Source monitoring and memory distortion

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SUMMARY

Memory distortion reflects failures to identify the sources of mental experience (reality monitoring failures or source misattributions). For example, people sometimes confuse what they inferred or imagined and what actually happened, what they saw and what was suggested to them, one person's actions and another's, what they heard and what they previously knew, and fiction and fact. Source confusions arise because activated information is incomplete or ambiguous and the evaluative processes responsible for attributing information to sources are imperfect. Both accurate and inaccurate source attributions result from heuristic processes and more reflectively complex processes that evaluate a mental experience for various qualities such as amount and type of perceptual, contextual, affective, semantic and cognitive detail, that retrieve additional supporting or disconfirming evidence, and that evaluate plausibility and consistency given general knowledge, schemes, biases and goals. Experimental and clinical evidence regarding cognitive mechanisms and underlying brain structures of source monitoring are discussed.

1. INTRODUCTION

The problem of verifying memories and separating true from false memories has received national attention in recent years, for example in highly publicized cases of children's testimony and apparently long-forgotten memories of childhood abuse that are remembered by adults, sometimes in the course of therapy (Ceci & Bruck 1993; Loftus 1993). These socially significant instances point to fundamental issues about human memory in general. Psychologists have known for some time that memory does not record experience like a video camera (Bartlett 1932). When we read novels or listen to friends or see an accident, we are comprehending the information in light of our expectations, making assumptions and inferences and filling in based on prior knowledge, and perhaps failing to notice or incorporate information that is incongruent with our currently active cognitive schemas. Likewise, when we think back on events and remember them, the same interpretive, inferential and motivational processes are operating. The resulting memories include not only perceptual information but our inferences, imaginations and thoughts (e.g. Bransford & Johnson 1973; see also Alba & Hasher 1983; Johnson & Sherman 1990, for reviews).

To manage as well as we do, given such a constructive memory system, we proposed that the system must have some mechanisms or processes designed to help us sort out information that was primarily derived from perception from information that was derived from our thoughts; we called these processes reality monitoring. That is, reality monitoring refers to the processes involved in discriminating memories and beliefs generated by reflection from those derived from perception (Johnson & Raye 1981; Johnson 1985, 1988, 1991, 1997). Reality monitoring failures occur when people misattribute something that was reflectively generated to perception or vice versa. According to this view, reality is not directly given in remembering, but is an attribution that is the outcome of judgement processes.

Reality monitoring is just a particularly interesting subset of the more general cognitive activity of source monitoring, which includes distinguishing between external sources or between internal sources, as well as between external and internal sources. For example, source monitoring includes identifying who told you something, whether you saw an event in real life or on television, whether an event happened a week ago or a month ago, and whether you told a secret to your friend or only thought about telling it. We have described source monitoring as an attribution which is the outcome of judgement processes that take into account certain phenomenal characteristics of memories, as well as consistency checks, plausibility judgements, and other extended retrieval and reasoning strategies (e.g. Johnson 1988; Johnson *et al.* 1993; Johnson & Raye 1981). Memory distortions can happen in many contexts and forms, but most memory distortion involves failures in monitoring the source of information.

2. A SOURCE-MONITORING FRAMEWORK

My colleagues and I proposed an integrative framework for characterizing and investigating processes involved in identifying the origin of information: the source-monitoring framework (SMF) (Johnson *et al.* 1993; Johnson & Raye 1981). This approach explains both veridical and distorted memory with a common set of principles. Fundamental are several ideas. First, an event memory consists of sets of phenomenal characteristics, which are the result of multiple distributed cognitive processes during the event (and after if the memory is reactivated or retrieved) (e.g. Johnson 1983, 1992). Second, memories from different sources differ in characteristic ways that can, in principle (but only on average), be used to identify the origin of information.

For example, perceived and imagined classes of events differ in average value along a number of dimensions or attributes. Memories originating in perception typically have more perceptual detail or features (e.g. colour, sound), more contextual detail such as time and place, more semantic detail and more affective information. In contrast, memories originating in reflection typically have more accessible information about cognitive operations, that is, about those perceptual and reflective processes that took place when the memory was established. Judgement processes capitalize on these average differences. Thus, differences in average value between perceptually and reflectively derived memories along these dimensions form one basis for deciding the origin of a memory. For example, one would be likely to decide that a memory with a great deal of perceptual information and very little cognitive operations information was externally derived (Johnson *et al.* 1979, 1981). Similarly, one might decide that a statement was said by person A rather than person B because the auditory information in the memory matches A's voice or the visual information matches A's appearance (e.g. Ferguson *et al.* 1992; Johnson *et al.* 1996*b*).

Other processes involved in source monitoring tend to be more complex. You may decide when an event occurred because you can relate it to another event memory that contains more definitive time information; or you may decide you read something in the newspaper rather than saw it on TV news because you remember thinking it was consistent with the newspaper's position, or because you cannot retrieve perceptual information about the broadcast that you feel you should be able to if you had seen it on TV. That is, more extended source monitoring may involve beliefs about memory and cognition as well as retrieving additional information from memory and evaluating the source of the target memory given these beliefs, other specific memories or general knowledge (e.g. Johnson *et al.* 1988*b*). For example, you might have a vivid memory of your great-grandmother holding you in her lap, but realize it cannot be accurate because you know she died before you were born.

Source monitoring typically takes place rapidly, in a heuristic, non-deliberative fashion, based on the general characteristics of memories that are activated (e.g. amount or type of perceptual detail). Generally. slower, more deliberate retrieval of supporting memories and reasoning processes (e.g. Does this seem plausible given other things I know?) are engaged less often. All source memory problems can be analysed in terms of the qualitative characteristics considered and the heuristic and systematic judgement processes used to make source attributions.

A third fundamental idea is that the judgement processes used in any given situation and the criteria adopted will be affected by such factors as the nature of the task, cost of mistakes, our preconceptions, amount of distraction and the social context. For example, criteria are likely to be more lax in a casual conversation with a friend (e.g. recalling the source of gossip) than in a professional meeting (e.g. recalling the source of scientific ideas), or more lax if a memory fits with what one already believes or wants to believe than if it does not.

