to smoking quitlines within large-scale populations. In this case, average brain activity in the value system within the 28 smokers who watched ads from the different campaigns inside the fMRI scanner correctly predicted the campaigns' relative effectiveness increasing quitlines calls in larger populations when the ads were aired at scale. Similar results were observed in a study linking brain activity in VMPFC in a small group of smokers to click through rates in a statewide email campaign attempting to motivate smokers to quit smoking (Falk et al. 2016). Activity in VS and VMPFC during exposure to health-related content have also been linked to large-scale sharing (n=117,611 internet shares) of the same health news articles on the New York Times website (Scholz et al. 2017).

Outside of the health domain, responses in the brain's value system in a group of 27 participants tracked with large-scale music sales (Berns et al. 2010). Specifically, increased activity within the ventral striatum while the group of 27 participants listened to the songs was directly associated with the later population level popularity of the songs. By contrast, participants' self-reports of liking and familiarity of the songs did not predict the population level sales. Likewise, in a large-scale study linking consumer ratings and biological responses to large-scale effectiveness of advertisements (Venkatraman et al. 2015), neural responses in ventral striatum were more tightly coupled with real-world outcomes than a range of other self-report and biological indicators. Consistent with the interpretation that positive value drives these effects, both self-reported positive arousal and activity in the ventral striatum from 28 people during exposure to photographs of potential recipients of microloans predicted the population level success of those photos in garnering actual loans based on an internet database consisting of 13,500 loan requests (Genevsky & Knutson 2015). Extending this logic to a cheaper and more portable neuroimaging technology, brain responses collected with EEG during exposure to movie trailers were significantly associated with objectively tracked box office ticket sales (Boksem & Smidts 2015). Specifically, EEG signals that are believed to originate in MPFC (beta oscillations) were associated with population level box office sales, above and beyond participants' self-reported ratings of movie trailers (Boksem & Smidts 2015). Taken together, these results suggest that there is enough commonality across individuals in which persuasive communications increase activity in the brain's value system that neural activity in small groups is associated with large-scale outcomes across populations. In addition, across these studies, brain activity has predicted variance in behavioral outcomes that differs from what is predicted using other methods such as self-reported intentions.

2.3 Summary

Value maximization is at the core of theories of persuasion and social influence across social sciences. Underscoring this perspective, decisions to share information, being socially influenced by information about others' preferences, and being persuaded by explicit arguments, all centrally involve the brain's value system, such that increased activity in the value system (in communicators) promotes sharing information and (in receivers) being influenced by that information. Several open questions remain, however, about the exact nature of the value system's involvement in different parts of the persuasion and influence process, and about the circumstances under which different components of the value system (e.g., VS, VMPFC) are most relevant. In addition, future research that takes a more nuanced view of sub-regions of the value system known to track valence (i.e., increase with positively valued stimuli, decrease with negatively valued stimuli) vs. salience or the absolute value evaluations (i.e., increase with both extremely positive and negative stimuli) will be informative in understanding receptivity and resistance to influence.

3. Selected inputs to the value computation

What factors increase or decrease subjective value? Social science theories highlight numerous antecedents to persuasion, social influence and behavior change. Likewise, the brain's value system is anatomically and functionally coupled with multiple other brain regions and networks, that serve a wide range of functions. As described above, these connections might be important factors in determining value during persuasion and social influence by contributing to the signal produced by the brain's valuation system. We highlight two inputs to subjective valuation -- self-relevance and social relevance -- that are common across theories of persuasion, social influence and behavior change, and which are especially important to the neural computation of value in information communicators and receivers (Scholz & Falk in press).

3.1 The value of self-relevance

Most studies of value-based decision making implicitly or explicitly focus on the value to *oneself,* rather than the value of an object to some other target. Self-relevance and self-interest also play a central role in several major theories of persuasion, social influence and behavior change. Complementing and extending these views, neuroscientists have linked activity in brain systems encoding self-relevance to valuation, persuasion and behavior change.

Neural activity associated with self-related processing, for instance when participants are judging whether a personality trait describes them or not, is frequently localized in clusters within medial prefrontal cortex (MPFC) and precuneus/posterior cingulate cortex (PC/PCC) (Murray et al. 2012). Neuroimaging research suggests that computations of self-relevance and value are highly intertwined (D'Argembeau et al. 2012, Enzi et al. 2009, Heatherton et al. 2006, Northoff & Hayes 2011). Specifically, functionally, similar regions of VMPFC are active in response to judgements of self-relevance (Denny et al. 2012, Falk et al. 2010, Murray et al. 2012, Northoff et al. 2006) and valuation (Bartra et al. 2013, Levy & Glimcher 2012). Paralleling links between self-relevance and value in the brain, psychologists have shown biases in the judgment of self-relevance and value which include positive illusions, positivity bias and self-serving attributions (Mezulis et al. 2004, Taylor & Brown 1988). On average, self-related entities are judged to be disproportionately valuable and things or concepts perceived to be valuable are readily attributed to the self. Perhaps in part due to its strong connections to valuation, self-relevance is a key consideration both for communicators in evaluating whether to share information and receivers in determining whether they are persuaded. This is also reflected in studies within psychology and communication which show that self-relevance influences how deeply arguments are processed (Johnson & Eagly 1989). In addition, consequences to the self (i.e., self-interest) influence whether people view arguments positively or negatively (Darke & Chaiken 2005).

