Metacognitive confidence: A neuroscience approach

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Abstract

Metacognition refers to thinking about our own thinking and implies a distinction between primary and secondary cognition. This article reviews how neuroscience has dealt with this distinction between first and second-order cognition, with special focus on meta-cognitive confidence. Meta-cognitive confidence is important because it affects whether people use their primary cognitions in guiding judgments and behaviors. The research described in this review is organized around the type of primary thoughts for which people have confidence, including judgments about memory, choices, and evaluative judgments. Along with other areas, prefrontal cortex and parietal regions have been consistently associated with judgments of meta-cognitive confidence in these three domains. Although metacognitive confidence might be associated with particular brain activity in most of the studies reviewed, confidence often seems to be confounded with other potentially important dimensions, such as effort and ease. Given that people tend to be less certain in tasks that are more difficult, more research is needed to examine the brain activity specifically linked to confidence.

Keywords: Metacognition, confidence, certainty, doubt, neuroscience, brain.

Confianza metacognitiva: una aproximación desde la neurociencia

Resumen

La meta cognición se refiere a lo que pensamos sobre nuestros propios pensamientos e implica la distinción entre cognición primaria y secundaria. El presente artículo describe como la neurociencia ha examinado esta distinción entre cognición de primer y segundo orden, presentado especial atención al concepto de confianza metacognitiva. Este tipo de confianza es importante ya que determina en qué medida las personas usamos los pensamientos a la hora de guiar nuestros juicios y acciones. La investigación descrita en este trabajo se organiza a través del tipo de cognición primaria sobre la que se tiene confianza o duda, incluyendo juicios sobre nuestra memoria y también sobre nuestras evaluaciones y decisiones. En la mayoría de estudios, las áreas de la cortera prefontal y parietal aparecen vinculadas con los juicios de confianza en estos tres dominios. A pesar de la asociación observada entre la confianza metacognitiva y algunas zonas concretas de actividad cerebral, el presente trabajo precisa que la confianza a menudo se confunde con otros aspectos como la facilidad y el esfuerzo. En la medida en que se suele estar menos seguro de los juicios de tareas difíciles, se hace necesario llevar a cabo investigaciones en las que se especifique con mayor precisión la actividad cerebral vinculada con la confianza.

Palabras clave: Metacognición, confianza, certeza, duda, neurociencia, cerebro.

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Metacognition refers to thoughts about our own thoughts or thought processes and implies a distinction between primary and secondary cognition (Dulonsky & Metcalfe, 2009). Primary thoughts are those that occur at a direct level of cognition and involve our initial associations of an object with some attribute, such as "I choose that product" or "I would like to sit down here with you." These primary cognitions are also called "object level" thoughts (e.g., Nelson & Narens, 1990). Following a primary thought, people can also generate other thoughts that occur at a second level. These thoughts involve reflections on the first level thoughts (e.g., "Do I really want to make that choice?" or "I am not so sure how much I would like to sit down here.").

Among other things, secondary thoughts are important because they can magnify, attenuate, or even reverse the impact of first order cognitions. As noted recently by Briñol and DeMarree (2012), metacognition has assumed a prominent role in social evaluations, decisions, as well as identity, and interpersonal interactions. In the present article, we review some of the work relevant for understanding how metacognition operates in the brain.

There are several dimensions on which metacognitions can vary. For example, Petty, Briñol, Tormala, and Wegener (2007) suggested that people can think about their thoughts in terms of dimensions such as valence, number, target, origin, evaluation, and confidence. Thus, two individuals might have the same thought but one believes that the thought stemmed from their own brains whereas another believes the thought reflects someone else's views. In another classic taxonomy, Dunlosky and Metcalfe (2009) classify metacognitions into three primary types: metacognitive knowledge (people's naïve theories about their thinking), monitoring (evaluating the appropriateness of one's own thoughts), and control (regulation on the thoughts). For example, students' perceptions that they "know" information for a test (over and above student's actual knowledge of the material) can regulate people's behavior (e.g., by discontinuing studying for a test on the target material; Flavell, Friedrichs, & Hoyt, 1970).

