Trends in Cognitive Sciences

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Review

Brain Mechanisms of Reality Monitoring

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Reality monitoring processes are necessary for discriminating between internally generated information and information that originated in the outside world. They help us to identify our thoughts, feelings, and imaginations, and to distinguish them from events we may have experienced or have been told about by someone else. Reality monitoring errors range from confusions between real and imagined experiences, that are byproducts of normal cognition, to symptoms of mental illness such as hallucinations. Recent advances support an emerging neurocognitive characterization of reality monitoring that provides insights into its underlying operating principles and neural mechanisms, the differing ways in which impairment may occur in health and disease, and the potential for rehabilitation strategies to be devised that might help those who experience clinically significant reality monitoring disruption.

How Do We Know What Is Real?

Thinking back over your life, you can often find yourself mentally transported back in time, reliving a past episode, sometimes in vivid detail. Except – how do you know that you were actually there when the event originally took place? How can you be sure that you are remembering a faithful representation of what happened, as opposed to an event you might have previously imagined, or a story told to you by someone else? In short, how do you determine whether your memories are real?

One prominent theory, the Source Monitoring Framework, proposes that there are decision processes involved in making attributions about the origin of information that comes to mind, including discriminating information that was generated by internal cognitive functions, such as thought and imagination, from information that was derived from the outside world by perceptual processes ('reality monitoring' [1,2]). According to this framework, memories do not contain propositional tags that directly specify their source. Instead, we make attributions about the origin of a mental experience by considering its features in light of assumptions about the characteristics that tend to be associated with various sources. For example, a person might infer that an apparent 'memory' rich in visuoperceptual detail is likely to be real ('I can remember what the dentist's office looked like' [3]) whereas one comprising mainly traces of internally generated thoughts might instead have been imagined ('I could remember I had a very specific reason for making the association'; 'I made the decision by knowing what my train of thought was during the exercise' [4]).

Reality monitoring errors tend to involve misidentifying internally generated events as being real, for example misattributing particularly vivid imaginations to perception, or assuming that the absence of memory for cognitive operations indicates that a memory is unlikely to have been self-generated [4], although misattributions in the other direction also occur, such as in cryptomnesia [5]. Similarity between potential sources increases the likelihood of source errors [6]. For example, misattribution errors are more common for auditory than visual stimuli,

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Mounting evidence identifies anterior prefrontal cortex as playing a key role in reality monitoring, the ability to distinguish internally from externally generated information.

Individual differences in reality monitoring performance in healthy volunteers are associated with variability in functional activity and structural morphology in this region of the brain.

Differences are also seen in clinical conditions such as schizophrenia, in which people sometimes experience disturbed awareness of what is real.

Dysfunction in anterior prefrontal cortex increases vulnerability to misidentify internally generated information as external in origin, providing a possible neurocognitive basis for psychiatric symptoms such as hallucinations.

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perhaps because 'inner speech' and real speech tend to be more similar than visual imagery and actual visual perceptions and, hence, are more vulnerable to confusion [7]. It is important to note that the features that are activated when a 'target' memory is cued are determined by processes engaged during encoding of the event (e.g., the quality of feature binding), during the interval between the initial event and the act of 'remembering' (e.g., the number of reactivations), and during retrieval (e.g., the cue eliciting the memory). In addition, features from other events can be activated at any point, potentially influencing the characteristics of the remembered event [8]. In addition to the phenomenal qualities of mental experiences, reality monitoring may also involve explicit retrieval of supporting or conflicting information, and may be influenced by prior knowledge, beliefs, and motives [9]. Thus, there are multiple factors operating during encoding and retrieval, as well as in the intervening period, that can produce source misattributions in healthy individuals, and multiple ways that processes can be disrupted in clinical populations.

In the past few years a number of laboratories around the world have explored the brain mechanisms underlying reality monitoring processes using cognitive neuroscience methods including functional brain imaging of healthy volunteers and studies of neurological, psychiatric, and developmental disorders, as well as of normal aging [10]. The aim has been to understand how the brain supports our capacity to determine the sources of mental experiences, including distinguishing what is real from what we have imagined, an ability that is vital for maintaining confidence in our memories, and in understanding ourselves as individuals in the world with a past and a future. In characterizing how these processes might be instantiated in the brain, we can better understand the way in which they may break down in disorders such as schizophrenia, in which a person's relation to reality can be altered in ways that disrupt their everyday functioning.