(*a*) *Sources of error and distortion in memory*

Using this source-monitoring framework, there are various ways in which source memory errors could occur (for recent reviews see Ceci & Bruck 1993; Johnson *et al.* 1993; Roediger 1996; Schacter 1995; Wilson & Brekke 1994): The schema-based inferences we make in simply comprehending events initially can later be misattributed to perception. For example, if someone tells you that *John pounded the nail* and you infer he used a *hammer*, you may later be likely to claim that the speaker told you John had a hammer (Johnson *et al.* 1973). Anything that disrupts the binding of features (e.g. semantic content, spatial location, colour) into a complex event memory, such as stress, distraction or brain damage, will reduce source memory (Chalfonte *et al.* 1997; Jacoby *et al.* 1989; Schacter *et al.* 1984; Shimamura *et al.* 1990). Certain types of emotional focus can disrupt feature binding as well (Johnson *et al.* 1996*b*). Memories that are similar in perceptual features or semantic content can easily be confused (Johnson *et al.* 1988*a*; Lindsay *et al.* 1991). Misinformation introduced through suggestion can be misattributed to a target event as shown by studies of eyewitness testimony (Belli & Loftus 1994; Zaragoza & Lane 1994). Reactivating and retrieving memories strengthens them, but also potentially embellishes them (Suengas & Johnson 1988; Ceci *et al.* 1994). Any disruption of the ability to revive or evaluate additional supporting or disconfirming information may create source monitoring errors (e.g. Craik 1982; Dodson & Johnson 1996; Jacoby 1991). Inappropriately lax criteria can produce source monitoring failures (Lindsay & Johnson 1989; Dodson & Johnson 1993; Multhaup 1995). And source memory is affected by the social context. Social context affects when, how often and how we rehearse and ruminate about past events (e.g. Neisser, this volume; Nelson 1993) and the criteria we use for evaluating the veridicality of our memories (Marsh *et al.* 1997). For example, part of the current controversy over the recovery of repressed memories concerns the possibility that the expectations of therapists might set up inappropriately lax reality monitoring criteria for patients (see Lindsay & Read 1994).

In short, autobiographical (i.e. episodic or explicit) remembering requires source monitoring. Over and above the activation and use of information (as shown in our everyday use of general knowledge, skills, and in certain 'priming' or transfer phenomena), episodic remembering involves identifying the context or source of memories. Such source monitoring, in turn, depends on a number of processes that take place during encoding when features of complex memories become bound together, during the retention interval when memories may be rehearsed and embellished, and at the time information is recruited (including potentially confusable non-target information) and may be subjected to relatively lax or stringent evaluation.

The next section provides examples of studies illustrating some fundamental principles of source memory processes and the following section considers some evidence about brain regions underlying source memory.

(*b*) *Cognitive studies of source memory*

The more similar memories from two or more sources are, the more likely they will be confused. For example, one early study varied the number of times subjects saw pictures and the number of times they imagined each picture (Johnson *et al.* 1979). Subsequently, subjects gave higher estimates of the number of times they had seen a picture the more often they had imagined it. Furthermore, compared to poor imagers, good imagers were more influenced by their imaginations (see also Dobson & Markham 1993; Markham & Hynes 1993). Thus one important factor in the likelihood that imagined information will be misattributed to actual events is how vivid the memory representation is. The impact on source monitoring of individual differences in imagery/fantasy ability remains a relatively unexplored, but potentially important research domain.

Other studies show that the more easily information is generated, the more likely it is later to be confused with perception (Durso & Johnson 1980; Finke *et al.* 1988; Johnson *et al.* 1981). For example, subjects are more likely to confuse the more common instances of categories they generate with perception than the less common instances (Johnson *et al.* 1981; Rabinowitz 1989). Generating uncommon instances presumably requires more cognitive operations, the records of which can be used to identify the source of memories. Thus information that is likely to be activated spontaneously (e.g. needle in response to thread; Anisfeld & Knapp 1968; Deese 1959; Roediger & McDermott 1995) is likely to be falsely remembered later, especially if there were repeated opportunities for the false information to have been incidentally activated (Underwood 1965) and/or if it is the central tendency or prototype for disparate pieces of presented information (Bransford & Franks 1971; Posner & Keele 1968). Such automatic associations, or easily inferred and generated information, may be filled in spontaneously at encoding or at test and misattributed with respect to source.

Nevertheless, recent evidence suggests that even such misattributed memories may differ in phenomenal characteristics from perceptually-derived memories. Mather *et al.* (1997) presented subjects with lists of associates to non-presented lure words (e.g. thread, pin, eye, sewing, sharp, point, prick, thimble, haystack, thorn are all associates of needle) in a procedure introduced by Deese (1959) and subsequently used by Roediger & McDermott (1995). As found by these other investigators, on a subsequent recognition test, subjects were very likely to falsely recognize the unpresented lures. However, on a Memory Characteristics Questionnaire (MCQ, e.g. Johnson *et al.* 1988*b*) that asked subjects to rate their memories on a number of qualitative characteristics, Mather *et al.* found that memories for lures had less auditory detail and less remembered feelings and reactions than did memories for presented words. Norman & Schacter (1997) found similar results. Mather *et al.* also varied the test conditions and found lower false recognition rates in some conditions when subjects were induced to examine their memories on several dimensions compared to when they were simply asked whether or not they remembered items. Thus, as suggested by the SMF, individuals may have source information that they do not, or cannot, use under some conditions.