3.1.1 Communicator's perspective.

From the communicator's perspective, the expected consequences to the self impact the value of sharing a piece of information. Sharing information can make an individual look smart, friendly or helpful, but could similarly harm sharers by making them appear ignorant or tactless.

More generally the promotion and maintenance of a positive self-image is a central human motive (Mezulis et al. 2004), which can be effectively served by communicating with and influencing others, for instance through self-enhancement, or the sharing of information which highlights desirable qualities of the sharer (Berger 2014, Cappella et al. 2015). In other words, the extent to which sharing a piece of information allows the sharer to present themselves in a positive light is one key input to the calculation of information sharing value.

Existing work in communication as well as social neuroscience supports this idea. Generally, the extent to which information is perceived to be self-relevant (Botha & Reyneke 2013) and in line with the sharer's existing beliefs (Cappella et al. 2015) affects whether and how intensively people engage with content. Further, self-relevant content is more likely to be shared, and consumers are more likely to exaggerate the benefits of self-relevant content (Chung & Darke 2006). Additionally, activity in brain regions implicated in self-relevance increases in response to ideas that communicators report wanting to share with others and ideas that are subsequently shared with enthusiasm (Falk et al. 2012b, 2013). For instance, in one study (Falk et al. 2012b), participants first learned about new TV show ideas while undergoing fMRI. Afterwards, they were video recorded while talking about each show idea with the intention of sharing it with another person. When scanned participants showed greater brain activity in regions associated with self-related processing (including MPFC and PC/PCC), among others, their later descriptions of those shows were more enthusiastic.

One often cited reason (e.g., Berger 2014) for why self-related information tends to be associated with high information sharing value, is the fulfillment of self-enhancement and self-presentational goals (Lee & Ma 2012, Matteo De Angelis et al. 2012, Wien & Olsen 2014). For instance, sharing research findings about a new fitness method might make a sharer look intelligent as well as health-conscious. To the extent that these qualities are in line with how the sharer wants to be viewed, this increases the value of sharing the information. Generally, topics that are self-relevant tend to be discussed most frequently (Dunbar et al. 1997, Landis & Burtt 1924, Naaman et al. 2010). For example, in an analysis of Twitter data, Naaman and colleagues describe 80% of their sample as "Meformers", that is users who primarily share information about themselves (Naaman et al. 2010).

Recent neuroscientific work further demonstrated a relationship between neural activity in brain regions associated with valuation and the act of sharing self-related information (Tamir & Mitchell 2012), adding support to the idea that sharing self-related information has value to the sharer. Specifically, in a series of behavioral and neuroimaging experiments, neural activity in both regions associated with self-related thought and valuation were more active when participants disclosed their own beliefs and opinions rather than when they considered those of others. In addition, when participants were given the choice to either answer questions about themselves for a small reward or questions about facts or the thoughts of others for a slightly higher monetary reimbursement, they were willing to forgo an average of 17% in potential earnings for the opportunity of self-disclosure (Tamir & Mitchell 2012). In sum, self-disclosure might be inherently valuable to communicators and engages neural systems similar to those engaged by monetary rewards.

3.1.2 Receiver's perspective.

Self-relevance and self-interest are key elements in several major theories of persuasion, social influence and behavior change. For example, both the Elaboration Likelihood Model of Persuasion (Petty & Cacioppo 1986) and Heuristic Systematic Model (Chaiken 1980) argue that people are more motivated to reflect more deeply on self-relevant information, and that this elaboration can in turn result in more durable attitude change. Studies in these traditions find robust evidence that when more self-relevant outcomes are at stake, people scrutinize the message more, and hence stronger messages show stronger persuasive effects (Johnson & Eagly 1989). Additional work has found that self-interest directly affects information processing and persuasion, such that people are more favorable toward ideas and actions that favor their self-interest (Darke & Chaiken 2005).

In the health domain, a core element of the Health Belief Model of behavior change is an individual's' perception of their personal susceptibility to certain health risks and diseases as consequences of health behaviors (Rosenstock 1990, Rosenstock et al. 1988), suggesting a core role of self-focused considerations. Further, various models of behavior change, among them the Reasoned Action approach (Fishbein & Ajzen 2011) and Social Cognitive Theory (Bandura 2001), emphasize the concept of self-efficacy or perceived behavioral control, which captures a receiver's perception of their ability and opportunity to carry out a specific behavior (Fishbein & Ajzen 2011).

