From Believing to Belief: A General Theoretical Model

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Abstract

■ Cognitive neuroscience research has begun to explore the mental processes underlying what a belief and what believing are. Recent evidence suggests that believing involves fundamental brain functions that result in meaningful probabilistic representations, called beliefs. When relatively stable, these beliefs allow for guidance of behavior in individuals and social groups. However, they are also fluid and can be modified by new relevant information, interpersonal contact, social pressure, and situational demands. We present a theoretical model of believing that can account for the formation of both empirically grounded and metaphysical beliefs. ■

INTRODUCTION

Believing is considered to be a mental activity constituted by neural circuits in the brain (Boyer, 2003). It has recently been proposed that the process of believing is composed of neural operations including perception, valuation, information storage, and prediction (Angel & Seitz, 2016). To capture this notion, the term "credition"—a neologism based on the Latin verb *credere* (to believe)—was coined (Angel, 2013). Its purpose is to provide a psychophysiological framework for the empirical study of believing at the neuroscientific, psychological, and social levels of analysis (Sugiura, Seitz, & Angel, 2015). This framework allows empirical data and theoretical concepts at each level to be translated and compared to those at the adjacent levels of analysis. Doing this enables us to do multilevel data mapping so that we can assess their degree of correspondence among levels (Paloutzian & Park, 2013, 2014). The greater their correspondence, the more evidence there is for the validity of the theoretical model that underpins the framework. The ideal outcome is the integration of knowledge about believing across the neural, psychological, and social levels, forming a multilevel interdisciplinary theory of the process of believing (Angel, 2017).

Owing to its character as a process, believing will result in a putative brain product that we call a "belief." It has been hypothesized that beliefs serve a purpose by being linked to personal intuitive judgments about the subjective certainty of sensory perceptions and mental constructs (Harris, Sheth, & Cohen, 2007). A long philosophical tradition exists that states that beliefs are tightly interrelated with knowledge and that it is the combination of belief and knowledge that represents the worldview of the believing individual (Visala & Angel, 2017). As a consequence of and through this process, believing people may intuitively attribute confidence to a given sensory perception or mental construct. Beliefs thereby function as building blocks of typically but not necessarily intelligent behavior in people. The behavior in question may be relevant only to the individual but also may be relevant to the collective verbal or overt behavior of a larger group or society (Howlett & Paulus, 2015; Taves, 2015; Elliott, Jobber, & Sharp, 1995). Thus, although a number of complex social, psychological, and sociological processes are added to them (see Fiske, Gilbert, & Lindzey, 2010, for an authoritative review), the seeds of believing in groups, societies, and cultures are imbedded in the neuroscientific level and are interactive with processes at the higher levels, consistent within the multilevel interdisciplinary paradigm (Paloutzian & Park, 2013, 2014).

On the basis of the notion that the raw material of believing is embodied in brain activity, we previously described the neurophysiological processes that afford believing in the individual (Seitz, Paloutzian, & Angel, 2017). We have also pointed out that these processes take place in the order of milliseconds and are prone to lifelong modification and refinement. Then, as connections between levels build upon and interact with one another and become multilevel as manifested via known psychological and social processes, it becomes possible to explain how narratives and rituals lead to the formation and maintenance of overarching belief systems in the form that can be observed in social groups and societies (Seitz et al., 2017). In this connection, we have argued that the principles that operate in environmental guidance, which can be studied empirically

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in neurophysiology, also enable us by analogy and extrapolation to understand processes at other scales of complexity independent of the level of analysis for brain function. The present article extends the prior discussion to present a theoretical account of the processes of believing to other levels, including believing, meaning making, and worldview construction not only in individuals but also in complex social formations.

MODEL OF BELIEVING BASED ON NEUROPHYSIOLOGY

The basic assumption of our model is that the believing process is afforded by neural activity in the nervous system. It involves the elaboration of a neural representation of an object or event in the external world and the simultaneous association of this representation with some kind of an emotional evaluation. In animals including humans, such representations are typically based on the initial implicit or explicit exploratory analysis of stimuli relative to their environmental context. The information from this exploratory analysis by the appropriate sense organs, in interaction with relevant cognitive schemas and the emotional system, then results in some degree of positive or negative value being assigned to the representation, as summarized in Figure 1.