Studies in which the time-course of memory reactivation and judgement has been measured indicate that source information is not revived in an all-or-none fashion but rather that memories take time to 'assemble'. Johnson *et al.* (1994) presented subjects with some pictures and some words and had them imagine pictures corresponding to the words (the cover task asked subjects to rate the perceived or imagined pictures for artistic merit). Subsequently subjects were presented with words and asked to indicate whether each corresponded to an item previously perceived, imagined, or a new item. Also varied at test was the time (from 300 to 1500 ms) from the memory probe until a tone indicated the subject had to respond. The time-course functions shown in figure 1 indicate that subjects can discriminate between old and new items well before they can discriminate between items from different sources (see also Hintzman & Curran 1994).

These time-course functions are generally consistent with the idea that recognition may be based either on familiarity or on the retrieval of more specific information (e.g. Atkinson & Juola 1973; Jacoby 1991; Mandler 1980). Such 'dual process theories' tend to characterize remembering as consisting of two processes (familiarity and recollection) or as memory being in one of two states: known or remembered (e.g. Tulving 1985; Gardiner & Java 1993). Although the general contrast between familiarity responses and more specific recollection has been (and remains) extremely fruitful (e.g. Jacoby 1991), as a basic theoretical distinction it is problematic (e.g. see Dodson & Johnson 1996). Based on the SMF, mental experiences do not fall into a simple dichotomy, but rather are characterized as potentially differing along a variety of characteristics (e.g. perceptual/contextual detail, emotional qualities, etc.), producing memories that vary in the amount of evidence they provide for various types of judgements and judgement contexts.

Not only do memories differ in various qualities, the amount of information an individual requires for a given source attribution varies as well. For example, we would expect anything that disrupted availability of more differentiated information (initial feature binding deficits, deficits in retrieval, etc.) to force

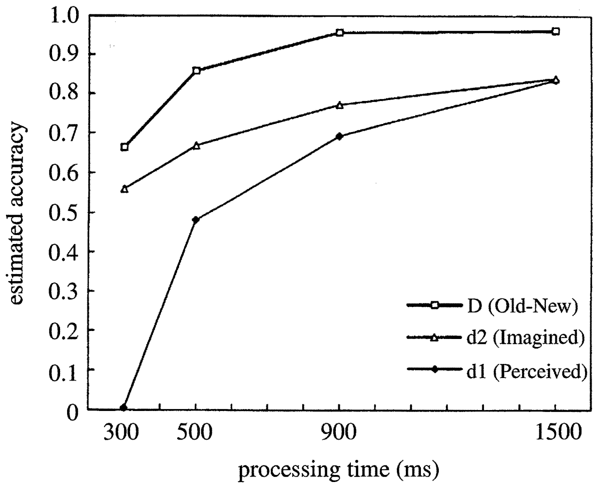

Figure 1. Time-course functions for old/new recognition and reality-monitoring performance (from Johnson *et al.* 1994).

subjects to rely more heavily on undifferentiated, global, familiarity information (e.g. as do amnesics, elderly adults, individuals under conditions of distraction, etc., see below).

One of the potentially most interesting factors determining the veridicality of memories is the rumination we do via reactivating and retrieving. One study (Suengas & Johnson 1988) had subjects participate in or imagine participating in various simulated autobiographical events such as wrapping a package, meeting someone and having coffee and cookies. Subjects engaged in some activities and were asked to imagine engaging in others, guided by a script. Later, subjects filled out an MCQ assessing various qualitative characteristics of their memories (How well do you remember the spatial arrangement of objects? How well do you remember how you felt at the time?). The impact on MCQ ratings of having subjects think about events after they happened was also investigated. After the initial MCQ ratings, subjects returned to the lab and were cued to think about each event either 0, 8 or 16 times. Then they returned again and filled out the MCQ. Initially, ratings on visual clarity were higher for perceived than for imagined events (see also Hashtroudi *et al.* 1990). For both perceived and imagined events, perceptual details tended to be less accessible over time unless the event was thought about (reactivated), in which case these details were maintained. This finding suggests that if people selectively reactivate imaginations, those memories could begin to rival in vividness memories for perceived events from the same time frame. At the same time, rehearsal might make it easier to generate the memory, reducing the cognitive operations cues that signal that a mental experience was initially imagined rather than perceived, further increasing confusion.

Ceci *et al.* (1994) recently presented dramatic evidence of the potential impact of rehearsal and elaboration. Through repeated questioning, they induced some young children to report that fictitious events had happened, for example, going to hospital after getting a finger caught in a mousetrap. Furthermore, with repeated questioning, the children's accounts became increasingly coherent and detailed. Similarly, Hyman *et al.* (1995) showed that some adults can be induced to falsely recall childhood events (e.g. a hospitalization for an ear infection) if encouraged to think about the events between a first and second interview (see also Loftus & Coan 1997). Garry *et al.* (1996) showed that asking adults to imagine a childhood event increased their confidence that the event occurred.

3. BRAIN MECHANISMS OF SOURCE MONITORING

The last section outlined source memory processes and the types of failures in source memory processes that lead to memory distortions. These ideas can provide a framework for exploring the brain mechanisms of source monitoring. Especially exciting are the possibilities for connecting cognitive concepts and neurobiology through advances in brain imaging and recording of electrophysiological brain activity. We do not have to start from scratch in identifying relevant brain areas, of course. Observations of patients with brain damage provide many insights.

There are a number of reasons to expect that frontal regions of the brain are critical for source monitoring and veridical remembering. First, frontal regions are likely to be involved in circuits with the hippocampus to promote feature binding (Goldman-Rakic *et al.* 1984; Johnson 1997; Shallice *et al.* 1994), and episodic or event memories are those that have cohesively bound source-specifying information. In addition, frontal regions are believed to have a number of 'executive' functions (Baddeley 1986; Baddeley & Wilson 1986; Goldman-Rakic 1987; Norman & Shallice 1986; Stuss & Benson 1986): they play a critical role in strategic retrieval, maintain the activity of representations and underlie controlled, evaluative processes. As described earlier, all these are necessary for adequate source monitoring in many situations.