Anterior Prefrontal Cortex (PFC) and Reality Monitoring

Neuropsychological and neuroimaging studies have identified a network of brain regions involved in the recollection of source information, which include prefrontal, medial temporal, and parietal cortices [10–12]. In broad terms, regions of PFC are thought to provide cognitive control over the encoding and retrieval of feature representations that are bound together in a spatial frame by the hippocampus and further integrated by parietal cortex into a first-person perspective that supports the subjective experience of remembering [9,13]. The role of the PFC appears to be particularly crucial for source memory, and lesions to the frontal lobes typically cause severe difficulties with the recollection of such contextual details even when old/new item recognition is unimpaired [14,15]. Distinct prefrontal regions may make separable functional contributions to source memory [11], with ventrolateral PFC subregions linked to the specification of retrieval cues and the maintenance of retrieved information, and the dorsolateral PFC exhibiting activity during post-retrieval monitoring [16–18].

One region that has emerged as playing a key role in reality monitoring is the anterior PFC, an area right at the front of the brain that, in relative terms, is roughly twice as large in the human brain than in even the great apes [19]. It has lower cellular density and higher dendritic complexity than comparable cortical regions [20], and is thought to be among the last areas to achieve myelination [21], enabling nerve cells to transmit information more rapidly and facilitating more complex cognitive abilities. As such, although the functions performed by this area are not well understood, they have generally been considered likely to be among the 'higher' levels of human complex cognition [21–24]. The role played by the anterior PFC in memory has been difficult to characterize. Several neuroimaging experiments published in the early 2000s reported activation in this region during the recollection of source details [16,18,25,26], but this was not consistently observed [17,27,28]. An absence of anterior PFC activity could of course always be attributable to insufficient experimental power or to

susceptibility in the fMRI signal owing to the proximity of the anterior PFC to the sinus area. However, another hypothesis is that the discrepancy between studies might have arisen because the types of information that participants were being asked to remember differed according to whether the information had been generated internally or externally at the time of encoding [29].

In the past decade or so this hypothesis has been tested by a number of experiments from different laboratories that have manipulated the recollection of internally generated and externally derived source details (Figure 1). Although there is some variability in the patterns of activity elicited by such tasks, these studies have consistently identified the medial aspect of the anterior PFC in particular as exhibiting differential activity during the retrieval of internal versus external aspects of context (Figure 2). For example, medial anterior PFC responses distinguish recollection of the encoding task undertaken compared to remembering where on the screen [29–31] or when in time [32,33] stimuli were presented, or remembering the size in which they were displayed [25,34]. The same region is involved in remembering whether verbal phrases were previously presented in full on the screen (e.g., 'bacon and eggs'), or whether a word was missing which participants needed to imagine (e.g., 'bacon and ?') to complete the phrase