The process is dynamic, such that the stimulus elements are identified and reiteratively synthesized and then result in multifaceted probabilistic representations (Angel & Seitz, 2016). Bottom–up and top–down processing co-occur throughout this process and characterize the interactions between the signals and the representations. These representations become prominent against background noise, most likely in a Bayesian sense (Dehaene, Lau, & Kouider, 2017; Ryzhov & Chen, 2017; Friston, 2010). The signals from the physical characteristics of objects or events are processed such that the perceived composition of the components of an object is compared with that of a previously perceived item (Adelson, 1993). This comparison process fosters new learning, which results in the updating of percepts of objects or mental constructs as well as the contents of imagination. At the neural level, these probabilistic representations are maintained by a locally specific brain activity, as was described in metabolic and electrophysiological studies (Juliano, Hand, & Whitsel, 1981; Hubel, Wiesel, & Stryker, 1978).

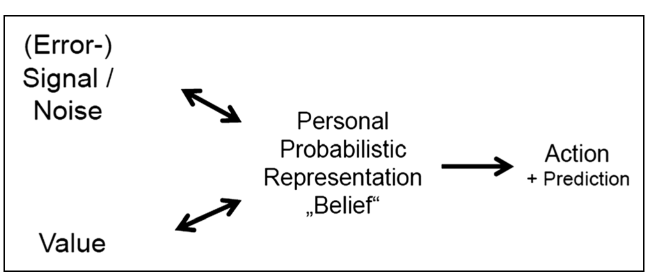

Figure 1. The model of the process of believing.

The processing speed of the above cognitive operations is usually in the magnitude of approximately 20–40 msec, depending on the complexity of the stimulus and its context (Sharan, Rosenholtz, & Adelson, 2014; Bar, Neta, & Linz, 2006). Objects become more identifiable against a noisy background when either the signal-to-noise ratio or the duration of their exposure increases relative to the high processing speed inherent in nervous tissue (Takai & Nishida, 2010). There is a long-standing philosophical discussion as to what point sensory information is processed in parallel, unimodal channels or whether there are general supramodal representations that apply to and comprehend the different sensory modalities (Altieri, 2015). Metabolic and electrophysiological studies have shown that these external signals are mapped into columns or synchronously activated neural assemblies in the cerebral cortex (Gray, König, Engel, & Singer, 1989; Clark, Allard, Jenkins, & Merzenich, 1988). However, the signals can also be manifestations of complex mental constructions such as those provided by narratives, rituals, and music—which can be heard or read and which may involve vivid imagery, imagination, or the identification and contemplation of values (Seitz et al., 2017).

Narratives are conveyed by an elaborated code. Space constraints preclude us from elaborating on the basic principles and processes of codification (Auletta, 2017), but in social contexts, they include such features as language, which can induce mental images and symbols as well as gestures, rituals, music, and so forth. For example, it is through some form of symbolic transmission of a story, a description of a sequence of events and their meanings, that we learn about the history, existence, and fate of a social group or society as well as the individuals within social groups or societies (Schnell, 2012; Belzen, 2010). The perception of a narrative involves a relatively long processing time, determined by the length and complexity of the stories, extending up to many minutes and even hours. Some experimental evidence sheds light on variations in narrative effects. For example, in a recent study, the experimental manipulation led one group of participants to interpret a set of narratives in the same way and another group to interpret the same set of narratives in different ways (Yeshurun et al., 2017). In the participants for whom the narratives shared the same interpretation, the activations that occurred in functional brain circuits involving areas of the default-mode network, language, mirror-neuron, and emotion systems were similar (Yeshurun et al., 2017; Amft et al., 2015). However, in the participants who interpreted the various narratives in different ways, the activation patterns differed among those who had different interpretations and this difference correlated with the magnitude of the differences in interpretations of the narratives.