In addition to expecting frontal regions to be critical for source memory on the grounds of the overlap between global frontal functions (e.g. Stuss & Benson 1986; Stuss *et al.* 1994) and factors outlined in the SMF (e.g. Johnson 1988), direct evidence regarding frontal involvement in source monitoring comes from studies of source memory in patients with frontal lesions.

(*a*) *Tests of source monitoring in patients with frontal damage*

On specific tests of source monitoring, frontal patients have deficits in temporal order information: for example, they have difficulty saying which of two items presented in the lab occurred most recently, or difficulty ordering historical events (Milner 1971; Milner *et al.* 1985, 1991; Shimamura *et al.* 1990; Butters *et al.* 1994; McAndrews & Milner 1991). Schacter and others (Schacter *et al.* 1984; Janowsky *et al.* 1989; Craik *et al.* 1990; Shimamura & Squire 1987) tested the source monitoring capabilities of frontal patients or individuals with presumed frontal damage by telling them various trivia facts (e.g. Bob Hope's father was a fireman) and then later asking them where they learned these facts. Frontal patients are likely to claim to have learned the fact before the experiment, from a magazine or newspaper.

As discussed above, another manifestation of source-monitoring failure common in neurologically intact individuals is false recognition of items that were not presented (e.g. Deese 1959; Johnson *et al.* 1973; Underwood 1965), and when the probability of such errors is manipulated in controlled experiments they provide evidence about the information and processes ordinarily used in source attributions (e.g. Anisfeld & Knapp 1968; Mather *et al.* 1997). Neurologically based memory problems do not invariably lead to false recognitions. Patients with medial-temporal lesions, who may show profound amnesia, often make few false positives; they are likely to say 'no' both to old and new items because very little seems familiar to them (e.g. Hirst *et al.* 1986). In contrast, some frontal patients show extremely high rates of false recognition (Schacter *et al.* 1997). Schacter *et al.* reported a patient, BG, who had an infarction of the right frontal lobe. On recognition tests involving either words, sounds, pronounceable non-words or pictures, BG falsely recognized an unusually large number of distractors. Furthermore, his false recognitions were not disproportionately increased for associatively related compared to unrelated distractors. However, when study items were drawn from specific categories and the distractors were drawn from a different semantic category than the studied items, BG's false recognition rates were normal. Evidently, he remembered that he had been presented with items of a general type, but was unable to discriminate along any other features that might have differentiated specific old and new items. In short, BG seemed to need a single, unambiguous cue to differentiate old from new items. Also interesting was that BG claimed to 'remember' many of the items that he falsely recognized when asked to make remember/know judgements about items he identified as old. Apparently, he felt that the cue he could remember (general class) was sufficient evidence for assigning a 'remember' response. Pathologically high false recognition rates are not always associated with remember responses. A patient (who had had an aneurysm of the anterior communicating artery, ACoA) reported by Parkin (1995) with unusually high rates of false alarms made primarily 'know' responses to falsely recognized items.

Another ACoA patient (M. Johnson, L. Grande, & W. Milberg, unpublished data) showed another intriguing false recognition phenomenon in the context of a source monitoring task. The patient, WL, saw a series of pictures and words referring to common objects. The cover tasks used at study were patterned after Durso & Johnson (1980; see also Johnson *et al.* 1994) to induce subjects to make images for the words. A subsequent source memory test required the patient to identify test words as previously presented pictures, words or new. WL was tested twice, shortly after her aneurysm and a year later (table 1). For the first session, there were two notable aspects of her data (table 1*a*). First, she identified 12 of 32 new items as old, a very high rate of false recognition. Second, almost all of these she claimed to have seen as pictures, regardless of whether they had been pictures, words or new items. At the second session, a year later, WL was given a similar test (table 1*b*) and she showed a response pattern typical of normal subjects (Durso & Johnson 1980). That is, her old/new and source memory were quite good and she showed the normal asymmetry in source monitoring errors on old items (more likely to claim to have seen a word as a picture than vice versa) that reflects confusion of previously imagined pictures with perceived pictures, a reality monitoring failure (Durso & Johnson 1980).

Table 1. *Scores on source monitoring test for patient WL: session 1 and session 2, one year later*

	response		
	picture	word	new
session 1			
source			
picture	21	0	13
word	13	3	18
new	12	0	20
session 2			
source			
picture	30	1	2
word	5	25	4
new	2	3	27

What might account for the unusual response pattern of WL at session 1? Clearly her overall memory was quite poor: old/new recognition was at chance (57%). If her memory was so poor, one might think that her phenomenal experience would be a vague sense of familiarity for some items, which should have been more likely to produce 'word' than 'picture' responses (or equal word and picture responses if she were simply guessing). Instead, she claimed to have seen pictures of almost all the items she called old. One possibility is that, similar to patient BG, she remembered only that she had seen some pictures and so called every item that seemed familiar a picture. Another hypothesis is that whenever a picture/image came to mind readily at test for an item, WL attributed it to recent perceptual experience. In both cases, like Schacter *et al.*'s (1997*a*) BG, she would have used a simple heuristic to make recognition decisions: BG evidently decided if an item was old on the basis of whether test items fit the general class of items he was shown; WL evidently decided that a test item had been shown as a picture if a picture came to mind or a concept seemed familiar. Interestingly, WL's heuristic is just the sort that could, in principle, lead to confabulation, claiming events as real that are only imagined. And, in fact, WL did show clinical evidence of confabulation, which had cleared by the second testing session a year later.

(*b*) *Confabulation in frontal patients*

Some of the most dramatic evidence of source-monitoring deficits from frontal damage comes from clinical observations of confabulation (Johnson 1991). Statements clinically classified as confabulations range from relatively minor filling in of memory gaps and confusions in where or when actual events occurred to bizarre and fantastic stories. Clinical descriptions of confabulating patients are generally consistent with the idea that reality monitoring involves two types of judgement processes (Johnson 1991). Patients who have had a cingulectomy (to control obsessive–compulsive behaviour) experience reality monitoring failures that appear to be the consequence of heuristic errors either produced by unusually vivid mental experiences, or lax criteria. For example, Whitty & Lewin (1957) described a patient who, when asked what he had been doing, reported a visit from his wife. The patient then realized that she had not visited that day, but commented on how real the event seemed. Thus vivid ideas initially may pass the heuristic reality-monitoring check based on their qualitative characteristics, but may be correctly evaluated by more systematic processes that check for consistency, plausibility, and coherence.