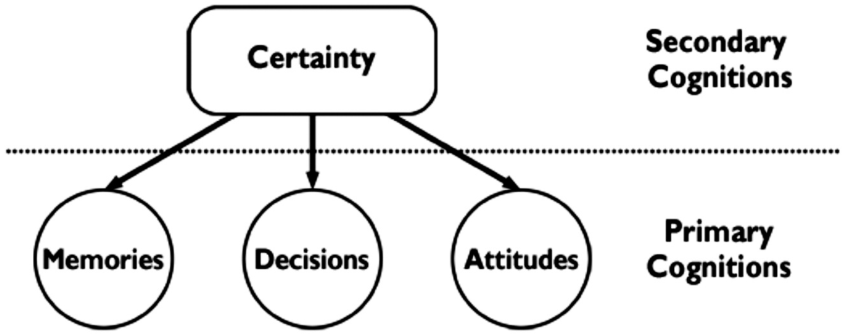
We begin this article by reviewing how neuroscience has dealt with this distinction between first and second-order cognition. Although we will refer to different types of metacognitions throughout, we will focus our attention on metacognitive confidence. The second part of the chapter describes the importance of considering metacognitive confidence because it affects whether people use their primary cognitions in guiding judgments and behaviors. The research described in that section is organized around the type of primary thoughts for which people have confidence, including judgments about memory, choices, and evaluative judgments.

Primary vs. Secondary Cognition

As just noted, a number of different frameworks highlight the importance of distinguishing between primary and secondary cognition. One of these approaches comes from Nelson and Narens (1990) who emphasize the difference between primary "object level" processing (e.g., perception or recognition) and secondary "metalevel" processing (e.g., top-down control processes). In this approach, primary vs. secondary cognition are organized hierarchically since metacognition operates as a top-down process to regulate primary cognition. Thus, the terms "primary" and "secondary" cognition do not merely refer to the temporal sequence of cognitions; more importantly, primary cognitions are the *target* of secondary cognitions (see Figure 1).

FIGURE 1

Metacognition refers to the phenomenon of having secondary cognitions about primary cognitions. This does not only imply a particular temporal sequence; rather, it is that the target of a thought, likea judgment of certainty, is a thought itself (e.g., a memory). Although instances of primary and secondary cognitions range beyond the example in the diagram, this review focuseson the examples depicted



Applying a neuroscience approach to metacognition, *dynamic filtering theory* proposes that the prefrontal cortex (PFC), with neural bidirectional projections to many cortical areas, is a filter mechanism that controls information processing and primary thoughts of posterior cortical regions (Shimamura, 2000; see also Metcalfe, 2009). Thus, the PFC may be critical for metacognitive processes. Indeed, existing research supports the role of the PFC in metacognitive, top-down control of information processing in domains ranging from perception to language (Del Cul, Dehaene, Reyes, Bravo, & Slachevsky, 2009). Metacognitive awareness can even be manipulated independent of primary cognitions using transcranial magnetic stimulation in the dorsolateral prefrontal cortex (DLPFC; Rounis, Maniscalo, Rothwell, Passingham & Lau, 2010).

Taken together, the examples described in this section suggest that primary and secondary cognition can be dissociated in terms of brain activity.

MetaCognitive Confidence

The confidence with which people hold their thoughts is one of the most essential dimensions of metacognition. Confidence refers to a subjective belief about the validity of one's thoughts or judgments (for a different use of the term confidence, see. e.g., Camblor & Alcover, 2012). The degree of *confidence* can vary from extreme certainty to extreme doubt in the validity of any primary cognition. This metacognitive confidence is consequential since it influences the extent to which primary cognitions influence behavior. As an initial example of the importance of metacognitive confidence, consider work on eyewitness identification. Eyewitnesses are more likely to act according to their identification judgments (primary cognition) when they have high (vs. low) metacognitive confidence in those judgments, regardless of actual accuracy. Furthermore, other people (e.g., juries) are also highly influenced by the confidence that eyewitnesses express in their testimony. In this context, judgmental confidence is one of the most compelling arguments to convince police investigators, prosecutors, and juries (Wells, Olson, & Charman, 2002).

Among other areas, metacognitive confidence has been examined systematically in the domains of memory, decision making, and evaluative judgments. In the next sections we review the neuroscience research conducted in those areas. In each of these domains, metacognitive confidence is important because it affects whether people translate their individual thoughts into more general judgments, and whether these judgments in turn are influential in guiding behavior. Although confidence has been studied across a variety of domains and with regard to many types of primary cognitions, an exhaustive review is beyond the scope of this article. In the next section, we focus on reviewing some of the main research conducted in neuroscience that has aimed to uncover the neural mechanisms that correspond with the roles that confidence and doubt play in memory and decision making. We will then apply these findings to the attitudinal domain and examine how attitude certainty might be represented at the level of the brain. Although we speculate as to why particular brain areas are implicated in confidence judgments, one of the main goals of this review is to bring together seemingly disparate literatures for a first glimpse at what common neural mechanisms might underlie a general process of certainty. Our goal is to review the research conducted so far on metacognitive confidence across different domains, highlighting brain areas that appear consistently across these diverse paradigms. A complete integration of existing findings is beyond the scope of this review, but by presenting this body of research, we hope to convey both the complexity and promise of neuroscience methods in understanding metacognitive processes.