Evidence from neuroimaging also points to a role for self-relevance in the effects of messages on receivers. Early studies in the brain-as-predictor tradition (Berkman & Falk 2013) within the field of persuasion have often focused on aspects of the VMPFC involved in both valuation and judgments of self-relevance. As described earlier in this review, several studies have shown that neural reactivity in VMPFC to persuasive messaging scales with subsequent, message-consistent behavior change in a variety of contexts. However, as mentioned above, both self-related and value-related processing are frequently co-localized within neighboring regions in MPFC, which causes ambiguity regarding the correct psychological interpretation of the observed activity (Poldrack 2006). More recent work has begun to examine both pathways. For instance, Cooper and colleagues (2015) examined both overlapping and non-overlapping regions of interest related to self-related and value-related thought within MPFC while participants were exposed to anti-smoking advertisements. Increased activity in a unique cluster associated with self-related processing and separately a unique cluster associated with positive valuation were each significantly associated with subsequent reductions in smoking, suggesting involvement of both processes.

The study reviewed earlier in which Vezich and colleagues (2016) tested whether activity in VMPFC in response to persuasive messages was associated with sunscreen behavior change argued that VMPFC activity may represent integration of the message's value into the receiver's self-concept. In one set of analyses, they tested whether activity in VMPFC was more strongly associated with behavior change for current sunscreen users or for non-users. If the former were true, this would indicate that VMPFC may index existing pre-dispositions to agree with messages. By contrast, for non-users, changing behavior in response to persuasive messages may involve incorporating message concepts into the self-concept. Vezich and colleagues showed that activity in VMPFC was more strongly associated with behavior change for participants who were not already heavy sunscreen users. The authors thus argue that activity in VMPFC likely tracks positive valuation of arguments and potential integration with a message receiver's self-concept (rather than simply a predisposition to value or identify with the messages).

Other studies have also examined activity across broader sets of brain regions implicated in self-relevance and value processing. For instance, average activity across non-overlapping regions within VMPFC and VS chosen for their role in valuation, and within MPFC and PC/PCC, chosen for their role in self-related processing, when participants are first exposed to abstracts of New York Times articles about health, scales with their intention to read the full text of each article (Baek et al. in press). Taken together, these studies suggest that both self-related thought and valuation are relevant to the impact of persuasion on receivers.

Next to this correlational evidence, the effects of self-related processing on both brain activity in VMPFC and downstream behavior change have also been shown in experimental studies which manipulated the self-relevance of messages to their receivers through techniques such as tailoring and self-affirmation. Specifically, one neuroimaging study manipulated the self-relatedness of anti-smoking messages through tailoring so that, in high-tailored blocks, participants received messages written to directly address their personal smoking habits (e.g. number of cigarettes/day), while, in low-tailored blocks, they received less extensively tailored messages, and in generic blocks, untailored, factual statements about smoking. Contrasting both high and low-tailoring blocks against generic blocks showed increased activity in areas within the brain's self-system, including MPFC and PC/PCC. The same was observed when contrasting high- vs. low-tailoring blocks (Chua et al. 2011). The same group used independent neuroimaging tasks to identify overlapping regions which are more active during exposure to tailored than to untailored messages, as well as during a self-localizer task which contrasts judgments about the self to judgments about valence. Neural responses to tailored anti-smoking messages within this conjunctive mask that responded both to tailoring and self-relevance significantly predicted smoking cessation at a 4-month follow-up measurement (Chua et al. 2011). These neural results are in line with a larger body of work on the effects of tailoring which demonstrates that messages that are tailored to specific individuals' traits and values can also increase persuasiveness and behavior change (Kreuter et al. 1999, Strecher et al. 2005), as well as research that highlights that messages of specific self-interest positively bias information processing and attitude judgements (Darke & Chaiken 2005).

Approaching the problem of self-relevance from another angle, self-affirmation interventions increase receivers' willingness to accept otherwise threatening information, for instance about negative health outcomes of a behavior, as self-relevant and can increase the effectiveness of persuasive messages (Cohen & Sherman 2014). This is achieved by reminding message recipients of their broader values which go beyond the element of their self-image which is attacked by the message (e.g. being a smoker). In an fMRI study of sedentary adults, those who were affirmed prior to receiving health messages about the risks of not getting enough physical activity showed greater activity in brain regions associated with processing self-relevance and value, compared to an unaffirmed control group. In turn, this increased activity within VMPFC was associated with greater message-consistent increases in physical activity (Falk et al. 2016). Together these studies suggest that manipulations that increase self-relevance may in turn increase the value of the message to the receiver and facilitate persuasion. As such, both neural and behavioral evidence highlight the importance of self-relevance in determining message value and persuasive impact.