Virtually simultaneously, upon confronting any given sensory perception (Figure 1), our subjective judgment, whether conscious or nonconscious, evaluates it relative to the notion "What does it mean to me?". Thus, a perceptual representation becomes instantaneously associated with an emotion, which renders the representation as relevant (Angel, 2016; Leuthold, Kunkel, Mackenzie, & Filik, 2015; Seitz, Franz, & Azari, 2009). One of the most important emotions in our system that fosters survival is fear (LeDoux, 2012), because it signifies a perturbation due to threat and danger (Pantazatos, Talati, Pavlidis, & Hirsch, 2012). Similarly, disgust (Schienle, 2009) arouses the animal or human to escape the physical or emotional circumstance. Conversely, the sense of satisfaction signals a beneficial experience that includes feelings of confidence and safety. Such attributions consist of subjective values that reflect relevance, reward, and, ultimately, survival (Paloutzian & Mukai, 2017; Seitz et al., 2017).

The valuation process has been shown to be manifest at the neural level by prominent activations in the medial dorsal frontal cortex (Lindenberg, Uhlig, Scherfeld, Schlaug, & Seitz, 2012; Seitz et al., 2008). Relatedly, the sense of reality, continuity, and subjective assessment of confidence has been localized to the OFC (Liverani et al., 2015; De Martino, Fleming, Garrett, & Dolan, 2013; Rolls, 2006). However, these value attributions are not absolute but dependent on the context, as demonstrated by assessing the effects of various incentive values of a stimulus (Rigoli, Friston, Martinelli, et al., 2016). Therefore, we hypothesize that this association between perception and valuation is a key aspect of the processes underlying belief formation.

Personal probabilistic representations are most often established subconsciously, but they can become explicit, or conscious, when the stimuli trigger high personal meaning (Friston, Sengupta, & Auletta, 2014). Tangible physical objects of high personal meaning can be highly relevant to behavior because they could evoke opposing responses, such as the impulses to avoid and desire an object at the same time (Rolls, 2006). High personal relevance may also be evident when individuals engage in ritual behavior during interpersonal interactions and in social groups (Seitz et al., 2017). To illustrate, a recent study described that involvement of children in ritual practices was one of the sources of an affective loading of cultural narratives (Fernandez, 2015). In general, it appears that the external and internal worlds are fused into unitary meaningful representations of high probability, which are understood as "beliefs" that the individual holds (Figure 1).

However, the strength or clarity of a perception and its attributed value need not be of similar weight for the individual. To the contrary, it is possible not only that the personal meaningfulness of a perception can vary but also that the perception itself and its impact can vary because of its relationship to the external or internal signals that triggered it and the magnitude and valence of the individual's value attributions to those signals. In addition, the contribution of each component to the overall process may vary over time. Thus, even a small or uncertain signal can have a high subjective value, sometimes because of the uncertainty itself. Even so, the signal and valuation components may appear to be at equilibrium, because both perceptual and metacognitive information are being processed in the anterior frontal cortex with a mutual limitation of resources (Maniscalco, McCurdy, Odegaard, & Lau, 2017).

These probabilistic representations that are the stuff of which meaning system processes make what we typically call beliefs (Paloutzian & Mukai, 2017) are the bases on which humans and other animals generate behavior (Figure 1). As such, they are at the root of conscious or nonconscious subjective predictions of the possible rewards and costs of achieving a goal (Seitz et al., 2017; Angel & Seitz, 2016). Accordingly, believing governs the choice of actions. These notions are supported by findings that suggest that sensory prediction is generated in parallel to motor output before an efferent motor action is present (Kurniawan, Guitart-Masip, Dayan, & Dolan, 2013). In terms of neural implementation, anticipation of putting forth effort and of gaining a reward has been shown to be accompanied by an fMRI increase in ACC, the anterior medial frontal cortex including pre-SMA (at the vertical plane through the anterior commissure), and the putamen, for better-than-expected outcomes compared with worse-than-expected outcomes (Bardi, Desment, Nijhof, Wiersema, & Brass, 2017; Kurniawan et al., 2013). In addition, neural activity in the sensory cortex was modulated in anticipation of an action consequence, when the motor signal in the motor cortex indicated effector selection (Stenner, Bauer, Heinze, Haggard, & Dolan, 2015). Furthermore, choice behavior is an integrative action sequence guided by activity in the dorsolateral and medial frontal cortex (Prochnow et al., 2014; Federenko, Duncan, & Kanwisher, 2013) and related to activity in the hippocampus, ventral tegmental area, and striatum, which represent information about the prevailing reward context of choice behavior (Rigoli, Friston, & Dolan, 2016). Thus, there is a widespread prefrontal and subcortical activity in the brain in relation to choice-related guidance of behavior. Interestingly, participants in choice experiments are typically unaware of their decision preferences, although the choices are determined by activity modulation in the anterior pFC (Kahnt, Heinzle, Park, & Haynes, 2010; Tusche, Bode, & Haynes, 2010).