MetaCognitive Confidence in Memory Processes

The initial work on metacognition is deeply rooted in the study of people's perceptions, feelings, and theories of their own memory. For example, a feeling of familiarity is often interpreted as indicating that something is known or remembered (Reder & Ritter, 1992). In addition to memory, early work in metacognition examined people's judgments of their own knowledge (Koriat, 1993) and learning (e.g., Metcalfe & Finn, 2008). For example, considerable research has shown that people's beliefs that they could recognize an answer from a list of available options predicted their actual recognition (e.g., Hart, 1965). Although findings such as this demonstrate some accuracy with regard to beliefs about memory, it is not the whole story. Indeed, the amount of time that students spend in studying for a test depends more on what they think they know than on their actual, objective knowledge (e.g., Flavell et al., 1970). Thus, it is clear that judgments about knowledge are sometimes based on the actual presence or absence of information in memory, but they are also influenced by ephemeral factors like the perceived ease with which information comes to mind.

As these examples illustrate, people can make judgments about what they think they already know, and also about what they think they will be able to know or retrieve from memory. These *feeling-of-knowing* (FOK) judgments can refer to a primary cognition in the future or in the past. That is, people can have different degrees of confidence that they will be able to remember some memory at a later time, and people can have retrospective confidence judgments about a memory that has already been retrieved (Pannu & Kaszniak, 2005). In other words, the primary cognition in FOK judgments is thought of as the prediction of future retrieval ability whereas the primary cognition in retrospective confidence judgments is a memory report that has already been made. Notably, however, the memory reports serving as primary cognitions for retrospective confidence judgments can include the recognition of previously learned stimuli, recollection of a memory's source, and other types of memories.

First, FOK studies often employ a paradigm in which participants learn a set of stimuli and later respond to memory cues by predicting how likely they would be to recognize or recall the appropriate target information. In these studies, greater perceived future retrievability corresponds with activation in the ventromedial prefrontal cortex (VMPFC) and medial and lateral temporal cortex (Schnyer, Nicholls, & Verfaellie, 2005). Greater FOK reports also activate the bilateral inferior frontal gyri (IFG), left medial frontal gyrus (MFG), anterior cingulate cortex (ACC), and bilateral caudate nuclei at the time of the FOK ratings. Several of these areas (MFG and ACC) were also related to later successful recall (Kikyo, Ohki, & Miyashita, 2002).

Importantly, FOK judgments and retrospective confidence judgments rely on unique neural processes (Fleming & Dolan, 2012). Although patients with damage to the VMPFC, compared to controls, demonstrate impaired FOK accuracy, the accuracy of their retrospective confidence judgments remains intact (Schnyer et al., 2004). The authors note that the VMPFC could be specifically implicated in FOK processes because of its role in integrating output from the medial temporal lobe.

Retrospective confidence judgments have been shown to evoke corresponding brain activations in the DLPFC. For instance, when people correctly indicate whether or not they have seen a target word in a previous list, right DLPFC is relatively more active when the judgment is accompanied by a high (vs. low) degree of subjective confidence (Henson, Rugg, Shallice, & Dolan, 2000). Consistent with work linking the parietal cortex to the subjective, phenomenological experience of memory (Wagner, Shannon, Kahn, & Buckner, 2005), parietal regions have also been associated specifically with retrospective memory confidence ratings. Across three studies, bilateral parietal lesion patients showed reduced confidence in their recollection of the source of target memory items, compared to controls (Simons, Peers, Mazuz, Berryhill, & Olson, 2010). Interestingly, these deficits were specific to source recollection confidence; confidence in recognition tasks (old/new judgments) did not differ between groups. These results suggest not only that parietal cortex is important for memory confidence (and not necessarily recall itself) but that making retrospective memory judgments might rely on unique neural processes, depending on the demands of any particular memory task.

Parietal regions may also play a role specifically in the process of *making* confidence judgments. Compared to making memory judgments (e.g., recalling the orientation of a name when it was encoded), when making confidence judgments about one's memory judgment, medial and lateral parietal regions show greater activation (Chua, Schacter, Rand-Giovannetti, & Sperling, 2006). These activations, however, may not reflect the necessary mechanisms of making such a judgment (i.e. the process of reporting certainty); rather, these parietal regions may be necessary for storing certainty representations that must be accessed when making such judgments.

Other brain regions have also been shown to correspond with the degree of confidence people express in their memory reports. For example, posterior cingulate cortex (PCC) and medial temporal lobe (MTL) activations have been shown to correspond with high (vs. low) confidence judgments in a Deese-Roediger McDermott (DRM) recognition paradigm (Moritz, Gläscher, Sommer, Büchel, & Braus, 2006) and in a paradigm in which subjects recall the orientation of names studied in a learning phase (Chua et al., 2006). Other brain regions shown to correlate with increasing confidence include medial prefrontal cortex (MPFC), ACC, insula, parahippocampal gyrus, the right hippocampus, and right medial temporal gyrus (Chua et al., 2006; Moritz et al., 2006).