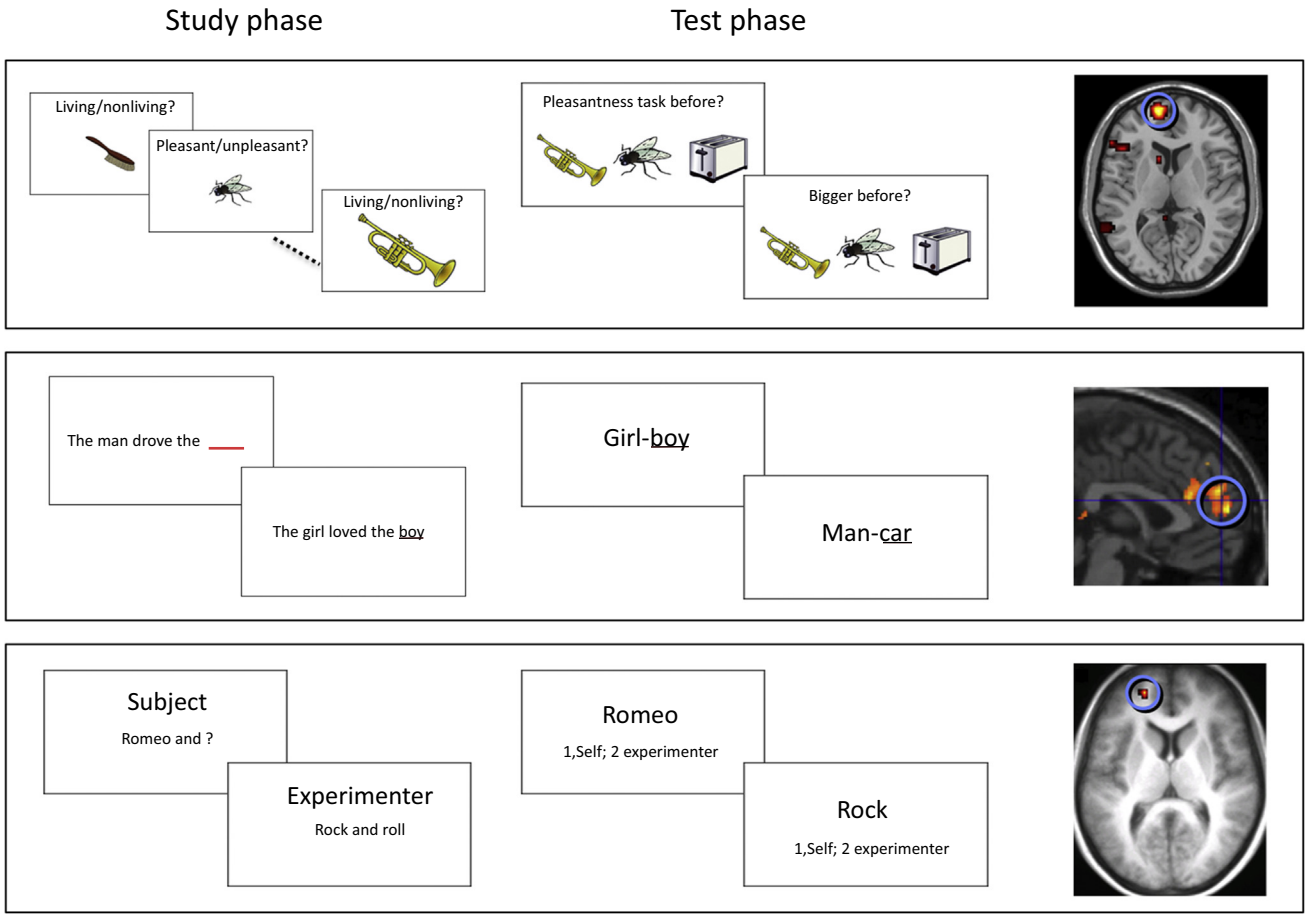

Figure 1. Three Examples Illustrating the Variety of Reality Monitoring Tasks and Activity Elicited in the Anterior Prefrontal Cortex. (Top panel) Memory for encoding task versus stimulus size [34] (fMRI image courtesy of Ian G. Dobbins). (Middle panel) Remembering whether words were seen or imagined [35] (fMRI image reprinted, with permission, from Elsevier). (Bottom panel) Distinguishing between word pairs read aloud by the participant herself versus the experimenter [37] (fMRI image reprinted, with permission, from MIT Press).

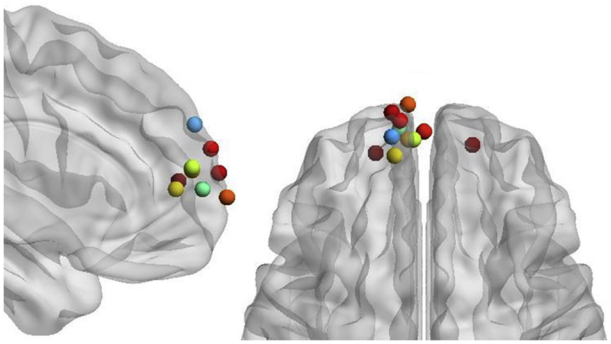

Figure 2. Locations of Medial Anterior Prefrontal Cortex Activity Reported by 12 fMRI Studies of Reality Monitoring in Healthy Volunteers.

themselves [30,35]. Likewise, medial anterior PFC is differentially engaged during recollection of whether a visual object was previously seen or imagined by participants [36], as well as when judging whether oneself or another person performed a particular action with stimuli [37–39]. The sensitivity of this region to reality monitoring distinctions is apparent regardless of whether words, faces, or objects are being remembered [29,32,34,36], suggesting that the effect is independent of stimulus type. Moreover, medial anterior activation has been observed irrespective of whether the 'internal' or 'external' condition is associated with lower recollection accuracy and longer response times, or vice versa, or whether such behavioral factors are matched between conditions [29,32], suggesting that an account in terms of differential task difficulty is unlikely to be sufficient. Possible explanations of the observed activity include that medial anterior PFC represents records of cognitive operations involved in self-generation, or is involved in self-referential processing or self-representation, or that the region operates as a gateway, biasing attention between self-generated and externally generated information, irrespective of whether that information is experienced currently or in the past [21,40].