Finally, information acquired in the past becomes stabilized by reinforcement learning, practice, interpersonal corroboration, and social and cultural adaptation, all of which facilitate a sense of familiarity and confidence (Meyniel, Schlunegger, & Dehaene, 2015; d'Acremont, Schultz, & Bossaerts, 2013; Henkel & Mattson, 2011; Chang, Doll, van 't Wout, Frank, & Sanfey, 2010). In addition, predictions based on prior experience may be matched by new experience, leading to a belief that knowledge and meanings based on past experience are reliable. For example, one consequence of performing rituals in groups or as a society is that the repetition of ritual behaviors assists in establishing personal, as well as group, meanings to narratives held by groups or society—a process underpinned by reinforcement learning, habit formation, interpersonal corroboration, and cultural expectations (Belzen, 2010). In animal studies, it has been found that reinforcement learning underlies habit formation by reorganization of cortico-subcortical circuits in the BG under the influence of dopamine (Graybiel & Grafton, 2015). On the contrary, prediction errors may occur when predictions based on probabilistic representations are violated by new experience. An individual may regard these prediction errors as so severe that the person's confidence in the previously held belief is shaken; the result may be a change in belief (Angel & Seitz, 2017). The continuously occurring error signals coded in the brain are the substrates of belief change and the learning of the new associated behaviors and are thereby the basis of context-related modulation of behavior. In particular, the interaction of the OFC and the amygdala has been reported to be of crucial importance for updating action–outcome valuations (Fiuzat, Rhodes, & Murray, 2017). In an interaction with many social and contextual variables, the outcomes can include change for not only small or innocuous matters but also belief change on matters of far reaching importance such as political ideology, religious conversion, and worldview (Paloutzian, Murken, Streib, & Rößler-Namini, 2013; Paloutzian, 2005).

RELATION BETWEEN BELIEF AND BELIEVING

Our basic hypothesis is that brain activity constituted by neural circuits that enable believing results in meaningful probabilistic representations, or putative brain products, called beliefs. Key to the process that relates the cognitive activity to the brain products is that, for a believing individual, a mental construct based on sensory perception (P) is associated with an emotional loading that leads to the attribution of a personal value (V) to this mental construct. The value V may be positive or negative and may vary in strength. We argue that the principles that operate in the environmental guidance of behavior as described neurophysiologically also apply to psychology. We propose that a "belief," although never absolutely fixed, is the end point of a neural process that reflects a preliminarily fluid, quasi-stable state. As such, a belief is a more or less clear meaning that an individual has been made out of initially unclear information that came before it, which first needed to be received, interpreted, and appraised before being responded to. Such fundamental processes operate across levels of analysis in nonhuman and human systems, although they vary in their particulars from the micro (e.g., neuro) to macro (i.e., social) levels (Paloutzian & Mukai, 2017).

Accordingly, the character of a "belief" depends on what has occurred across the time (t) consumed in the course of believing. This means that belief (B) is a function of believing (b):

$$B = \boldsymbol{f}(b, t).$$

When we enlarge this function and integrate the named parameters, we can say that **b** stands for **P** and **V**. This gives us the function $B = \boldsymbol{f}(P,t) * (V,t)$, which means that a belief is a function of perception and valuation at a point in time.

However, the notion "belief" does not provide a direct relation to the notion "process of believing," nor can a definition of what the verb "to believe" indicates be derived from a definition of the noun "belief." Because of this, conceptualizing a belief as a function of the process of believing requires that we tackle at least five theoretical problems.