Finally, in attempting to isolate brain regions associated with reliable confidence ratings, Yokoyama et al. (2010) found that activity in a posterior-dorsal part of the right frontopolar cortex was not only uniquely active during confidence judgments (vs. control judgments) but also sensitive to the reliability of those confidence judgments.

The phenomenon of false memories (e.g., remembering a stimulus one has not actually encountered) also warrants discussion because such false memories can be held with high degrees of confidence (Payne, Elie, Blackwell, & Neuschatz, 1996). Thus, whether or not the primary cognition has a strong basis in accuracy, it can be held with relative subjective certainty. At the neural level, it seems that confidence judgments are associated with distinct neural activations depending on whether the memory is a true (correct) recognition or a false (incorrect) recognition. In particular, confidence in correct recognitions activates the MTL, a region that tends to relate to general recollection processes, whereas confidence in incorrect recognitions activates frontoparietal regions that tend to relate to familiarity judgments (Kim & Cabeza, 2007). Thus, although people can feel confident in both true and false memories, it seems that the neural mechanism leading to such confidence is at least in part dependent on the actual accuracy of the memory. When the memory corresponds with actual recognition, traditional memory pathways mediate memory confidence. When the memory is not accurate, however, people must rely on other processes, such as assessing familiarity, to make a confidence judgment. Further understanding of the neural basis of metacognitive confidence can contribute to shed light to the study of false memories, along with other phenomenon such as confabulation and self-deception (e.g., Hirstein, 2005; see also on this monograph, Aiger, Palacín & Cornejo, 2013; Hernandez, Ricarte, Ros, & Latorre, 2013).

In sum, memory-related certainty processes have been linked relatively consistently with prefrontal regions that include the DLPFC (Henson et al., 2000; Kim & Cabeza, 2007) and medial PFC (Chua et al., 2006: Schnyer et al., 2005; Schnyer et al., 2004). Such activations make sense particularly in light of theories in neuroscience that propose the DLPFC is important in memory encoding and retrieval generally (Rugg, Otten, & Henson, 2002; Yonelinas, 2002) and that the MPFC is particularly sensitive to introspection and self-relevant processing (Jenkins & Mitchell, 2011; Johnson et al., 2002). Introspection is a process relevant to making certainty judgments because they involve reflecting on one's own knowledge and the means by which a conclusion has been reached, including memories, decisions, etc. Also, there seems to be evidence that the MTL and PCC are associated with greater subjective memory confidence (Chua et al., 2006; Moritz et al., 2006), which fits with prior research demonstrating greater PCC activation during memory reports characterized by strong episodic recollection vs. mere familiarity (Eldridge, Knowlton, Furmanski, Bookheimer, & Engel, 2000).

The question remains, however, regarding the similarity of confidence judgment processes across memory and other domains (Fleming & Dolan, 2012). There is indeed some evidence for common neural mechanisms underlying confidence across different domains from direct within-subject comparisons of confidence judgments in different tasks (Fleck, Daselaar, Dobbins, & Cabeza, 2006). As we will describe later, some neural regions seem relevant to certainty processes in both memory and decision-making domains.

MetaCognitive Confidence and Decision-Making

Neuroscience methods have recently been enthusiastically applied to decision-making research (Vartanian & Mandel, 2011), including the role of certainty in decisions. This research falls primarily in two categories: the role of certainty as it relates to the outcomes of a future choice and the role of certainty in a choice that has already been made. Conceptually, this is similar to the role of certainty in memory processes, distinguishing uncertainty as it relates to future events (i.e. decision outcomes or perceived future memory retrievability) and past events (i.e. choices that have been made or memories that have been retrieved). As we describe in this section, many of the brain regions implicated in memory confidence processes, including the DLPFC, MPFC, and parietal regions, also show decision certainty-related activations.

The Role of Outcome Uncertainty

First, in making a decision, people must consider the outcomes of their choices. Choices can be accompanied by certain or uncertain outcomes. That is, some choices are accompanied by known outcome probabilities (e.g., purchasing lottery ticket A comes with a 1% chance of winning $100) whereas other choices are accompanied by unknown outcome probabilities (e.g., the chances of winning $100 by purchasing lottery ticket B are unknown at the time the choice is made). Under conditions of uncertainty, people must make predictions about outcomes and somehow come to a decision. Each of these processes–making predictions under uncertainty and making choices under uncertainty–have been studied in neuroscience.