Not everyone exhibits perfect reality monitoring performance, of course. Performance varies considerably even in apparently healthy individuals, with some people reliably able to distinguish internally from externally generated stimuli whereas others perform closer to chance levels [41]. Consistent with the functional neuroimaging evidence discussed above, recent research points to these individual differences as having a specific brain structural basis in the medial PFC. One structural landmark in this region of the brain that exhibits considerable morphological variability within the general population is the paracingulate sulcus (PCS), which lies dorsal and parallel to the cingulate sulcus (Figure 3). The PCS, which is prominent in roughly half of the normal population, is a tertiary sulcus, one of the last structural folds to develop before birth and, due to a combination of genetic and environmental influences, varies considerably in size between individuals [42]. This brain structure variation appears to be linked to reality monitoring ability: healthy, apparently cognitively intact, adults whose MRI scans indicate bilateral absence of the PCS are significantly less accurate in reality monitoring decisions than people with a prominent PCS on at least one side of the brain [41]. PCS reductions are typically associated with increased grey matter volume in the surrounding anterior cingulate cortex [43] and, consistent with this observation, voxel-based analyses reveal that reality monitoring performance correlates negatively with medial PFC volume [41]. Reduced sulcal folding and increased surrounding cortical volume may reflect weakened local and long-range connectivity, according to theories of morphogenesis [44,45]. These findings thus suggest an explanation for individual differences in reality monitoring ability as reflecting, in part, variations in connectivity between the medial PFC and other cortical regions involved in processing the sensory/perceptual and other features that constitute our memories.