1. Noun and verb: The issue of the relationship between the notions of "belief" and "believing" rests on the Western linguistic tradition. When using this distinction, one follows implicitly the principle of so-called "universal" or "generative" grammar (Yang, Crain, Berwick, Chombsky, & Bolhuis, 2017; Hauser, Chomsky, & Fitch, 2002), which places importance on grammatically structuring elements such as "noun," "subject," or "verb." However, such common subject–object patterns are not present in many languages from other traditions. Thus, use of such patterns rests on preconditions (universal grammar, generative grammar) that are based on an artificial language composed of a blend of elements of certain actual languages (thus termed "Standard Average European") and therefore has been criticized for its reductive approach, especially by new ontogenetic developmental insights into the complexity of how children acquire language (Goldberg, 2008; Tomasello, 2003, 2008). Developmentally, what one believes is what the person has been told to believe, in that the believing person comes to see the message as relevant to the self and therefore generalizable—and from which the individual develops this capacity himself or herself but which is also constantly recalibrated (Tomasello, 2003, 2008; Sperber, 1996). However, such initial believing and the constant recalibration of beliefs constitute processes of making and remaking meaning based on successive probabilistic representations. Therefore, our model, which is rooted in these processes, accommodates the linguistic problem of how to relate nouns to corresponding verbs.
2. Time and tense in verbs: In many European languages, verb forms are used to indicate the time when an action or event takes place. There are grammatical means to specify the time when an action or

event has occurred or when a state or process is ongoing. This linguistic reference to time is called "tense" (Hamm & Bott, 2016). Widely used is Reichenbach's famous distinction between speech time, event time, and reference time to differentiate between language and reality (Reichenbach, 1947). In addition, for languages, the propositional logic has to be extended to a propositional temporal logic (Goranko & Galton, 2015), a concept that was introduced by Prior (1967) and meanwhile has been highly formalized (Gabbay, Hodkinson, & Reynolds, 1994). Therefore, our model that is rooted in this background accommodates time-related linguistic expressions to attribute tense to corresponding verbs, especially to the verb "to believe."

3. Time: Because any process extends over time, a theoretical issue is how a process is best understood and described in relationship to time. Because in antiquity time has been one of the most vividly reflected concepts and is still widely discussed (Le Poidevin & McBeath, 1993), natural philosophers have struggled to comprehend the nature of three tightly interconnected concepts: space, time, and motion (Huggett & Hoefer, 2017). The most reductive way to formulate the relationship between process and time is based on conceptualizing time as measurable. Doing this makes it possible to relate a specific state (S_1, S_2, etc.) to a certain point in time (t_1, t_2, etc.). However, the notion of time goes beyond measurement. The Ancient Greeks used the term "*kairós*" (καιρός) to indicate a "quality of time," which can, for instance, appear as the right moment for a decision (Gallet, 2007; Vardaman, 1998; Wilson, 1980). Since then, two contradicting approaches stimulated the discussion (cf. Markosian, 2016): Aristotle and others (including, especially, Leibniz) argued that time does not exist independently of the events that occur in time (known as "reductionism/relativism with respect to time"). The opposing view was defended by Plato, Newton, and others (normally referred to as "Platonism/substantialism with respect to time"). On this view, time is like an empty container into which things and events may be placed, but it is a container that exists independently of what (if anything) is placed into it. In modern science, after the development of relativity, the spacetime theory (Huggett & Hoefer, 2017) found interest among philosophers (Friedman, 1983; Sklar, 1974). Moreover, in an influential article, McTaggart (1908) even denied the existence of time arguing that the appearance of a temporal order of events to the world is a mere appearance unless illusory (Markosian, 2016). In the Whiteheadean philosophy (Whitehead, 1929/1978), the issue of how to relate a specific state to a certain point in time is a conundrum. The fundamental issue is how an "actual entity" (i.e., a specific state) comes into being while it is itself a constituent for the upcoming time (Maaßen, 2017). Taking into account the complexity and pluriformity of time concepts, our model highlights the problem of how to integrate time into the processes of believing.
4. Mathematical: Using the form of a mathematical formula, we have raised the question of what kind of function is adequate to express the relationship between the state of a belief (B) and its underlying process (b). Despite the ongoing discourse on the notion of time, we acknowledge that the process **b** accomplished in the brain extends over time (t), which can be measured. The neurophysiological model of this process as expressed in the equations below is the initial snapshot needed to reflect the core ingredients of the "belief"–"believing" relationship.
5. Multilevel translation of concepts: Many important psychological concepts are stated primarily as nouns. The list includes words such as knowledge, trust, confidence, balance, attribution, and value. Of relevance to our argument, the predominance of noun-related use is apparent for "belief" and "faith." One might assume that these nouns and their verb forms (e.g., to know) would be related to the same brain activities. However, noun and verb uses are related to different brain activities (Pulvermüller, Lutzenberger, & Preissl, 1999), indicating that nouns and verbs are processed in neurophysiologically different ways. Because of this, to neuroscientifically differentiate between a "belief" and the "believing" process (credition) in any one case, we must translate the concepts and data that represent the belief, and/or the concepts and data that represent the process of believing, into a form that enables us to assess their degree of correspondence at a common level of analysis. Extrapolating this point, when we analyze the activities that comprise "while believing," we ought to also be able to do likewise with parallel concepts and mental activities (e.g., "while knowing"; Runehov & Angel, 2013).