The work described above is agnostic to the fact that different pieces of information are relevant to the self for different reasons (e.g. because they relate to a core value or a current, short-term project one is involved in). Construal-level theory of psychological distance argues that people use themselves when determining how close (or relevant) information is, such that the reference point for psychological distance "is the self in the here and now, and the different ways in which an object might be removed from that point—in time, in space, in social distance, and in hypotheticality—constitute different distance dimensions" (Trope & Liberman 2010), which are related to one another and affect preferences and behaviors through similar cognitive pathways. Similarly, in the brain these core proximal dimensions of self-representation overlap within MPFC (Tamir & Mitchell 2011), suggesting that different ways of making messages psychologically closer to the self might each similarly affect the value signal, which in turn leads to persuasion and behavior change. In sum, evidence from psychological and neuroscientific studies suggest that various forms of self-relevance (e.g., tailoring arguments to specific receivers; highlighting proximal consequences; testimonials from socially proximal sources who are similar to the receiver) may affect persuasion, preferences and action through similar underlying paths.

3.2 Social-relevance and value processing

Returning to one of our core arguments regarding the neural bases of successful communication, social belonging is a critical feature of human society which has supported the survival of the human race for thousands of years (Baumeister & Leary 1995). Several studies have demonstrated links between social outcomes and valuation. Indeed, the same brain regions that encode non-social rewards and punishments are also sensitive to social rewards and punishments such as approval and rejection by others (Bhanji & Delgado 2014, Fareri & Delgado 2014, Lieberman & Eisenberger 2009). As such, next to self-related thought, considerations of the impact of sharing information on others and, crucially on one's social relationships with others, are relevant to determining the value of information (Berger 2014) as well as in being receptive to persuasion and social influence (Cialdini & Goldstein 2004, Fishbein & Ajzen 2011). That is, sharers need to consider their receivers' current mindsets to estimate their potential responses to shared information in order to determine the impact of sharing on a conversation or relationship. Similarly, receivers need to evaluate the intentions and opinions of sharers to contextualize shared information and devise appropriate responses. Others' preferences can influence receivers not only by providing information about what is valued by others (and hence might be valuable to the receiver) but also providing opportunities for social acceptance through conformity (Cialdini & Goldstein 2004).

The cognitive process of considering the mental states of others is often called theory-of-mind or mentalizing (Frith & Frith 2006, Schurz et al. 2014). Neurally, a broad set of regions including the temporoparietal junction (TPJ), temporal lobes, and dorsomedial prefrontal cortex (DMPFC), are consistently functionally associated with mentalizing (Dufour et al. 2013). Below, we review evidence for the involvement of mentalizing in both sharers' decisions to share and receivers being influenced.

3.2.1 Communicator's perspective.

To effectively transmit information or further a persuasive attempt, communicators need to consider the characteristics, knowledge, beliefs and current mental states of potential message receivers. This can have implications for the expected social outcomes of sharing and thus impact information sharing value. Neuroscientific evidence supports the idea that information sharing value in communicators is partly driven by thoughts about the mental states of receivers. For example, people showed greater activity in the brain's mentalizing system when they considered whether to share New York Times health articles with others compared to other types of decisions (i.e., decisions to read the articles themselves and decisions about the articles' contents) (Baek et al., in press). The same study further identified a positive relationship between activity in neural regions associated with mentalizing and self-reported intentions to share health news information with others. Together these results highlight that brain regions implicated in mentalizing are more engaged during the social context of sharing than other contexts, and scale with preferences to share certain information over others.

Psychological (Traxler & Gernsbacher 1993) and neural (Dietvorst et al. 2009) evidence also indicates that taking the perspective of others can increase the effectiveness of communication, and that successful persuaders activate brain regions that support understanding others' minds more than unsuccessful persuaders (Dietvorst et al. 2009, Falk et al. 2013). For instance, Dietvorst and colleagues (2009) studied mentalizing in salespeople, who need to understand the mindsets of their customers in order to devise effective sales pitches. More successful salespeople tended to be stronger self-reported mentalizers, and showed more neural activity in a set of brain regions associated with mentalizing including TPJ and MPFC.

Based on a communicator's considerations of the mental states of their receivers, the communicator can adjust their sharing strategies to anticipate and mold expected audience responses. This can serve to improve persuasive attempts and maximize impact on receivers, or to manage an interaction or broader relationship between sharers and receivers. This type of audience-sensitivity is often called 'audience tuning'. Existing empirical work has demonstrated the frequent occurrence of audience tuning in communicators (Barasch & Berger 2014, Clark & Murphy 1982). For instance, across several experiments, Barasch and Berger (2014) showed that participants systematically adjust their information sharing behavior depending on the audience characteristics such as the number of people receiving their messages. For instance, during broadcasting (or sharing with many others) participants avoided sharing content that could have reflected negatively on themselves and during narrowcasting (or sharing with one specific other) participants were more inclined to share content that might be useful to the receiver. Audience characteristics can also affect persuasion and social influence indirectly by altering communicator motivations. Specifically, based on further self-reports, Barasch and Berger (2014) concluded that their effects were driven by sharer focus; sharers tended to be more self-focused and concerned about motives like self-enhancement during broadcasting, leading to high sharing value for information that reflected positively on the communicator, and more other-focused during narrowcasting, resulting in more helpful sharing.