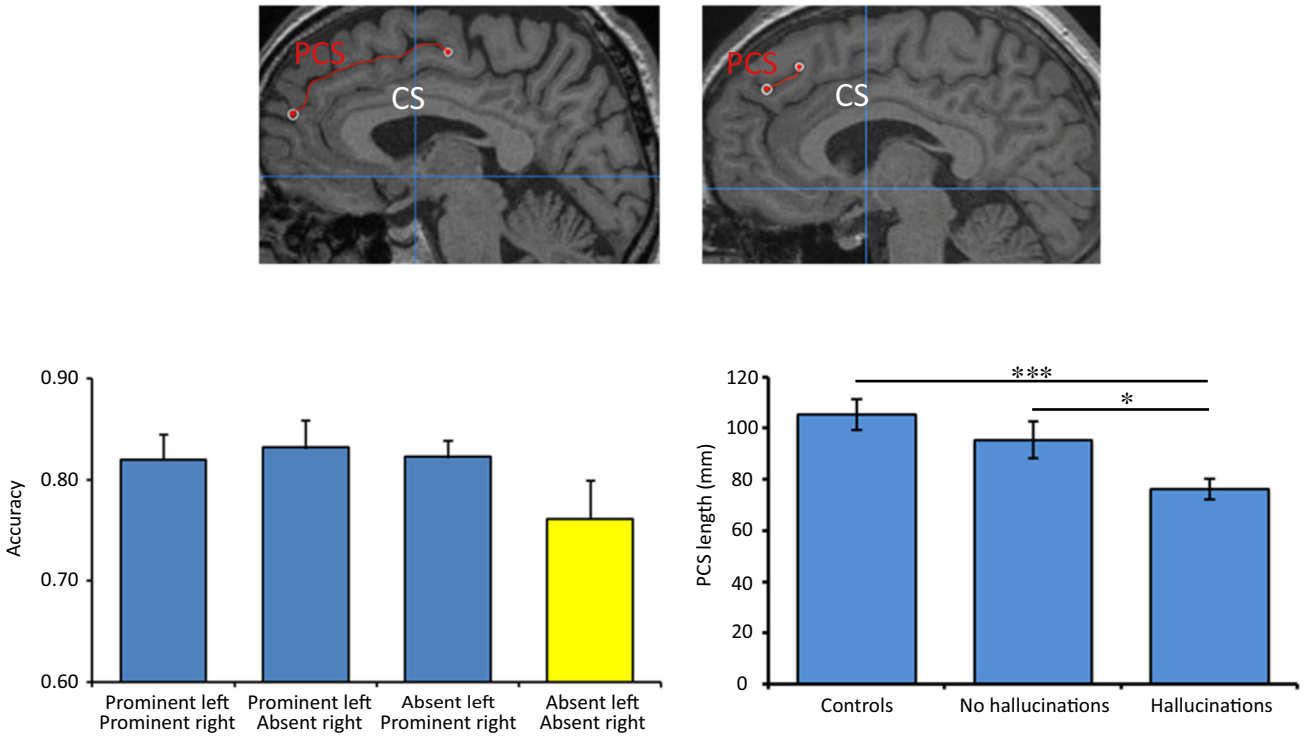

Figure 3. Paracingulate Sulcus (PCS) and Reality Monitoring. (Top panel) The PCS (shown in red), located in the medial prefrontal cortex (PFC) dorsal to the cingulate sulcus (CS), differs in length considerably between individuals (reprinted, with permission, from Nature Publishing Group). (Bottom left panel) Reduced reality monitoring performance in healthy volunteers in whom PCS is absent in both hemispheres [41]. (Bottom right panel) PCS length differentiates hallucination status in patients with schizophrenia, as well as distinguishing patients with schizophrenia from healthy control participants [78] (reprinted, with permission, from Nature Publishing Group). Asterisks indicate statistical significance.

Reality Monitoring in Schizophrenia

One of the applications of the work seeking to characterize the brain mechanisms of reality monitoring has been to inform understanding of the cognitive dysfunction seen in clinical conditions such as schizophrenia. Although schizophrenia can vary in its presentation, among the positive symptoms often observed are hallucinations, such as hearing voices when none are present. For example, a person with schizophrenia might imagine a voice conveying a specific message, and misidentify that voice as being real, coming from another person. Hallucinations also occur in other psychiatric conditions including bipolar disorder, major depressive disorder, borderline or schizotypal personality disorder, post-traumatic stress disorder, and dissociative identity disorder [46–48], but affect between 60% and 80% of patients with a schizophrenia diagnosis [49,50]. Auditory and visual hallucinations are the most common forms, with a prevalence of around 59% and 27% in schizophrenia, respectively [51], but olfactory, tactile, somatic, and gustatory hallucinations have also been reported [52–54]. Activity associated with hallucinations is often observed in sensory processing areas, such as the superior temporal gyrus during auditory hallucinations and extrastriate cortex during visual hallucinations [55], suggesting that separable modality-specific impairments contribute to different types of hallucinations across patients. One possibility is that hallucinations primarily reflect unusually vivid internally generated experiences represented in one or more of these modality-specific processing areas, experiences that are so vivid that they seem to be external events. In addition, it is possible that hallucinations may in part result from a more central difficulty in discriminating between perceived and imagined information, perhaps

because self-generated events have attenuated or missing records of the cognitive or motor operations that produced them [56].

Despite the interpretational complexities inherent in studying a heterogeneous syndrome such as schizophrenia, a number of predictions have been tested that arise from the hypothesis linking disrupted reality monitoring with hallucinations, and the assumption that some common processes are involved in distinguishing reality from imagination both retrospectively and in real time. One prediction is that individuals with schizophrenia should be impaired on seen versus imagined memory tasks that have been shown to elicit anterior PFC activity in healthy volunteers. Of 20 studies of reality monitoring in schizophrenia surveyed for this article (Table 1), involving a total of 700 patients and 505 controls, 19 studies reported impaired reality monitoring in the patients, including four studies in which the deficit was found to be specific to reality monitoring, with item recognition memory being preserved [57–60]. A second prediction, if hallucinations result from misidentifying imagined stimuli as being real, is that an externalization bias should be observed in schizophrenia during reality monitoring performance, with more errors on self-generated than externally generated trials, and that this bias should be greater in patients with schizophrenia who experience hallucinations than in those who do not. Of the four studies reporting a specific reality monitoring impairment in schizophrenia, three noted that the deficit only (or disproportionately) involved the misidentification of internally generated stimuli as having been externally generated [58–60]. Furthermore, all five studies that compared reality monitoring in patients with and without hallucinations, and measured externalization bias, observed a greater likelihood of misidentifying internally generated stimuli as being real in the patients who experienced hallucinations ([57,61–64], see also [65,66] for previous reviews highlighting such associations).