Source-monitoring errors that appear to result from disruption in systematic processes are likely to be seen in patients with more extensive frontal damage. Such patients may make bizarre or implausible statements, for example, claiming to have been returned to life after being shot and killed (Stuss *et al.* 1978), or claiming to have been a space pirate (Damasio *et al.* 1985). With deficits in systematic processes, vivid ideas that pass a heuristic reality monitoring check are not caught. Baddeley & Wilson (1986) and Moscovitch (1995) also identify strategic processes with frontal functioning and emphasize the importance of disrupted frontal function in producing confabulation.

Fischer *et al.* (1995) considered nine patients with aneurysm of the anterior communicating artery (ACoA) and concluded that degree of confabulation was related to the extensiveness of the frontal lesions. Similarly, DeLuca & Diamond (1995) reviewed the literature concerning ACoA patients and suggested that both frontal lobe and basal forebrain lesions are necessary to produce fantastic confabulation (that persists beyond the initial confusional state). ACoA patients have also been shown to have source deficits in temporal order (Parkin *et al.* 1988; Johnson *et al.* 1997*b*), spatial memory (Shoqeirat & Mayes 1991) and modality (visual vs. auditory) (Shoqeirat 1989, cited in DeLuca & Diamond 1995).

Overall then, there is no question that the frontal lobes are critically involved in reality monitoring and source monitoring in general. In addition, we have a relatively good understanding of the cognitive processes involved in accurate source monitoring and the factors that result in memory distortion (Johnson *et al.* 1993; Johnson 1997). Nevertheless, we still have some way to go to match brain structures with what has been learned about memory and cognition.

Some of the complexity of these issues is illustrated by an ACoA patient, GS, who suffered frontal lobe damage (Johnson *et al.* 1997*b*). GS's confabulations were generally realistic. For example, he believed that he had fallen and hit his head while standing outside talking to a friend whereas, according to his wife, his aneurysm ruptured while he was in an upstairs apartment fixing the bathtub when he suddenly collapsed. We compared GS to three age-matched normal controls and to three non-confabulating frontal patients who were matched with him on several standard neuropsychological tests of memory, attention and so-called 'executive' or frontal functions. Of interest was subjects' performance on several tasks that have been used to study source monitoring in normal populations.

In one set of tasks, the subjects saw and heard a man and a woman say various words or sentences. Later, subjects had to identify whether test items were said by the man, the woman or were new. The old/new recognition and source identification results were both quite typical and the data are shown in rows 1 and 2 respectively of table 2. Frontal patients and GS showed no deficit relative to controls on old/new recognition, but did show a marked deficit in source accuracy. Row 3 of table 2 reflects scores on an autobiographical memory test in which the subjects were asked to describe several events from their lives, for example, a *time with a friend* and a *vacation*. Frontal patients showed a marked deficit compared to controls in the amount of autobiographical detail they could give, another typical finding. But GS's recall was extremely impoverished, even in comparison to other frontal patients. Finally, in another task subjects participated in some events and imagined participating in others, e.g. they actually hammered a nail in a board and imagined making a paper snowflake with scissors. Twenty-four hours later, they were asked to describe the events, and their descriptions were rated for various types of detail. The frontal patients and GS recalled less than normals, but in contrast to both normals and the other frontal patients, GS recalled somewhat more detail for imagined events than he did for actual events.

In short, GS showed profound deficits in the systematic retrieval of autobiographical memories, source-monitoring deficits on the speaker identification task, and a propensity towards detailed imaginations. Any one factor alone might not produce a clinically significant pattern of confabulation, but together they could produce confusion between fact and fiction. Against a background of impoverished autobiographical memories, any highly detailed 'memory' (whether real or invented) would stand out. With poor source information, and with markedly impaired ability to retrieve additional confirming or disconfirming autobiographical memories, GS would not be able to reflect on other evidence in determining the authenticity of such memories. Consequently, he would be predisposed to accept them as real events.

GS and the other frontal patients were matched on neuropsychological tests, not on lesion site. In fact, GS had bilateral damage whereas the three frontal controls all had evidence of left frontal damage. Burgess (1992, cited in Shallice *et al.* 1994), suggested that confabulation is more likely to occur after right than after left-side damage to the prefrontal cortex. However, there are some reports of confabulation in left unilateral patients, so confabulation is not restricted to right or to bilateral damage. Nevertheless, it is tempting to speculate that GS's profound deficit in retrieving

Table 2. *Memory scores on several tasks for patient GS (data from Johnson et al. 1997)*

	GS	frontal controls	normal controls
old/new recognition	0.70	0.68	0.67
speaker identification	0.26	0.27	0.53
autobiographical recall	2.50	16.83	30.58
rated details			
actual	4.20	3.93	6.32
imagined	5.47	2.61	6.34

autobiographical memories was related to his right frontal damage, consistent with recent proposals (see §3*a* and §3*b*) that right frontal regions are particularly important for episodic retrieval (Tulving *et al.* 1994*a*; Shallice *et al.* 1994).

It should be noted, however, that not all frontal patients confabulate and not all confabulations are accompanied by signs of frontal dysfunction. To go beyond currently available evidence, we need case studies with a more complete characterization of the nature of patients' confabulations (e.g. Dalla Barba 1993), more extensive testing on a variety of source memory tasks (e.g. Johnson *et al.* 1997*b*), and clearer specification of the areas of brain damage (e.g. Fischer *et al.* 1995).