A neuroimaging study on the same phenomenon revealed that brain regions associated with mentalizing were in fact more active during both narrow- and broadcasting when each type of sharing was compared to a control condition in which participants identified the main topic of the article, suggesting that people are not exclusively self-focused during either type of sharing interaction (Scholz et al. 2016). A direct comparison of narrow- and broadcasting, however, suggested more intensive mentalizing activity during narrowcasting, dovetailing with the findings regarding other-focused sharing reported by Barasch and Berger (2014) above. Thus, these findings suggest that sharers take into account the current context as well as thoughts and potential reactions of their audience in order to decide what to share and how to do it.

In sum, these findings suggest two important conclusions. First, mentalizing is an important component of the cognitive architecture of sharing decisions across contexts. Second, contextual characteristics like audience size might affect sharing value indirectly by altering the relative weight of sharer motives (e.g. to self-enhance or manage social relationships) which are used to judge information sharing value.

3.2.2 Receiver's perspective.

Social factors also strongly shape the degree to which receivers are influenced. Receivers consider the potential mental states including motives, expertise and opinions of communicators in determining whether they are persuaded (Wilson & Sherrell 1993), and may also consider implications for their relationship with the communicator (DeWall 2010). The importance of social considerations in the targets of persuasive attempts is evident in work within the field of communication science, economics, as well as the social psychological and neuroscientific literatures.

A large number of studies demonstrate that social motives such as affiliation are strong drivers towards compliance and conformity. Cialdini and Goldstein (2004) provide an overview of this work and argue that conformity in receivers is partly driven by the desire for social approval and to promote bonding. When receivers agree with communicators, more harmonious, amicable interactions and relationships ensue. The prospect of positive relational outcomes, in turn, increases the value of compliance and conformity to receivers, somewhat independently of the value of the target belief or behavior. Consistent with this argument, motivation to connect with others has been associated with greater mirroring of a confederate's behavior, an effect which is heightened when earlier attempts to affiliate are hindered by an unfriendly confederate (Lakin & Chartrand 2003). Likewise, people who wrote about being excluded (relative to those who wrote about inclusion or a neutral topic) were more likely to form attitudes on a new policy that were consistent with an anticipated discussion partner's attitudes (DeWall 2010). In other words, behavioral and attitudinal conformity may offer a means to connect with potential social ties, and this motive may be enhanced when other bonds are threatened.

In addition, neural evidence reveals a central role of social relevance in conformity. For instance, greater activity in the mentalizing system when adolescent participants were exposed to feedback suggesting that others' ratings of mobile game applications differed from their own was associated with a greater likelihood of updating recommendations to conform to group feedback (Cascio et al. 2015). Welborn and colleagues (2016) also highlight a central role of the brain's mentalizing system in conformity in adolescents. During a pre-scan survey, a group of 16 to 18-year-old participants made ratings of artwork, and then received feedback for each piece that consisted of parental opinions, peer opinions, or a no-feedback control condition. Critically, the research team focused on neural activity in situations when parental and peer opinions diverged from the participant's. In addition to activity within the value system (in VMPFC), the authors found evidence for increased activity in several brain regions implicated in mentalizing (e.g., bilateral TPJ, precuneus) and cognitive control (e.g., RVLPFC) during social influence from both parents and peers. Further, activity in some of these regions (including VMPFC, rTPJ, rVLPFC) scaled with the participants' susceptibility to peer influence. The authors interpret these findings to indicate that mentalizing and cognitive control resources may help to make sense of others' opinions and then override one's own existing opinions in favor of the social norm. These findings are aligned with theories of influence that place strong emphasis on social norms (Cialdini & Goldstein 2004, Rimal & Lapinski 2015) and suggest that norms are shaped both by external social forces as well as internal perceptions of value in individuals (Rimal & Lapinski 2015). Likewise, the co-presence of activity within brain systems tracking the mental states of others as well as value provide an interesting additional perspective on classic theories of behavior change that give central roles to both social and self-focused dimensions in determining people's intentions to behave in specific ways (Fishbein & Ajzen 2011, Rimal & Lapinski 2015).

3.3. Summary

Two key inputs to the brain's value computation in both communicators and receivers are the self-relevance and social-relevance of the information. Opportunities to increase positive self-views, to increase bonding and to increase social status each promote sharing. Likewise, to the extent that information increases positive expectations for the self, illustrates positive outcomes achieved by others, or promises to promote social bonding with a communicator, this also increases the value of conformity in receivers.