A third prediction is that the anterior PFC region activated in healthy volunteers during reality monitoring performance should be among the areas that are dysfunctional in patients with schizophrenia. Consistent with this prediction, the anterior PFC region linked to reality monitoring in healthy volunteers overlaps closely [30] with one of the areas that consistently exhibit reduced activity in patients with schizophrenia compared with controls during performance of a range of cognitive tasks [67–71]. Moreover, lower anterior PFC activity in healthy individuals during reality monitoring correlates with proneness to psychosis and schizotypal trait expression [37], an effect that is also observed in adolescents at risk of developing schizophrenia [72], suggesting its potential as a possible marker in young people of those with heightened likelihood of converting from prodromal to full psychosis [73].

A fourth prediction is that healthy volunteers who exhibit reduced levels of activity in anterior PFC should make more of the externalization misattribution errors often observed in schizophrenia. Accordingly, analysis of activity in the anterior PFC across participants during reality monitoring performance has revealed a significant negative correlation with the likelihood of mistakenly endorsing imagined items as having been seen [30]. A fifth prediction is that patients with schizophrenia should exhibit disproportionately reduced activity in anterior PFC during performance of reality monitoring tasks, an effect that has been reported in three studies to date [60,74,112], and which may be partly ameliorated by cognitive training interventions [74] (although this latter possibility requires replication in larger samples). A sixth prediction, if hallucinations in schizophrenia are attributable to overstimulation of sensory processing areas and reality monitoring dysfunction, is that altered functional connectivity should be observed between posterior sensory cortices and anterior PFC. Accordingly, several studies have reported impaired functional integration between superior temporal cortex and medial regions of anterior PFC associated with misattribution by patients with schizophrenia of their own speech as that of somebody else [75,76]. Finally, based on the specific structural basis for reality monitoring identified in the PCS [41], hallucinations in schizophrenia should be

Table 1. Studies of Reality Monitoring in Schizophrenia

Patients with Schizophrenia versus Healthy Controls							
Study	Task	Subjects		Impairment in		Increased	Refs
		Patients (n)	Controls (n)	Recognition memory	Reality monitoring	Externalization bias	
Anselmetti *et al.* (2007)	Word-stem completion	45	54	Yes	Yes	Yes	[99]
Bentall *et al.* (1991)	Word-stem completion	22	22	–	Yes	No	[62]
Brebion *et al.* (2000)	Semantic association	40	40	–	Yes	–	[63]
Brunelin *et al.* (2007)	Word recognition	15	15	–	Yes	–	[64]
Brunelin *et al.* (2008)	Word recognition	30	24	–	Yes	–	[100]
Fisher *et al.* (2008)	Sentence completion	91	30	Yes	Yes	Yes	[101]
Franck *et al.* (2000)	Word recognition	17	17	–	Yes	Yes	[102]
Harvey *et al.* (1988)	Word recognition	26	25	–	Yes	–	[103]
Keefe *et al.* (2002)	Word-stem completion	29	19	Yes	Yes	Yes	[104]
Moritz *et al.* (2003)	Semantic association	30	21	Yes	Yes	No	[105]
Moritz *et al.* (2005)	Semantic association	30	15	Yes	No	No	[106]
Nienow and Docherty (2004)	Sentence completion	52	52	Yes	Yes	Yes	[107]
Seal *et al.* (1997)	Semantic association	21	15	No	Yes	No	[57]
Stephane *et al.* (2010)	Sentence recognition	39	26	No	Yes	Yes	[58]
Subramaniam *et al.* (2012)	Sentence completion	31	16	–	Yes	Yes	[74]
Szoke *et al.* (2009)	Semantic association	54	41	–	Yes	No	[108]
Vinogradov *et al.* (1997)	Sentence completion	26	21	No	Yes	Yes	[59]
Vinogradov *et al.* (2008)	Sentence completion	8	8	No	Yes	Yes	[60]
Waters *et al.* (2004)	Object pairing	43	24	Yes	Yes	No	[109]
Woodward *et al.* (2007)	Sentence completion	51	20	Yes	Yes	No	[61]
Total subjects		700	505				