The uncertainty inherent in predictions can be thought of as a subjective assessment of one's knowledge regarding some outcome. One class of primary cognitions in this domain is a person's knowledge regarding an event that has already occurred. For example, imagine somebody has removed one card from a full deck of playing cards. If the person displays the face of this card, one's knowledge of the card's identity is held with certainty. If, however, the person keeps this card face-down, knowledge of the card's identity is uncertain. Elliott, Rees, and Dolan (1999) simulated this experience in an fMRI, asking participants to either guess or report the color of playing cards. When people were guessing the color of face-down cards (uncertainty), compared to reporting what they could actually see (certainty), brain areas including the lateral PFC, right orbitofrontal cortex (OFC), ACC, inferior parietal cortex, and right thalamus were relatively more active. When task difficulty was elevated on some trials (guessing the suit of the card rather than just the color), participants showed greater activation in the left lateral and medial OFC. Because difficulty in this task corresponds with a greater number of outcome possibilities, it seems that it might also correspond with greater degrees of outcome uncertainty. Alternatively, because the outcome probabilities (.25 and .5) are not themselves accompanied by more or less certainty across levels of difficulty, these results may not necessarily tap into differing degrees of uncertainty. As it was the case in other studies, certainty and uncertainty might be confounded with other related variables, such as ease and difficulty.

Other studies have used similar methods with conditions conceptually corresponding to "guessing" vs. "reporting." In these scenarios, however, the primary cognitions are those representing knowledge of events that have not yet occurred. For instance, when people predict a future event (vs. report an outcome that has already been determined), they show greater activation in prefrontal (dorsomedial prefrontal cortex [DMPFC], middle frontal gyrus, and superior frontal gyrus) and parietal (precuneus, inferior parietal lobule) areas (Paulus et al., 2001; Volz, Schubotz, & von Cramon, 2003). Interestingly, the activation of DMPFC occurs regardless of whether people perceive uncertainty to spring from their own, controllable lack of sufficient relevant knowledge or from coincidental, uncontrollable events in the world (Volz, Schubotz, & von Cramon, 2004, 2005).

In sum, across these studies that examined predictions under uncertainty, several parts of the brain appear somewhat consistently more active in prediction tasks involving uncertainty than in reporting-based, more certain tasks. These include inferior parietal areas (Elliott et al., 1999; Paulus et al., 2001), MPFC (Volz et al., 2003, 2004, 2005), and the DLPFC (Eldaief, Deckersbach, Carlson, Beucke, & Dougherty, 2012).

Making decisions with uncertain outcomes accompanying each choice alternative (vs. merely anticipating outcomes) also deserves mention. In the case of these decisions, like direct predictions, the (un)certainty is a judgment about the outcomes of decision alternatives. That is, the primary cognition is one's understanding of the outcomes of each alternative. For instance, the decision to purchase a raffle ticket that comes with a 95% chance of winning a designated prize is characterized by greater outcome certainty than the decision to purchase a raffle ticket that comes with an unknown chance of winning the prize. Under more uncertain situations like this, the OFC, through neuroimaging, lesion, and single cell recording methods, has been associated with assessing degrees of uncertainty in decision outcomes (Hsu, Bhatt, Adolphs, Tranel, & Camerer, 2005; Kepecs, Uchida, Zariwala, & Mainen, 2008). As previously discussed, decision-making under uncertainty requires the representation of current and predicted states, a process proposed to rely on the insula cortex, which can facilitate uncertainty-relevant risk assessment (Singer, Critchley, & Preuschoff, 2009). For example, in a study on dispositional neuroticism and decision-related uncertainty, Feinstein, Stein, and Paulus (2006) suggested that right anterior insula may be involved in processing subjective uncertainty. Similarly, other work has shown the right anterior insula is more active during risky (vs. safe) decisions (Paulus, Rogalsky, Simmons, Feinstein, & Stein, 2003), during stimulus categorization trials characterized by uncertain (vs. certain) categorizations (Grinband, Hirsch, & Ferrera, 2006), during choices with relatively high learned outcome uncertainty (Huettel, Song, & McCarthy, 2005), and during choices with unknown (vs. known) outcome probabilities (Huettel, Stowe, Gordon, Warner, & Platt, 2006).