4. Biological coupling as an index of successful communication and influence

Above we have presented evidence that activity in the brain's value system in both communicators and receivers is associated with social influence and persuasion. Connecting these two literatures, we argue that this is not a coincidence. Beyond the processes in either party alone, the degree of synchrony between speakers and listeners is one hallmark of successful communication.

Synchronization of psychological and biological processes in communicators and receivers may facilitate successful communication, social learning and relationship maintenance (Burgoon et al. 2007, Cacioppo & Cacioppo 2012, Cappella 1996, 1997). This has been observed across multiple modalities, including synchronization of non-verbal signals (Cappella 1996, Lakin & Chartrand 2003, Richardson & Dale 2005), language patterns (Branigan et al. 2000, Gonzales et al. 2009, Niederhoffer & Pennebaker 2002) and brain activity of speakers and listeners (Hasson et al. 2012, Silbert et al. 2014, Stephens et al. 2010). Social learning theory emphasizes mirroring as a way to learn not only specific actions, but also the social normative context surrounding those actions in society (Bandura 2001). Neuroscientists have also argued that 'mirror neurons', which fire both when an actor performs or observes the same action, provide an efficient path to understanding others, and to learning and adopting actions (for a review, see Iacoboni 2009). More broadly, this embodied view of social cognition suggests that biological systems that promote mimicry allow us to understand, and in some cases take on, the experiences, thoughts and emotions of others (Hatfield et al. 1993, Semin & Cacioppo 2008), which in turn can promote joint coordination of action (Semin & Cacioppo 2008) and bonding (Cacioppo & Cacioppo 2012). Indeed, even in the absence of a goal to persuade, brain regions involved in mentalizing and value show increased activity when receivers are synchronized with a communicator (Cacioppo et al. 2014); in this way, synchrony may be one indicator of successful communication, which in turn may increase the expected value of continued communication and social interaction and prime neural resources for understanding others' minds and effectively interacting (Spunt et al. 2015).

4.1 Communication between pairs

In the domain of successful communication, Stephens and colleagues (2010) demonstrated evidence of speaker-listener coupling in several brain regions involved in value, self-relevance and mentalizing, including the medial prefrontal cortex, striatum, posterior cingulate and temporal parietal junction. Importantly, the degree of synchrony between speaker and listener brains was associated with successful communication, defined in terms of the listener's comprehension of the speaker's story. Furthermore, in some of the brain regions that showed this coupling (mPFC, striatum, dLPFC), listeners' brains actually anticipated (i.e., preceded) the speaker's corresponding activity, and the degree of this 'anticipatory' coupling was also associated with successful communication. Stephens and colleagues also show that these effects are specific to the process of successful communication-- speaker-listener pairs that did not share the same language (i.e., speaker speaks Russian, listener does not), did not show the same results. This work highlights the possibility that successfully creating shared understanding of information relates to speakers' and listeners' brains synchronizing. The demonstration of anticipatory coupling complements and extends theories of social cognition that emphasize that communicators and receivers do not merely synchronize arbitrarily, but rather use coupling as a means to understand one another's needs and coordinate or co-regulate one another's behaviors (Semin & Cacioppo 2008).

The process of synchronization and coupling may be driven by biological processes and conscious or unconscious motivations in either a communicator, receiver or both (Semin & Cacioppo 2008). As reviewed above, there is value to both communicators and receivers to being in sync with the other, and in the real world, communication processes are often bi-directional. Conformity and synchronization between communicators and receivers may promote bonding (Cialdini & Goldstein 2004) by allowing dyads to understand one another and to co-regulate behavior to coordinate complex tasks (Semin & Cacioppo 2008). In line with this view, synchrony between pairs may be reinforced not only in the brain of the person conforming, but also the person being mirrored (Cacioppo et al. 2014). Cacioppo and colleagues randomly assigned communicators to experience differing degrees of synchrony with their non-verbal communication signals. Communicators not only liked receivers more when they evidenced greater synchrony, but also showed increased brain activity in regions implicated in mentalizing and value processing when receivers synchronized with them. This aligns with the view presented above that coupling may be reinforced and perpetuated both by value maximization in the communicator and receiver.

Scholz and colleagues (2017) examined neural coupling as a possible pathway to social influence. The team measured brain activity as a first set of participants read news article headlines and summaries, which they subsequently communicated to others in the form of social media posts. A second group of participants were then exposed to the same article headlines and the commentaries from the first group. Both groups rated the articles, allowing a quantification of the degree of preference correlation between communicators and receivers. At the neural level, the team found correlated brain activity in regions of interest implicated in valuation, self-relevance and mentalizing between sharers and receivers. This effect was selective to communicating pairs, such that no such effect was observed for randomly paired, noncommunicating group 1 and group 2 participants. Further, the degree of correlated activity within these brain networks was also associated with the degree of correlation between speaker and listener preferences.