Patients with Schizophrenia: Hallucinations versus Non-Hallucinations							
Study	Task	Subjects		Impairment in		Increased	Refs
		Hall. (*n*)[a]	Non-hall. (*n*)[a]	Recognition memory	Reality monitoring	Externalization bias	
Bentall et al. (1991)	Word-stem completion	22	16	–	No	Yes	[62]
Brebion et al. (2000)	Semantic association	22	18	–	No	Yes	[63]
Brunelin et al. (2006)	Word recognition	30	31	No	Yes	Yes	[110]
Seal et al. (1997)	Semantic association	10	11	–	No	Yes	[57]
Waters et al. (2006)	Object pairing	19	24	No	Yes	–	[111]
Woodward et al. (2007)	Sentence completion	16	35	No	No	Y;1;;1;es	[61]
Total subjects		119	135				

[a]Hall., hallucinations; non-hall., non-hallucinations.

associated with differences in PCS morphology, among other areas. Providing support for this prediction, a quantitative measure of PCS length has been shown to be capable of distinguishing not only patients with schizophrenia from healthy controls [77], but also patients who have experienced hallucinations from patients with no history of such symptoms (Figure 3) [78]. The PCS reduction in patients with hallucinations appears to be evident irrespective of the sensory modality in which they were experienced (e.g., auditory, visual, tactile, olfactory), consistent with the observation described above that healthy volunteers exhibit anterior PFC activity during reality monitoring regardless of the type of stimuli being remembered [29,32,34,36].

Reality Monitoring and Hallucinations

These findings provide evidence that reality monitoring impairment may be a key component of the cognitive basis for the hallucinations experienced by many patients with schizophrenia. However, it is not only people with a mental health diagnosis who experience hallucinations. Approximately 1% of the general population report hearing voices when no speaker is present, but do not seek professional help or receive a clinical diagnosis [79]. Phenomenally, the auditory hallucination experience tends to be similar in clinical and non-clinical voice-hearers in terms of loudness, involvement of others' voices, number of voices, and so forth, but can differ in frequency, duration, and content, with patients typically experiencing negative voices whereas non-clinical individuals are sometimes more likely to report neutral or pleasant content to their hallucinations [80–82]. Recent interest has focused on whether there might be a common neurocognitive basis for hallucinations in clinical and non-clinical groups. If reduced reality monitoring ability is part of the explanation for the hallucinations observed in schizophrenia, can it also account for the symptoms experienced by non-clinical voice-hearers?

Evidence consistent with a common underlying mechanism comes from one study of reality monitoring in healthy volunteers which found that participants who were prone to experience hallucinations were more likely than other participants to misidentify self-generated words as having been spoken by the experimenter [83]. However, two more recent studies involving healthy individuals with a proneness to hallucinations found no evidence of an impairment in source or reality monitoring, or of an increased externalization bias, in such non-clinical voice-hearers [84,85]. Evidence from neuroimaging suggests common hallucination-related activity in auditory processing areas such as the superior temporal gyrus in clinical and non-clinical groups [86], and a correlation between the auditory hallucination proneness scores of non-clinical participants and activity in superior temporal gyrus when imagining voices they subsequently misidentified as being heard [87]. Clinical and non-clinical voice-hearers also have similar aberrant microstructure of the arcuate fasciculus connection between frontal and temporal cortices [88,89], but there is so far no evidence as to whether hallucinations experienced by non-clinical individuals reflect the same pattern of anterior PFC dysfunction that has been observed in patients with schizophrenia.

It may well be that there is more than one route by which hallucinations might occur in clinical and non-clinical groups. Hallucinations are sometimes experienced spontaneously in healthy individuals during periods of sensory deprivation [50], auditory hallucinations can follow the onset of deafness [90], and visual hallucinations can occur following visual cortex injury [91]. These observations fit with the proposal that hyperactivation of sensory processing cortices might provide the perceptual content for hallucinatory experiences [92]. Consistent with this proposal is evidence that, in healthy individuals during periods of silence, there is spontaneous random activity in speech-sensitive auditory processing areas within the superior temporal gyrus, together with associated activation in the anterior cingulate region of the medial PFC [93]. Thus, it is possible that a hallucination is initiated by spontaneous random activity in sensory processing areas, such as the superior temporal gyrus in the case of auditory hallucinations, reflecting spontaneous 'inner speech' and/or remembered speech, which may occur with greater intensity or frequency during periods of stress or heightened emotion [81]. In healthy individuals who do not experience hallucinations, such sensory activity may be correctly identified as being internally generated by reality monitoring processes supported by anterior medial PFC, and experienced as an imagined voice. In patients with schizophrenia who experience hallucinations, spontaneous sensory hyperactivity may be even more intense, accompanied by hypoactivation of medial PFC regions (consistent with studies of connectivity [75,76]), resulting in a reality monitoring impairment that leads to failure to recognize the activity as self-generated and to the experience of a hallucination. In non-clinical voice-hearers, the spontaneous activity in sensory processing areas may either be of such intensity, or be