Retrospective Decision Confidence

Within decision-making, the concept of certainty and uncertainty can also relate to perceptions of the choice itself rather than to the conditions under which the choice is made. In line with previously described work on memory confidence, this type of decision-related confidence might be referred to as "retrospective decision confidence." Here, the primary cognition is the choice a person has already made, and he or she can be relatively sure or unsure of that decision. Thus, in the previous example, once people choose to purchase the raffle ticket, they can judge how confident they are in that decision. Note, however, such a metacognitive judgment could refer to how certain a person is that he or she made the *correct* choice or to how certain a person is that he or she made the choice he/she intended to make. In the literature reviewed here, confidence primarily refers to judging whether one has made the (objectively) correct decision. The type of neural mechanisms underlying certainty processes in this context can show some similarities to decision-related certainty in general (e.g. probability processing in the OFC) but can also be unique to this specific sort of retrospective confidence (e.g. monitoring the strength of the information used in decision-making).

To further understand retrospective decision certainty, Kepecs et al. (2008) developed a way for rats to give a behavioral report of decision confidence; rats preferentially opted out of trials characterized as more uncertain by a theoretical model. That is, the rats appeared to be able to compute something like a confidence estimate in their choices. The authors, although careful not to overstate the results, suggest that in choice contexts, the brain generates both a decision as well as an accompanying evaluation of confidence that is based on the same information that informed the choice itself. However, because Kepecs et al. (2008) only measure single neurons specifically in the OFC, these results could very well represent only a piece of the story. Although it seems reasonable that the neural processes underlying decision certainty are informed by those underlying decision-making itself, other processes not accounted for in this research could also inform confidence. Indeed, confidence can be potentially based on many types of information, related and unrelated to the choice itself.

Kiani and Shadlen (2009) also considered decision confidence in animals, taking single neuron recordings in the lateral intraparietal (LIP) cortex of rhesus monkeys. Similar to Kepecs et al.'s (2008) paradigm, these monkeys participated in a perception task with a behavioral measure of decision confidence. Firing rates in the same LIP neurons corresponded both with the decisions made and with the degree of certainty in those decisions; specifically, reduced neuron firing accompanied trials characterized by reduced confidence. It is worth pausing a moment, however, to consider the extent to which certainty can be meaningfully modeled in animal subjects. Although the behavioral measures of decision certainty utilized by both Kepecs *et al*. (2008) and Kiani and Shadlen (2009) do accurately correspond with objective features of the decisions that would theoretically predict decision certainty, the extent to which these measures correspond with a subjective experience of certainty remains unclear. Thus, even though the behavioral measures of decision certainty correlate with neuron firing in the OFC and LIP, these neural processes may not necessarily produce subjective experiences of certainty (cf. Kepecs & Mainen, 2012). Instead, such behavioral measures and neural activations in these studies may be more simply reflections of task difficulty.

Moving closer to understanding the neural correlates of decision confidence as indicated by subjective reports and as distinct from choice difficulty, recent research has also examined retrospective decision certainty in human subjects. In a task where people had to reason through a forced choice problem (e.g., choosing which city in a presented pair they thought had a higher average temperature), greater confidence in choices was associated with deactivation in the MPFC, and greater degrees of overconfidence (i.e. confidence ratings that do not correspond with choice correctness) was negatively correlated with OFC activity (Beer, Lombardo, & Bhanji, 2009). Also, across a series of choices between food items that participants could later consume, the decisions about which people indicated greater choice confidence (i.e. greater subjective certainty that they chose the option that was best for them) related to greater activation in the VMPFC and the precuneus (De Martino, Fleming, Garrett, & Dolan, 2012). Critically, this study also found that activations in the right rostrolateral prefrontal cortex (rRLPFC) were associated with decision confidence independent of the difference in value that participants placed on the competing choice alternatives. These results also point once again to the importance of distinguishing between decision certainty and task difficulty.

Finally, individual differences in the extent to which confidence ratings are appropriately calibrated to objective decision criteria (i.e. "metacognitive accuracy"; for a review, see Fleming & Dolan, 2012) has been related to individual differences in brain structure and connectivity. For instance, people whose ratings of confidence were more closely matched with the accuracy of the relevant judgments had more grey matter volume in the right anterior PFC (Fleming, Weil, Nagy, Dolan, & Rees, 2010). These people also had greater white matter integrity for fibers linking anterior and orbital PFC in the corpus callosum.

Although this research on the neural underpinnings of judgment and decision-making processes has produced evidence regarding the role of certainty in decision situations, it has done so from many angles. The primary cognitions about which people can make metacognitive certainty judgments range from knowledge of future outcomes to choices that have already been made. Consistent with Shimamura's (2000) proposal that secondary cognitions are processed by prefrontal areas, regions in the PFC were involved in many of the paradigms reviewed here, particularly medial prefrontal regions (Beer et al., 2009; De Martino et al., 2012; Eldaief et al., 2012; Huettel et al., 2005; Volz et al., 2003, 2004, 2005) and the OFC (Beer et al., 2009; Elliott et al., 1999; Hsu et al., 2005; Kepecs et al., 2008). Again, the medial prefrontal activations make sense in light of neuroscience research linking the MPFC to introspection and self-relevant processing, discussed above. Also, the consistency of OFC activations in these studies follows from research demonstrating the importance of the OFC in decision processes, generally representing reward and value processing (Wallis, 2007) and suggests that the OFC's role in certainty-related processes may be closely tied with the process of assessing the value of choice alternatives.