THEORETICAL MODEL DESCRIPTION

Let us now summarize our model in a mathematical equation. We think it is capable of summarizing the processes of believing at both a neurophysiological level and a social level, as detailed above.

Neurophysiological Level

Given that believing is a fundamental brain process that leads to representations of high subjective probability, and although the precise relationship between believing and belief has yet to emerge, we suggest that the process of believing results in a belief. Formally, this can be stated thus:

$$\mathbf{B} = \mathbf{S}/\mathbf{N} \times \mathbf{V}$$

A belief (**B**) is afforded by the perception (**P**) of an object or event, that is, by identification of a signal (**S**) out of a sample of ambient noise (**N**). The greater **S** is in proportion to **N**, the more reliable the sampled information is. In addition, the individual attributes (**x**) a value (**V**) to a given perception. The value can be either positive (indicating reward or attraction) or negative (indicating aversion, threat, or danger), as valuation tends to be bimodal, not graded (Vlaev, Chater, Steward, & Brown, 2011). Because humans tend to avoid aversive situations, behavior is usually guided by stimuli that promise positive emotions. In addition, **S/N** and **V** are independent of each other; thus, a large **S/N** can have a small **V**, and a small **S/N** can have a large subjective **V**. Thus, in general, a positive value of **B** is an indicator of a meaningful representation of high probability, that is, a "belief." This equation allows us to account for various "beliefs."

Beliefs are acquired fast but may change over time because of new experience and contradictions to predictions based on previously held beliefs. This possibility is apparent by an additional term in the equation:

$$\mathbf{B} = \mathbf{S}/\mathbf{N} \times \mathbf{V} + (\boldsymbol{\alpha} \times \boldsymbol{\delta}) \times \mathbf{V}_{\boldsymbol{\delta}}$$

As reflected in this equation, beliefs are fluid. They are constantly being adjusted by the perception of new signals (**+**), in a Bayesian sense. These meaningful probabilistic representations are also modified over time by new learning ($\boldsymbol{\alpha}$), which is a fundamental capacity of brain physiology ($\alpha = 1$). However, a belief based on previously held information may be violated by new information, resulting in a prediction error ($\boldsymbol{\delta}$), whose compatibility with or aversion to the previously held belief is valuated ($\mathbf{V}_{\boldsymbol{\delta}}$), as described above. Consequently, the change term in the equation acquires a positive value (1) if the prediction error is relevant for a person. This means that a new belief replaces the previously held belief. However, if a prediction error has no subjective value or meaning (0), there is no change in belief.

Social Level

The logic of our model can be extrapolated to accommodate processes of believing at the social level. The structure of the equation is the same, as beliefs are formed and modified in the way explained above in the individuals who are members of social groups or societies. However, the believing processes involve probabilistic representations of complex social stimuli, making meaningful percepts out of multiple mixes of stimuli transmitted through many media and in varied contexts, and complicated interpersonal and social appraisals, responses, and meaning remaking via channels and iterative feedback loops functional at the social level. The processes include human two-way interactions, small and large group dynamics, and societal and cultural traditions, expectations, and communications (see Fiske et al., 2010, for comprehensive reviews)—the blend of which is analogous to the "smaller" mechanisms at the neural level and functionally equivalent to them. This means that, for example, at the social level, **B** represents collective or group beliefs. The processes of aggregate believing involve information, arguments, debate, attempts at persuasion and attitude change, and exposure to new information—all of which may affect new learning ($\boldsymbol{\alpha}$). In addition, collective doubt, resistance, and confrontation with input contrary to previously held beliefs would all imply some degree of prediction error ($\boldsymbol{\delta}$). Finally, the combined result of these processes is assigned some degree of a collective positive or negative value ($\mathbf{V}_{\boldsymbol{\delta}}$). Thus, the processes involved in believing at the aggregate level, and likelihood of the maintenance or change of a belief, differ in their particulars but are brought about by the believing processes at the neural level in individuals.

