Published in final edited form as:

Psychol Sci. 2011 December ; 22(12): 1574–1582. doi:10.1177/0956797611418245.

How Do I Remember That I Know You Know That I Know?

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Abstract

Communication is aided greatly when speakers and listeners take advantage of mutually shared knowledge (i.e., common ground). How such information is represented in memory is not well known. Using a neuropsychological-psycholinguistic approach to real-time language understanding, we investigated the ability to form and use common ground during conversation in memory-impaired participants with hippocampal amnesia. Analyses of amnesics' eye fixations as they interpreted their partner's utterances about a set of objects demonstrated successful use of common ground when the amnesics had immediate access to common-ground information, but dramatic failures when they did not. These findings indicate a clear role for declarative memory in maintenance of common-ground representations. Even when amnesics were successful, however, the eye movement record revealed subtle deficits in resolving potential ambiguity among competing intended referents; this finding suggests that declarative memory may be critical to more basic aspects of the on-line resolution of linguistic ambiguity.

Keywords

language; memory; cognitive neuroscience

During conversation, individuals build and maintain representations of *common ground*, the information they jointly share with their conversational partner (Clark & Marshall, 1978, 1981; Stalnaker, 1978). Common ground is thought to be a central, if not the most central, component of discourse understanding (Clark, 1992), as it shapes both what partners talk about and how they talk about it (Clark & Wilkes-Gibbs, 1986; Horton & Gerrig, 2005a). Examples are seen in the successful use of one of the most frequent linguistic forms, definite reference (e.g., “*that* cake,” “*our* dog”), which requires that the speaker and addressee jointly believe that the referent is identifiable in their common ground with respect to multiple candidate objects to which the speaker might refer (Clark & Marshall, 1978, 1981).

In successful conversations, partners jointly establish shared names for the objects, places, and things they talk about. These names confer clear communicative advantages, but only for partners who share the names in common (Schober & Clark, 1989; Wilkes-Gibbs &

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

Clark, 1992). It is critical to note that representations of what information is shared and what information is private can facilitate the moment-by-moment decisions that listeners make as they understand language in practice (Brown-Schmidt, Gunlogson, & Tanenhaus, 2008; Hanna, Tanenhaus, & Trueswell, 2003; Metzing & Brennan, 2003; but see Barr, 2008, for an alternative view on the precise timing of these effects). That is, common-ground information can help to resolve potential ambiguity in on-line linguistic processing. Note that such a role is possible only if such information is stored in memory in a form that can be accessed within the time frame of on-line processing.

The dominant view of common-ground representations is that when individuals encode information about events, they tag those memories with information about who was there and what each person's role was in that event (Clark & Marshall, 1978, 1981). Such putative common-ground representations include information about things that were jointly experienced by the partners, either because those things were visually copresent, linguistically mentioned, or culturally shared. For example, if Eleanor and Otto go to a movie together, Eleanor's memory of the event includes the information that it was Otto who saw the movie with her. This example of common ground emphasizes declarative memory and the relational representations it supports of the elements of experience—including information about the co-occurrences of people, places, and objects along with the spatial, temporal, and interactional relations among them—as part of the record of one's experience over time (Cohen & Eichenbaum, 1993; Eichenbaum & Cohen, 2001).

Declarative, or relational, representation of common ground seems rich enough to support the ability to remember complex representations, such as that I know you know that I know, and to permit the speaker to take advantage of this information. But an important question, one that we addressed in the study reported here, remains: Can such representations be accessed quickly enough to be used in the course of on-line processing in language interactions? The sorts of relational representations ascribed to declarative memory are often thought to be essential in deliberative, consciously mediated retrieval, rather than in the very rapid and possibly implicit retrieval needed for on-line processing during language interactions.