Other regions not in the prefrontal cortex, however, were also implicated in certainty-relevant processes across a number of decision-making studies. Parietal regions, for example, consistently relate to certainty-relevant tasks reviewed here (Elliott et al., 1999; Kiani & Shadlen, 2009; Paulus et al., 2001). As noted, parietal regions are linked to probabilistic reasoning in decision tasks (e.g., Yang & Shadlen, 2007). Uncertainty also consistently activated the anterior insula across a number of studies (Feinstein et al., 2006; Grinband et al., 2006; Huettel et al., 2005; Paulus et al., 2003). The insula's involvement in decision-related uncertainty can be linked to a more general process of risk processing (Singer et al., 2009). Despite some convergence across tasks and domains, it is still unclear to what extent the consistent activation of these areas in certainty-related processes in decision-making are meaningful (or not) for certainty processes in general. Further work will be needed to integrate these findings and further determine the common neural processes necessary for the phenomenon of decision-related certainty.

MetaCognitive Confidence in Attitudes and Persuasion

Metacognitive confidence has been also examined in the context of evaluative social psychology. For example, attitudes (e.g., "I like Angela") are one of the primary cognitions for which people have different degrees of metacognitive confidence (e.g., "I am sure of my evaluation of Angela"). Attitudes held with greater certainty are more resistant to change, stable over time, and predictive of behavior than attitudes about which there is doubt (e.g., Gross, Holtz, & Miller, 1995). Thus, attitudes can vary in their *strength* with strong attitudes being those that are held with confidence, come to mind easily, influence thought and behavior over time, and are resistant to change (Petty & Krosnick, 1995). In another illustration relevant to social psychology, research on self-validation (Petty, Briñol, & Tormala, 2002) has shown that generating thoughts in response to a message is not sufficient for those primary cognitions to have an impact on judgment. Rather, one must also have some degree of confidence in them. In this case, thoughts in response to persuasive proposals are the primary cognition and the confidence in those thoughts, the secondary cognition (see, Briñol, Petty, & Stavraki, 2012, for a recent example).

Despite the importance of metacognitive confidence in this domain (Briñol & Petty, 2009; for a review in Spanish, see Briñol, Gandarillas, Horcajo, & Becerra, 2010), it has not yet received attention in social neuroscience. Therefore, it is still unclear whether the certainty with which a person holds an attitude or the confidence a person has in his or her thoughts in response to a persuasive message relies on the same neural mechanisms as memory confidence or decision certainty. There are a number of important factors and distinctions that can be relevant from this point of view.

First, attitudes are often conceptualized as a relatively enduring construct with a stored representation (Fazio, 2007; Petty, Briñol, & DeMarree, 2007). In addition to associating attitude objects with general evaluative summaries (e.g., good/bad) that are stored in memory, social psychologists have shown that people sometimes develop an attitude structure in which attitude objects are linked to both positivity and negativity separately (see also Cacioppo, Gardner, & Berntsen, 1997). Following the distinction between two levels of cognition, the *MetaCognitive Model* (MCM, Petty et al., 2007) of attitude structure assumes that people can tag their good and bad evaluations as valid or invalid, or held with varying degrees of confidence. Furthermore, these validating (or invalidating) metacognitions can vary in the strength of their association to the linked evaluation, and the strength of these links will determine the likelihood that the perceived validity of the evaluation will be retrieved along with the evaluation itself. Most notably, the MCM contends that perceived validities, like the evaluations themselves, can be stored for later retrieval. As we have reviewed throughout, the extent to which an evaluation requires (or does not require) the retrieval of these storage validity tags might be consequential for the neural correlates involved. For example, reporting attitude certainty might be similar to retrieving a memory (retrospective memory confidence judgments) in terms of neural activity since the certainty could be stored along with the attitudes, at least for familiar objects.

Second, another important distinction between attitude certainty and the other forms of certainty considered here pertains to the criterion against which certainty can be compared. Oftentimes, decision certainty or memory certainty can be compared against an objective criterion (e.g., whether or not the person actually studied a word in the learning phase of an experiment). As noted, metacognitive confidence typically refers to the estimation of how likely it is for an answer (e.g., a judgment or a decision) to be correct, and criteria for accuracy are typically available. Attitude or thought certainty, however, does not have such an objective comparison criterion. As a result, attitude-relevant certainty processes may rely on neural mechanisms distinct from those involved in other forms of certainty assessments such as decision or memory confidence.