(*c*) *Ageing and source monitoring*

Older adults show impairments in a variety of tasks that assess memory for source or contextual information (Johnson *et. al.* 1993). This impairment may be related to a loss of frontal functions associated with normal aging (e.g. Craik *et al.* 1990; Janowsky *et al.* 1989). Sometimes source accuracy is positively correlated with high functioning scores on neuropsychological tests of frontal function such as the Wisconsin Card Sorting Test or the verbal fluency (FAS) test (e.g. Craik *et al.* 1990) and sometimes it is not (e.g. Johnson *et al.* 1995; Spencer & Raz 1994). Johnson *et al.* (1995) suggested that such inconsistencies in outcomes may not be surprising given the variety of qualitative characteristics and processes potentially involved in source memory and the lack of specificity of neuropsychological tests of frontal function. Glisky *et al.* (1995) recently reported that better prediction of performance can be achieved when elderly subjects are given composite scores derived from several standard neuropsychological tests assessing frontal or medial temporal functions. Using this approach, Glisky *et al.* found a dissociation between item memory and source memory: subjects' old/new recognition for sentences was associated with high scores on the medial temporal composite whereas subjects' ability to identify the speaker of the sentences was associated with high scores on the frontal composite. This composite score approach should be particularly promising in combination with a broader range of source tasks administered to each subject.

(*d*) *Brain imaging*

Positron emission tomography (PET; Roland *et al.* 1995) uses cerebral blood flow as an index of brain activity (functional magnetic resonance imaging, fMRI, is promising but has been used less to date). The PET scan is recorded while a subject performs the target task and, in a separate scan, a reference (or baseline) task. For example, subjects might be presented with category-exemplar word pairs (e.g. poet-Browning) and asked to learn them (target task) or just asked to repeat the words (reference task) and later asked to recall. Typically, brain activity during the reference task is subtracted from activity in the target task to reveal activity that is specific to the target task (e.g. Buckner *et al.* 1995; Fletcher *et al.* 1995; Kapur *et al.* 1994; Shallice *et al.* 1994; Tulving *et al.* 1994*b*; see Buckner 1996, for a discussion of the subtraction procedure). Imaging studies of episodic encoding and retrieval tasks have been reviewed by Buckner & Tulving (1995) and Nyberg *et al.* (1996*a*). Episodic memories by definition include information about their source (Tulving 1983), thus attempts to identify brain correlates specific to processing episodic memories are relevant to understanding source monitoring.

Episodic encoding reliably results in greater activation in the left prefrontal cortex, whereas episodic retrieval reliably results in greater activation of the right prefrontal cortex (Tulving *et al.* 1994*a*). Buckner (1996) concludes that an area in the right prefrontal cortex near BA 10 appears common to retrieval of episodic information independent of stimulus materials, orienting task, modality, etc.

Researchers have attempted a finer analysis of episodic retrieval processes by manipulating the likelihood that subjects will be successful at remembering during the block of trials within a scan (e.g. by varying encoding task or the proportion of old items tested) and found that high performance tends to be associated with medial temporal hippocampal or parahippocampal activity (Kapur *et al.* 1995; Schacter *et al.* 1996*a*; Nyberg *et al.* 1996*b*). Nyberg *et al.* suggest that medial temporal activation may reflect the actual activation of the sought-for stored information. Kapur *et al.* propose that the prefrontal area drives the retrieval search and that successful retrieval and the experience of remembering is related to activity of the posterior multimodal associative cortex.

Investigators have also begun to use PET to identify brain correlates of relatively subtle differences in phenomenal experience. As noted previously, Mather *et al.* (1997) and Norman & Schacter (1997) found that subjects gave higher ratings of auditory information for memories of words they had actually heard than for associated words that they falsely recognized. Consistent with this, Schacter *et al.* (1996*b*) recently found that, compared to lures, old items resulted in greater blood flow in the temporo-parietal region, especially on the left, an area that has been linked in other studies to phonological processing. Schacter *et al.* also noted that, compared to new items (and to old words), the related lures produced more activation in anterior prefrontal cortex (BA 10), orbitofrontal cortex (BA 11) and the cerebellum. This greater frontal activation for critical lures is consistent with the idea that lures should present a particularly difficult source-monitoring problem as subjects attempt to identify the origin of items that seem familiar but for which clear source information is not available. The next section presents converging evidence from event-related potentials that source identification and simple old/new recognition (both episodic tasks but requiring different degrees of source monitoring) differ in brain activity especially in frontal regions.

(*e*) ***Event-related potentials***

Although PET and fMRI provide excellent information about spatial location of regions of activation in cognitive tasks they are less useful for identifying temporal properties of cognitive processing. Characterizing the duration and sequencing of component processes is central to specifying the transactions among brain regions that underlie cognitive activities (e.g. Goldman-Rakic *et al.* 1984; Johnson & Reeder 1997). Excellent temporal resolution, along with coarse location information, is obtained from recording electrical activity from the scalp using the event-related potential (ERP) technique. ERPs are derived from segments of the ongoing electroencephalogram that are averaged with respect to a discrete event, for example, the presentation of a test word. Because ERPs provide information about brain activity as it develops within trials, a combination of imaging and ERP techniques is likely to provide an especially productive approach for the future. To date, not enough ERP studies have been done with variations of the same paradigm to yield clear temporal patterns of source monitoring; however, ERP studies are providing data consistent with spatial localization findings from PET and some suggestive temporal findings are in as well.

There have been a number of ERP studies of episodic memory (see Rugg 1995 for a review) and a few that specifically address issues of source memory. One hypothesis is that the magnitude of ERP amplitude differences between correct responses to old and new items reflects whether or not contextual detail has been recovered ('recollection') or whether the subject is attempting to recover contextual detail. For example, Wilding & Rugg (1996; see also Wilding *et al.* 1995) presented subjects with words in either a male or female voice and subsequently presented these same items visually, mixed with new items, and asked for old/new decisions with each followed by a source judgement. They found a greater ERP positivity for correct old responses compared to correct news (the 'old-new effect'), especially in left parietal (500–800 ms post stimulus) and right frontal (1100–1400 ms post stimulus) sites. Furthermore, these old-new effects were greater for items recognized as old that were also correctly identified as to source than for items that were incorrectly identified as to source.