There are alternative ideas about the representational basis for common ground that do not require declarative memory. One view suggests that interlocutors align their mental models via priming at many levels of linguistic representation (Pickering & Garrod, 2004). Alignment results in implicit common ground; explicit modeling of other peoples' mental states occurs only when necessary. Horton and Gerrig (2005a, 2005b) suggested that low-level, automatic, cue-based associations between partners may serve as the basis for much common ground. Although they do not specify the kind of memory that would support such associations, they contrast it with the "reference diary" kind of explicit representation advocated by Clark and his colleagues (e.g., Clark & Marshall, 1978). An advantage of the view proposed by Horton and Gerrig is that it offers a reconciliation of findings of rapid use of common ground during on-line understanding (Hanna et al., 2003) with assertions that accessing common-ground representations would be too resource intensive to routinely guide language processing (Keysar, Barr, Balin, & Paek, 1998). In this view, as with the priming-based proposal, explicit calculations of common ground are not always necessary for common-ground-based inferences.

In the study reported here, we examined the representational basis of common ground by testing amnesic patients with selective impairment of declarative memory. In the only prior study of common ground in patients with amnesia (Duff, Hengst, Tranel, & Cohen, 2006), we demonstrated that amnesic participants can establish shared names for novel shapes with a communication partner across multiple trials, despite their profound memory impairments.

This finding indicates that at least one kind of common ground is used by amnesics (but see Wu & Keysar, 2007, who speculated that the amnesic participants may have succeeded on the basis of their private knowledge alone).

In the present study, we employed eye movement measures to test the degree to which declarative memory is necessary in establishing common ground with a partner and in using common-ground information to guide on-line language understanding. Little is known about the real-time language-processing abilities of individuals with amnesia, as most previous work has used off-line measures or explicit judgments (e.g., Duff, Hengst, Tranel, & Cohen, 2007; MacKay, Burke, & Stewart, 1998). Previous studies have shown that neurologically intact listeners rapidly integrate visual and linguistic information, fixating objects whose names have the same initial sounds of a target word within 200 ms of word onset (Alloppenna, Magnuson, & Tanenhaus, 1998) and ruling out privileged-ground competing objects within approximately 400 ms (Hanna et al., 2003; Heller, Grodner, & Tanenhaus, 2008). However, no study has rigorously examined the time course with which participants with hippocampal amnesia interpret spoken words in real time. By tracking participants' eye movements as they process language in real time, we provided novel insights into if and how declarative memory might contribute to on-line processing and, more specifically, to the resolution of ambiguity in a naturalistic conversational setting.

In our study, each amnesic (or healthy matched comparison) participant completed a task with an experimenter in which they jointly viewed scenes with objects. Some of these objects were in common ground, and some of them were in the amnesic participant's privileged ground. Participants were asked to look at some target object. For example, the experimenter asked the amnesic participant to "Look at the cactus" in scenes containing two cacti. In some conditions, only one of the two cacti was in common ground. Thus if the amnesic participant represented common ground, he or she could use this information to resolve the ambiguity (Fig. 1a). By monitoring the eye movements made by amnesic participants as they interpreted the experimenter's instructions, specifically by measuring the distribution of viewing to the various potential target objects and the changes in viewing over time, we were able to determine if and when amnesic participants accessed common-ground representations and then used them to facilitate on-line language understanding.

If the use of common ground to resolve linguistic ambiguity requires access to declarative memory representations (Clark & Marshall, 1978), amnesic participants should show deficits in all of these tasks and dramatic failures when there is no external memory cue. Alternatively, if nondeclarative representations of common ground (Horton & Gerrig, 2005a, 2005b; Pickering & Garrod, 2004) can be used to resolve ambiguity, we would expect amnesic participants to perform as well as healthy participants.

Method

Participants

Five amnesic participants (1 female, 4 male) with bilateral hippocampal damage due to anoxia ($n = 3$) or herpes simplex encephalitis ($n = 2$) participated. The amnesic participants had severe and selective declarative memory impairments yet generally preserved intelligence and cognition (e.g., language skills). Table 1 summarizes the demographic and neuropsychological characteristics of the amnesic participants. Five healthy participants were matched pairwise to the 5 amnesic participants on age, handedness, education, and sex.