DISCUSSION

Putative Brain Process

Our model of believing at the individual level highlights putative processes resulting in probabilistic representations in the brain. It aims to explain the most fundamental aspects of the processes of believing in neurophysiological terms, based on evidence that believing is mediated by neural circuits and synaptic activity. The model argues for a tight integration of objective information and subjective worldviews as a basic aspect of believing as it occurs within brain circuits. Admittedly, the subjective content of these representations in a person's mind, including personal beliefs, is not directly accessible to others. Thus, their exact nature, and therefore their veridicality, is neither provable nor disconfirmable. However, we can do a scientific exploration of their proxy manifestations, such as verbal reports, emotional reactions, and behaviors that stem from them.

Subjective Valuation

Our model of believing is consistent with a similar psychophysical argument about how people acquire, hold, and modify empirically based beliefs (Nassar, Wilson, Heasly, & Gold, 2010). However, our model adds the subjective domain in belief formation as it emphasizes the importance of the attribution of some subjective value to the analysis of signal relative to noise, that is, to a formal signal analysis. Accordingly, people's belief systems involve a unique preevidential and probabilistic judgment of the world that biases subsequent categorizations and evaluations. The beliefs that emerge from this process are therefore, to some degree, intuitive (Morewedge & Kahneman, 2010).

The resulting intuitive beliefs can be a powerful component of an individual's belief system and can include the individual's implicit or explicit answers to questions about how to cope with the future and how to provide existential meaning, whether secular, political, spiritual, or religious (Kaplan, Gimbel, & Harris, 2016; La Cour & Hvidt, 2010). They also affect answers to other issues such as what values to hold, what priorities to live by, and what is ultimately most important. Such beliefs are typically experienced as bipolar—being either true or false—rather than on a gradient of subjective uncertainty (Johnson, Merchant, & Keil, 2015; Vlaev et al., 2011). Moreover, because beliefs can profoundly affect behavior, whether worldview-driven such as costly but humane acts due to one's religion or behaviors more immediate as has been found for gaze and other similar responses to primes (Wiese, Wykowsky, & Müller, 2014; Kristjansson & Campana, 2010), we can assume that personal probabilistic representations are of high momentary subjective relevance.

Social Level

Our model of believing extrapolated to the group or societal level highlights that the processes involved in believing not only go on in the brain of individual participants. Rather, they feed and are fed by psychological and social processes, within which individuals communicate, interpret the possibly varied meanings in communications, and then settle upon one representation of them to which to respond. Therefore, as people grow up and are imbedded in social groups, successful communication is fundamental to the exchange of meanings of perceptions, imaginations, and mental states. Thus, evolution of social groups in addition to, not in place of, the personal maturation of individuals becomes important. Living in a society requires the generation of systems of meaningful representations that are similar across individuals and exhibit a liability for communities as they give meaning to people's collective work. Moreover, emotional value and personal meaning are attributed to the belief systems that are shared by groups of people and societies. As metaphysical beliefs are rooted in narratives or myths that refer to the past, even beyond the limits of personal experience, they can constitute the experience and knowledge and, thereby, the belief systems of individuals from childhood onward (Seligman & Brown, 2010). Nevertheless, the contents of the believing process can be secular or nonsecular and different across different social groups, societies, and cultures (Seitz et al., 2017; Vogeley & Roepstorff, 2009).