Dywan *et al.* (1996) reported an experiment in which young adults showed good source identification for items that did not show a marked frontal positivity. Conversely, older adults showed large positivity for items for which they made many source errors. Based on their findings, Dywan *et al.* suggested that a difference between old and new items in positivity is not necessarily an index of recollection but may, instead, represent the amount of attention paid to a stimulus. For example, if positivity reflects attempted retrieval or evaluation/monitoring, Dywan *et al.*'s results suggest that older adults are engaging such processes but are less successful than younger adults in doing so. The factors determining the size and temporal and topographical distribution of old-new differences in ERPs in source monitoring paradigms remain to be sorted out.

The results of two recent experiments (Johnson *et al.* 1996*a*; 1997*a*) suggest that ERP components are sensitive to direct manipulations of source monitoring demands as predicted by the SMF. In one experiment (Johnson *et al.* 1996*a*) subjects saw pictures and words at study. In the Artist Difficulty condition, on picture trials, subjects rated how difficult the object would be for an artist to draw; on word trials, subjects imagined a line drawing of the referent of the word and rated how difficult the imaged picture would be for an artist to draw (an explicit imagery condition). In the Function condition, subjects rated the number of functions they could think of for each item. The Function group was expected to engage in some spontaneous imagery on word trials (Durso & Johnson 1980), but, in general, the perceptual information associated with memories for pictures and words should be more similar in the case of the Artist than the Function condition because the Artist subjects should be generating more pictorial information on word trials.

After a brief rest, subjects were tested while ERPs were recorded. Some subjects received a surprise old/new recognition test; for each item (a visually presented word), they responded old if it corresponded to either a picture or a word from phase one, and new if it did not. Other subjects received a surprise source monitoring test; for each item, they responded picture, word or new. Differences in information and processes required between old/new and source decisions should be reflected as differences in brain activity. As noted above, both old/new recognition and source identification require source information, but source identification typically requires more specific information (e.g. voice, colour, etc.) whereas old/new recognition can often be made on the basis of undifferentiated familiarity. Likewise, differences in the information that is most discriminative for source decisions in the Function and Artist conditions should be reflected in corresponding differences in brain activity.

Figure 2 shows wave forms for correct responses recorded at selected frontal and occipital sites, collapsed across acquisition condition for the two types of test: old/new vs. source monitoring. These ERP waves are plotted with time (in 100 ms. units) going from left to right, with positive voltages plotted up and negative voltages plotted down. As shown in figure 2, the main difference was recorded at frontal sites and was long-lasting, and the two tasks did not

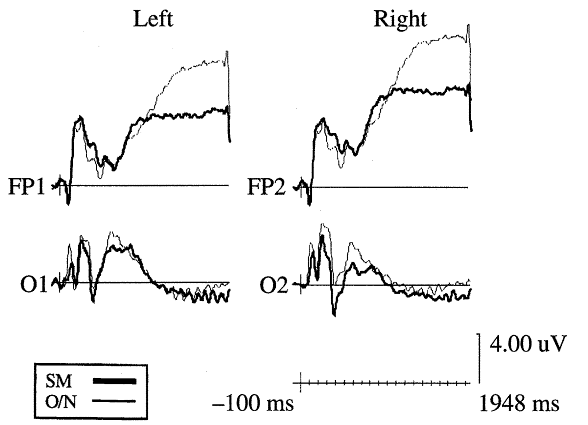

Figure 2. Event-related potentials recorded at prefrontal (FP1/FP2) and occipital (O1/O2) sites for source monitoring task (bold) and old/new task (thin), collapsed across acquisition group.

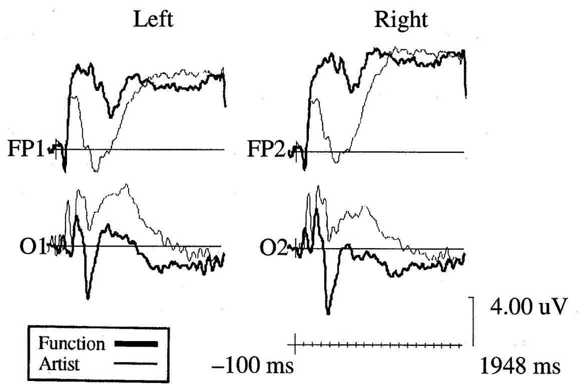

Figure 3. Event-related potentials recorded at prefrontal (FP1/FP2) and occipital (O1/O2) sites for source monitoring test task. Subjects had made either Function (bold) or Artist difficulty (thin) judgements at acquisition. Test stimuli and task are identical for the two groups.

look very different at more posterior sites. This is what one would expect if source monitoring is more dependent on frontal functions than is old/new recognition, as suggested by evidence from brain damaged patients (e.g. Schacter *et al.* 1984; Janowsky *et al.* 1989).

Now consider the waveforms for the source monitoring task broken down separately for the two conditions (figure 3). Both conditions showed a distinct negative deflection at approximately 400 ms, but this negativity was focused at frontal sites in the Artist condition and at the occipital sites in the Function condition. The test list and test task were identical for these two conditions, thus these results indicate that the distribution of ERP activity depends on what was initially encoded and/or what information subjects are consulting (attempting to access or weighting most heavily) at test.

One hypothesis is that for Function subjects, amount of perceptual detail is a good cue about the origin of information in memory and, hence, the Function group consults or relies on information represented in occipital sites. In contrast, for Artist subjects, amount of perceptual detail is not as good a cue about origin because images generated for the words would include perceptual detail that would make them difficult to discriminate from pictures. Artist subjects, therefore, are more likely to evaluate cognitive operations information in order to make source discriminations. Assessing records of such self-initiated operations should involve more frontally distributed processes. Thus the results shown in figures 2 and 3 suggest a general, relatively long-lasting frontal component that reflects the difference between old/new and source monitoring tasks and briefer specific deflections that represent the distributed types of information likely to be playing a role in source monitoring in particular situations.