4.2 Synchrony across audiences

Beyond direct coupling of brain responses in communicators and receivers, mass media may also serve as a vehicle to bring an audience into sync, thereby capturing the collective mind. Early neuroscience research on intersubject correlation demonstrated that there is a significant amount of similarity in the way that different people's brains respond to natural stimuli like movies (Hasson et al. 2004). More recent research also demonstrates similarity in the functional connectivity patterns as people listened to stories, such that similarity of neural responses was associated with greater narrative comprehension (Simony et al. 2016). Applying this to test whether effective mass communications may exert their effects by capturing the collective mind of an audience, Schmaelzle and colleagues (2015) examined brain responses to strong and weak political speeches. They found that stronger (i.e., more effective vs. less effective) political speeches elicited greater intersubject correlation in medial-frontal cortex among an audience of listeners (Schmälzle et al. 2015). They suggest that more powerful or persuasive media take hold of audiences more collectively, and drive synchronization not only in brain regions implicated in auditory and language processing, but also in higher order systems that help make sense of the message. Complementing these results, Dmochowski and colleagues (2014) showed that synchrony of neural responses originating in MPFC also predicted the degree of audience engagement during the pilot episode of a television show and during Super Bowl advertisements (Dmochowski et al. 2014). Such a process of collective audience engagement is consistent with the idea that cultures align around common values (Schwartz 2006) which are in part influenced by collective exposure to media (e.g., Gerbner 1998). This offers the potential for a finer-grained analysis of which elements of a communication bring audiences most readily in and out of sync with one another, and to tie these dynamics to downstream effects on an audience's ideas, preferences and behaviors.

4.3 Summary

Synchronization of responses between communicators and receivers promotes successful communication and social influence. Importantly, this synchrony seems to occur across communication contexts, but may be influenced by communicators, receivers, their combination, or by an external force such as media. Theories of embodied cognition argue that synchrony allows one actor to simulate the experience of the other and to anticipate and coordinate action. In the context of persuasion and social influence, this type of coupling may facilitate the spread of specific value signals, and hence preferences and behaviors, which may be mutually reinforced by the value of coordination and remaining in sync with valued referents.

5. Future directions

With a few notable exceptions reviewed above, existing research on the neuroscience of persuasion and social influence has primarily focused on individuals in isolation or in asynchronous communication between dyads. In parallel, in examining those individuals' brains, research in this domain has focused primarily on average activity within specific regions of interest. Finally, as with much social and neuroscientific research, the populations studied have tended toward Western, educated samples. Growing bodies of research, however, suggest that incorporating information about broader social networks, brain network dynamics during tasks, and examining a broader set of study populations may substantially expand understanding and the precision of forecasts derived from brain data. Within each of these areas, additional research is also needed to determine the extent to which conscious awareness of the process in question alters the brain and behavioral dynamics at play.

5.1 Social networks and the brain

A small number of studies have examined individual differences in social network position as it relates to the neural processes involved in successful communication. For example, teens who connected more otherwise unconnected friends in their social network (i.e., information brokers) showed greater activity within brain systems associated with mentalizing during decisions about what to recommend to others (O'Donnell et al., 2017). Further research is needed to document the links between the properties of a person's social network and their brain's response to the possibility of sharing ideas and being influenced. Initial studies document the role of the brain's value system in processes that are highly relevant to successful communication, such as tracking popularity within a social network (Zerubavel et al. 2015). As such, integrating social network and neuroscience data will facilitate more nuanced consideration of the different pathways through which ideas spread, as well as links to a range of related social, cognitive and affective processes. For example, extant research on the neural bases of sharing has not distinguished between independent sharing events spurred by a single mass broadcast and sharing that occurs through deep chains (i.e., structural virality; Goel et al. 2015); future research may determine whether the underlying psychology and neuroscience of sharing differ in these contexts. Future research can also elucidate the extent to which sharer characteristics, receiver characteristics and/or interactions between them are most important for determining the likelihood of influence (c.f. Scholz & Falk in press).

5.2 Brain network dynamics supporting social influence and persuasion

A small number of studies building on an emerging literature in network-neuroscience

(Bullmore & Bassett 2011) have also begun to examine how broader network dynamics in the brain might relate to susceptibility to social influence. For example, Wasylyshyn and colleagues (in revision) found that teens who showed more global coupling between key brain regions implicated in mentalizing (and the rest of the brain) during social exclusion also showed greater susceptibility to peer influence on their later driving decisions. These types of studies may also help clarify when and how specific regions of interest are most important; for example, in the current review, we have focused heavily on the brain's value system, and on VS and VMPFC in particular. Although these regions are clearly implicated in both successful communication and susceptibility to influence, some studies have found more robust evidence for one or for the other, and additional research is needed to clarify the roles of each, as well as their relationships to other brain systems in support of communication and influence.