In sum, future research considering the neural underpinnings of attitude certainty appears to be a fruitful endeavor in light of existing evidence regarding the neural correlates of metacognitive certainty in other domains. Although the existing social neuroscience literature is silent to these attitude processes, preliminary evidence reveals that when people evaluate topics about which they later report to be relatively certain (vs. uncertain) of their attitude, there is greater activation in medial parietal regions, and when people evaluate topics about which they later report to be relatively uncertain (vs. certain) of their attitude, there is greater ACC activation (Luttrell, Hasinski, & Cunningham, 2013). Although many studies have shown these regions related to confidence judgments (e.g., Kiani & Shadlen, 2009; Moritz et al., 2006; Simons et al., 2010), these attitude certainty results differ in that they do not reflect brain activity while making attitude certainty judgments; rather, they reflect brain activity while considering a topic that is accompanied by more or less certainty. Further research should consider both the implications for brain activity during this stage of processing any certainty-relevant construct, including decisions and memory reports, as well as the brain activity during explicit judgments of attitude-relevant confidence (see Chua et al., 2006).

Conclusion

In closing, the research described in this review reveals that metacognitive confidence is associated with neural activity in particular locations in the brain. Across domains like memory, decision-making, and attitudes, people can be more or less certain of a relevant primary cognition. They can be sure that they saw a word during a learning trial, that they made the right decision for them, and that they have expressed their true opinion. In all of these cases, distinct areas of the brain demonstrate sensitivity to the degree of confidence and the process of making confidence judgments. Some of these areas include the MPFC, OFC, PCC, ACC, and insula. The extent to which this wide-ranging collection of brain regions is implicated in a unified system of certainty-related neural processes remains to be shown.

Many of the areas highlighted in this body of research have also been implicated in the "default mode network." The default network is a collection of brain areas demonstrating functional connectivity (i.e., they tend to coactivate) that are relatively more active during "resting" conditions than during conditions of goal-directed task performance (Raichle et al., 2001). Meta-analyses confirm that this network is comprised of the MPFC (ventral and dorsal), PCC, and inferior parietal lobule (Buckner, Andrews-Hanna, & Schacter, 2008). Although the exact nature of this network remains a topic of debate among neuroscientists, some have proposed that the default network's function is to facilitate self-relevant mental explorations, which is similar to metacognition (Buckner et al., 2008). For instance, this default network is relatively more active during instances of recalling autobiographical events, imagining the future, and inferring the mental states of others (Spreng & Grady, 2010; see also Díaz, 2013, this monograph). Future research addressing the question of whether metacognitive processes operate through the same default network channels as other self-relevant tasks might also consider how much certainty systematically relies on other neural networks to meet the unique demands of this kind of metacognitive judgment. However, as noted, in many of these studies confidence seems to be confounded with other dimensions, such as ease. Indeed, people tend to be less certain in tasks that are more difficult, and therefore it is not clear whether the observed brain activity reflects uncertainty, difficulty, a combination of both, or some other factor related to them. This problem is not unique to memory, decision-making, or neuroscience research, and it is not new within social psychology. For example, although metacognitive certainty naturally covaries with other aspects of the primary cognition, certainty can be isolated from those other related variables. Although attitude certainty is often confounded with other attitude strength variables like attitude extremity, importance, ambivalence, and knowledge (see Petty et al., 2007), these variables are conceptually and empirically distinct (e.g., Visser, Bizer, & Krosnick, 2006). Regarding the potential confound between certainty and ease, other work has shown that attitudes that come to mind more easily are often held with greater certainty (Holland, Verplanken, & van Knippenberg, 2003). Ease and confidence, however, are distinct in these paradigms as confidence can also be accompanied difficulty. Taken together, these examples from research on attitude confidence reveal that it is possible to dissociate confidence from other related constructs. We believe that future research on neuroscience can benefit of these more precise paradigms in order to identify the particular brain activity relevant to metacognitive confidence.

Indeed, greater clarity regarding the locations of certainty-related activation is welcome. Moving beyond this, however, it is especially interesting to ask how neural patterns differ with regard to making certainty judgments vs. reflecting on confidently held cognitions vs. *using* confidently held cognitions. As the analytical tools available to social cognitive neuroscience advance, research should also work to understand how these distinct regions of the brain associated with judgments of certainty might work together in a larger network involved in metacognitive judgments. That is, coactivation of various regions may contribute to certainty beyond any single area of activation. By understanding this neural system and drawing from research on phenomena showing similar neural patterns, researchers can begin to make novel predictions about how people become certain of attitudes, memories, and decisions and what consequences that certainty might have.

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