Believing, Knowing, and Belief Change

In an important philosophical tradition, beliefs are understood as epistemic attitudes toward certain propositions or content (Visala & Angel, 2017). This corresponds to Gettier's most famous definition of knowledge as "justified true belief" (Gettier, 1963). Beliefs can be based on objective empirical evidence, a priori knowledge, or social experience. However, the meanings that render beliefs personally relevant can also create subjective resistance to challenges by outgroup individuals. For example, as sets of beliefs become combined in increasingly complex webs to form overarching attitudes, worldviews, and ultimate concerns, they also become more firmly accepted as good, wise, and true and, as such, more difficult to change. We highlight that, according to our model, the processes of believing connect someone's past sensory experience to his or her predictions about the future. These predictions correspond to personal expectations and have highly subjective emotional loadings but may be violated by the person's social environment (Angel & Seitz, 2017). For example, it has been found that beliefs can be modulated by varying the number of repetitions of presenting an individual with new information (Kaplan et al., 2016). Accordingly, beliefs can be modified by repeatedly confronting someone with new information but are not likely to be fully reversed by such confrontation.

Affective Relevance

A belief may be of high affective relevance for the individual, but its content can be elusive, defying objective verification. Specifically, the contents of a belief may be the objects of sensory experience but also depend on other mental constructs. Because a belief is determined by the sensory, emotional, and mental capacities of an individual, it is imbedded in an ongoing process of development and is immersed in new experience, education, and learning.

Certain mental constructs, including religious and political beliefs, are based on narratives and rituals known to convey largely similar meanings in large groups of people or societies (Schnell, 2012; Belzen, 2010). Such beliefs can be viscerally held and difficult to change. For example, in one study, political beliefs were found to be less prone to discounting because of contradictory statements, as compared with nonpolitical beliefs (Kaplan et al., 2016). In another study, people who were against education about condoms were found to resist believing that using condoms helps decrease pregnancies and sexually transmitted diseases (Liu & Ditto, 2012). Similar findings are found not only in research on other examples of believing but also on related research on attitudes and attitude change (Albarracin & Johnson, 2018), as illustrated in longitudinal in-depth interviews of those who retain their belief in a political figure although compelling facts document his or her dishonesty (Hochschild, 2016). A potentially fruitful explanation for such findings may be that beliefs that are difficult to change exist within a relatively tightly knit self-sustaining network (Castillo, Kloos, Richardson, & Waltze, 2015), and it may be that efforts to change them work better by invoking values, not facts. In addition, because religious beliefs typically are stable, small changes in religious beliefs (e.g., change from uncommitted to committed, within the same religious tradition) may be more likely to occur and be less cognitively demanding than major changes in religious beliefs (e.g., conversion from one religion to another), as highlighted by Paloutzian (2005).

Neuroscience of Believing

The psychophysical and neurophysiological processes that underpin the expression of beliefs have been found to involve the medial dorsal pFC (Kaplan et al., 2016; Krueger & Grafman, 2013; Seitz & Angel, 2012). In a cross-cultural comparison, narratives about individuality and belonging to a social group were shown to be associated with activation of the dorsal medial frontal cortex (Han et al., 2008), supporting the idea that the medial dorsal frontal cortex plays a critical role in maintaining a stable belief. In context of stable political beliefs, activity in the anterior dorsal medial frontal cortex was shown to be high but decreased in context of nonpolitical beliefs (Kaplan et al., 2016). Furthermore, neuroimaging has shown that widespread areas in higher-order brain areas become activated when a person is engaged in believing (Han, Zhang, Wang, & Han, 2017; Howlett & Paulus, 2015). This widespread brain activity probably corresponds to transregional binding of oscillatory brain activity in extensive neural networks that has been reported to underlie encoding, retrieval, and association of information from different modalities (Singer, 2009; Gross et al., 2004). The model characterized by these neuroscientific findings is compatible with findings about long-acting influences of hormones and long-term changes in neurotransmitter substances, which are considered important for the manifestation of depressive symptoms (Nadim & Bucher, 2014). Thus, our model is also able to account for pathological brain states that can result in the acquisition and maintenance of abnormal beliefs such as in delusions or hallucinations, because they may employ similar cerebral pathways (Pechey & Halligan, 2012; Bell, Halligan, & Ellis, 2006).

Earthbound

Perhaps, the ultimate mental construct is the human notion of God. However, even with all of our neuroscientific, psychological, and sociological knowledge about beliefs and believing and with the beginnings of our understanding about the processes mediating them, all believing, even the mental construct of God, is nevertheless inherently earthbound, residing within the limits of human existence.

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