5.3 Cultural and environmental determinants

Additional research is also needed to determine the extent to which findings described above apply across cultures, socio-economic circumstances and developmental stages. For example, value, self and social processes may be given relatively different weights according to cultural background, environmental constraints and developmental stage. Preliminary evidence suggests that social influence may operate differently in the brain depending on cultural variables such as socio-economic background (Cascio et al. 2017) and brain systems most relevant to social influence may differ between adolescents and adults. Finally, additional research is needed to understand when and how culture (Chiao et al. 2016, Han et al. 2013) influences the neural bases of persuasion, social influence and communication more broadly. Likewise, understanding how these processes might vary in cross-cultural or intergroup communication settings is also critical.

5.4 Implicit and explicit motivations

Although we have argued that one strength of neural models of social influence and persuasion is that they are agnostic to whether the processes are consciously accessible to participants, there may be distinctions between conscious and unconscious processes related to persuasion and social influence from the perspective of communicators (Cacioppo et al. 2014, Scholz et al. in press) and receivers (Gawronski & Bodenhausen 2011) in terms of the antecedents of the value calculation or other dimensions that could be modeled in the brain. Future research is needed to unpack the ways in which the degree of persuasive intent in communicators or conscious awareness of susceptibility in receivers alters the value computation and communication process.

6. Conclusion

From the perspective of both communicators and receivers, successful communication and social influence involve positive valuation of ideas, driven in part by self and social relevance. Beyond these processes being associated with both decisions to share and the influence on receivers, emerging research suggests that an active biological coupling between sharers and receivers may facilitate successful communication. Conceptualizing persuasion and social influence under the umbrella of a more general class of value-based decisions offers a framework to link prior social science theories with emerging research in neuroscience, which in turn may provide new theoretical insight (e.g., about the antecedents and dynamics of how this process is implemented) as well as practical advantages in improving our ability to model and predict specific outcomes.

Summary Points

- Decision processes within the realm of persuasion and social influence (e.g. decisions to share information or to be influenced) can be effectively conceptualized as forms of a more general class of value-based decision making.
- Value-based decision making involves explicitly and implicitly weighing perceived costs and benefits to arrive at the value of specific choices or actions. Highly valued options are more likely to be pursued.
- In communicators, the brain's value system tracks the value of sharing information and is implicated in sharing decisions.
- In receivers, the brain's value system tracks the value of incoming information about the opinions and behaviors of others, relative to one's own, and is implicated in conforming to persuasion and social influence.
- Self-relevance is one key source of value that influences decisions to share information and to conform to social influence and persuasive attempts. Neural signatures related to self-related processing are positively associated with both information sharing and reception.
- Social relevance is a second factor which influences the value of decisions to share information and to conform to social influence and persuasive attempts. Neural signatures related to considering the mental states of others are positively associated with both information sharing and reception.
- Communicator-receiver synchrony in key brain regions related to valuation, self-related thought and social processing may underpin successful persuasion, social influence and

communication more broadly.

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Terms and Definitions list (as many as 20, at ≤20 words each)

- Persuasion: Changes in preferences or behaviors in information receivers to conform to active attempts by a communicator to encourage such changes
- Social Influence: Changes in preferences or behaviors resulting from passive observation of others' actions, inferences about others' perspectives, and broader social norms
- Contagion: The spread of ideas or behaviors from person to person through persuasion or social influence
- Information sharing: Transmission of information from communicators to receivers with the implicit (social influence) or explicit (persuasion) goal to exert influence
- Subjective value: A person- and situation-specific estimate of choice value (c), from the weighted average of differently valued choice-relevant dimensions (d): $SV(c) = \Sigma weight_d * value_d$
- Value-based decision making: Choice selection based on the extent to which each option is positively or negatively valued
- Conformity: Changes in receivers' preferences or behavior which are in line with those of others due to persuasion or social influence
- Reinforcement learning: Changes in the choice likelihood of a particular option, based on expected rewards and punishments experienced through past behavior
- Social learning: Changes in choice likelihood of a particular option, based on observed behaviors, rewards and punishments experienced by others
- Communicator-receiver synchrony: Similarities between communicators and receivers in behaviors, cognitions, or preferences during social interactions about shared information

Figure 1

Overview of persuasion and social influence from the perspectives of communicators and receivers. Within this review, we examine the role of valuation in decisions to share (2.1) and in influencing receivers (2.2). We highlight self-relevance (3.1) and social-relevance (3.2) as inputs to the value computation, and neural coupling (4) as a process through which subjective value may be transmitted between communicators and receivers. The brain image shown here depicts the ventral striatum and parts of VMPFC from an automated meta-analysis of studies that involve the term “value” (Yarkoni et al. 2011).