Our data suggest that topographic distribution of prominent ERP components may be associated with which component processes are engaged and not necessarily with what information is activated or found. First, the prominent negative deflections over frontal and occipital sites that differentiated the Artist and Function groups, respectively, occurred not only for old items, but for new items as well. Presumably, new items do not give rise to the same types of information (at least to the same degree) as do old items but must be subjected to the same operations as old items (e.g. noting the amount of perceptual information they activate).

Our findings, along with those of Wilding & Rugg (1996) and Dywan *et al.* (1996) indicate that ERPs may provide important converging evidence about brain processes central for source monitoring. Our results support the idea that what the individual is trying to do—their agenda—affects the processes engaged and/or features that are activated or evaluated. For example, our data are consistent with evidence from brain lesion findings that frontal areas are often more critical for source monitoring than for old/new recognition. In addition, how information was encoded initially may have a greater impact on source monitoring wave forms than on old/new recognition waveforms. This is consistent with behavioural findings from cognitive studies showing that source monitoring requires more or more differentiated information than does old/new recognition (Johnson *et al.* 1994). Furthermore, like Wilding & Rugg (1996) we found greater left–right frontal asymmetry (see figure 2) in later portions of the wave forms suggesting that left–right asymmetries in episodic memory tasks found with PET (e.g. Tulving *et al.* 1994*a*) reflect differences in processing that emerge over time as memories are revived and evaluated (e.g. Johnson *et al.* 1994).

Finally, consider another study suggesting that subjects' agendas affect brain activity as they identify the origin of memories, and another illustration of the potential value of obtaining converging evidence from ERP and imaging techniques. PET studies typically require that test trials occur in blocks of similar items (e.g. a scan in which subjects are presented with all old items, followed by a scan in which subjects are presented with all lure items) because scans measure average activity over a fixed time period in the order of several seconds. In contrast, ERP waves can be obtained with designs in which items of various types are randomly intermixed because individual waves are recorded for each stimulus presentation. From the SMF, we would expect that this procedural difference in test might result in subjects considering different characteristics of memories to distinguish between items. Given trials of randomly intermixed old and lure items, subjects may respond more on the basis of familiarity than when sequences of test trials are all olds and all lures. In a sequence of similar items, familiarity will not vary as much between items, and subjects should be more likely to consider more specific differentiating information in an attempt to make distinctions among items within a block that are not easily discriminable.

To test this prediction, Johnson *et al.* (1997*a*) looked at ERP waves for falsely recognized items that were associatively related to studied items under conditions where old and lure items were either blocked or randomly presented at test. In the blocked test condition, there were differences in the ERP waves to 'old' responses to presented items (hits) and 'old' responses to lures (false recognitions), consistent with the PET findings (Schacter *et al.* 1996*b*). In contrast, in the random test condition, the ERP waves for false recognitions and hits were strikingly similar, suggesting that subjects were making old/new decisions largely on the basis of overall familiarity of the semantic concept. In the blocked condition, we suggest subjects were considering each item more completely, attempting to discriminate among essentially similar items within a block. This closer examination resulted in differences between ERP waves for hits and false recognitions, presumably reflecting differences in underlying representations of old and lure items (Mather *et al.* 1997; Norman & Schacter 1997). In behavioural studies, whether perceived and inferred memories appear to have similar or different qualitative characteristics is influenced by the information subjects are induced to consider at the time of test (Mather *et al.* 1997). Similarly, in imaging or ERP studies, which brain areas differentiate among items from various sources will depend not only on what information was encoded but also on what information subjects are induced to consider at test.

4. CONCLUSIONS

In conclusion, cognitive and social psychological behavioural studies have provided a rich array of empirical findings and a cohesive set of theoretical ideas for understanding the mechanisms yielding veridical and distorted memories. These facts and ideas, summarized in the source monitoring framework (Johnson *et al.* 1993; Johnson & Raye 1981) point to, among other things, the importance of initial feature binding processes, rehearsal and potential elaboration of memories, and heuristic and systematic retrieval and evaluation processes. Included in the latter are the factors that determine which qualitative characteristics are given most weight and the extensiveness of the search and examination of evidence. Based on observations of patients with brain lesions, it appears that the frontal cortex is involved in all of these functions. New evidence for frontal lobe involvement in source memory is beginning to accumulate from PET and ERP studies of normal subjects. Furthermore, initial results are generally consistent with the SMF, which proposes that distributed memory characteristics (e.g. stored in occipital, frontal, temporo-parietal areas) are selectively activated and weighted, depending on the subject's agenda. The challenge for the future is to more closely associate specific frontal brain regions (or transactions between specific frontal brain regions and other brain areas) with component cognitive processes implicated in source monitoring (e.g. Johnson 1997; Johnson & Reeder 1997). That is, a primary goal is to further specify the transactions between particular frontal regions and, for example, particular occipital or temporo-parietal regions that we hypothesize constitute reactivation or evaluation of qualitative characteristics of memories such as visual or auditory detail, and to specify the role of the hippocampal region in source memory (e.g. binding attributes, reactivating memories). In this endeavour, PET and fMRI techniques provide the best opportunity for identifying brain regions that are generally active in given tasks and in isolating the brain regions that discriminate between tasks. ERPs appear especially promising for exploring the temporal dynamics of how particular attributes of source are accessed and used, particularly if it turns out that differences in wave form patterns and topography are reliably associated with various attributes of source. We may be able to use PET, fMRI and ERPs in combination to map out a dynamic picture of on-line processes and brain structures underlying source monitoring in different situations. This would move us closer to understanding the brain mechanisms underlying the cognitive mechanisms that give rise to both veridical and distorted memory.

Preparation of this paper was supported by NIA grant AG09253.

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