sufficiently unusual in character (perhaps due to emotional stress, trauma, or tiredness [81]), that an otherwise intact reality monitoring system fails to recognize the stimuli as generated internally, and a sporadic hallucination is experienced. A multifactor model such as this (see also [92,94]) can also explain why some participant groups, such as older adults [95], people with developmental disorders such as autism [96], and healthy volunteers with bilateral PCS absence [41], may exhibit reductions in performance on reality monitoring tasks but do not apparently experience hallucinations. These findings may be less compatible with single factor accounts, such as those involving prediction error (e.g., [97]).

Concluding Remarks

There is still much to discover about the brain mechanisms underlying reality monitoring, and the ways in which they may fail in health and disease, impairing the accuracy of judgments about what is real (see Outstanding Questions). Reality monitoring processes are fundamental for maintaining an understanding of the self as a distinct, conscious agent interacting with the world, perceiving and interpreting external information relating to events happening around us and generating our own thoughts and imaginations and responses. Generally, people are able to keep the 'internal' and 'external' worlds distinguished sufficiently from one another to function under everyday circumstances but, occasionally, anyone may confuse real experiences with those they might have been told about or imagined or dreamt. Some individuals face a greater difficulty in reality monitoring, perhaps reflecting specific individual differences in the general population or, in more severe cases, dysfunction caused by neurological or psychiatric disease.

The evidence from cognitive neuroscience research to date converges to suggest that the anterior PFC region of the brain is central to reality monitoring ability and disability. It is a key component of brain networks that are engaged when distinguishing internally and externally generated information, and its disruption is associated with misattributions of reality, confusing internally generated information with events taking place in the outside world. It appears to play an important, and previously underappreciated, role in the psychotic experiences that characterize disorders such as schizophrenia. The processes underlying reality monitoring are, similarly to many higher cognitive functions, complex [9], but progress has been made by laboratories around the world in recent years leading to a greater understanding of the brain regions, especially the anterior PFC, that subserve reality monitoring mechanisms. An important next challenge will be to apply this knowledge to the development of cognitive training techniques and other rehabilitation interventions aimed at enhancing the ability to distinguish between real and imagined experiences in people whose sense of reality may be disturbed. Preliminary evidence suggests that such an approach might have potential [74,98], but researchers are only at the beginning of this road and there is much further work to do before it can be determined whether the potential is real.

Outstanding Questions

Although much has been learned in recent years about the mechanisms of reality monitoring, and the way they may be impaired in neurological and psychiatric disorders, there is much still to be discovered. In particular:

Which regional and interregional brain mechanisms, and related cognitive processes, might explain the intriguing observations that poor reality monitoring performance in healthy individuals is associated not only with reduced anterior PFC activity but also with PCS reductions and greater volume of surrounding cortex?

What are the common and distinct components of neural activity associated with reality monitoring tasks that require a distinction between self and other, and internal source monitoring between self-generated activities (e.g., imagined and performed)?

Do hallucinations experienced by non-clinical individuals without a psychiatric diagnosis reflect a similar pattern of anterior PFC dysfunction and reduced PCS length to that observed in patients with schizophrenia? Are similar functional and structural markers also present in prodromal individuals who subsequently progress to a diagnosis of schizophrenia?

What can explain the subjective differences between hallucinations typically experienced by patients with schizophrenia and by non-clinical individuals with a proneness to psychosis? Why are some people with hallucinations fully aware that their experiences are erroneous perceptions, but others are not?

Does the range of findings concerning hallucinations require a multiple factor explanation, or can they be explained equally fully by more parsimonious single factor accounts, such as prediction error?

What are the similarities and differences in dysfunction in the brain mechanisms underlying reality monitoring processes that lead to hallucinations, confabulations, and delusions?

Can interventions that involve cognitive training, brain stimulation, or neurofeedback be developed according to

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theoretical hypotheses about disrupted functions to improve reality monitoring ability and, if so, can they be demonstrated to reduce the incidence of hallucinations in people who experience them?

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