Stimuli and design

The experimenter and participant were seated facing each other and each viewed a separate three-dimensional rendering of a 3×3 cubbyhole display with everyday objects on their respective computer screens (Fig. 1). These screens were placed back to back to give participants the illusion that they and the experimenter were viewing the same display from opposite sides. The participant's display contained open cubbyholes (through which the green background behind the display could be seen) in the top row, closed cubbyholes in the middle row, and partially closed cubbyholes (i.e., closed at the back but open at the front) in the bottom row. Objects shared between the participant and the experimenter appeared in the top row, and privileged objects (those visible only to the participant) appeared in the bottom row. A green poster board was placed on the wall behind the experimenter to encourage the perception that the open (green) cubbyholes held shared objects. The experimenter's display contained open cubbyholes with shared objects in the top row, partially closed cubbyholes with the experimenter's privileged objects in the middle row, and closed cubbyholes in the bottom row. A fixation cross was presented in the middle cubbyhole of the two displays throughout the duration of each trial.

The objects used in the display were 174 colorized drawings of easily nameable objects from the Snodgrass and Vanderwart database (Snodgrass & Vanderwart, 1980; Rossion & Pourtois, 2004) and similar pictures. The participant's gaze was recorded at 250 Hz using an EyeLink 1000 portable remote eye tracker (SR Research, Kanata, Ontario, Canada). Headset microphones recorded the speech of both partners.

Procedure

We examined two types of common ground: common ground for information that was visually shared and common ground for information that was linguistically mentioned. Although both visual and linguistic information can be used to establish common ground, linguistic evidence may be weaker and more susceptible to memory decay over time (Clark & Marshall, 1978).

To test the use of visual common ground, we compared online interpretation in two conditions, one in which the referent of the critical object named by the experimenter was ambiguous, and one in which visual common ground resolved the ambiguity. On 18 trials in the visually ambiguous condition, the experimenter first asked the participant to "Look at the cross" in the center of the screen, and then told participants to look at a specific object (e.g., "Look at the cactus"). It is crucial to note that in this condition there were two identical objects in the common ground between the experimenter and participant, making the experimenter's instruction to look at a specific object ambiguous (Fig. 1b). The 18 trials in the visually unambiguous condition followed the same format, except that although the target was visually shared, the competitor (i.e., a second object identical to the target object) was in the participant's privileged ground (Fig. 1a). If participants can use common ground to constrain on-line interpretation of the experimenter's instructions, they should look significantly more often at the shared target in the unambiguous condition than in the ambiguous condition. On each of 36 filler trials, the experimenter instructed the participant to look at a visually shared object for which there was no corresponding competitor (e.g., in the display shown in Fig. 1a, the experimenter would say "Look at the snake").

To test the use of linguistic common ground, we created situations in which a privileged-ground object was introduced into the discourse by the participant and then subsequently mentioned immediately by the experimenter (no-delay condition) or after a delay (filled-delay condition; Fig. 1b). The delay manipulation allowed us to examine whether linguistic common ground was maintained over time. On each trial, the experimenter first asked about

a privileged object (e.g., “What’s in your bottom left cubby?”). The participant’s response (e.g., “An elephant”) would bring that visually privileged target object into linguistic common ground. Then, after no delay (on 18 trials) or a filled delay (on 18 trials), the experimenter asked participants to “Look at the cross” and then look at the linguistically mentioned privileged object (e.g., “Look at the elephant”). On the filled-delay trials, participants were instructed to form a short story about two of the shared objects. Example stories were provided by the experimenter if the participant was unable to produce a story on his or her own; participants’ stories lasted approximately 40 s. During the filled delay, the display was left on the screen, and the participants tended to look at the shared objects mentioned in the story. Filler trials followed the same format, except that the experimenter ultimately asked the participant to look at a visually shared object (e.g., “Look at the zebra”).

Results

Analyses were performed on eye movements following the onset of the critical word in the experimenter’s final instruction (e.g., “cactus” in “Look at the cactus”). We report results of two types of analyses. First, we examined the time course of target identification in the visual and linguistic common-ground conditions. Gaze was analyzed in terms of target advantage, which is the average proportion of looks to the target minus the average proportion of looks to the competitor. Target-advantage scores were analyzed across eight 400-ms time epochs beginning 200 ms prior to the start of the critical word. The first epoch served as a baseline because of the time needed to program and launch a saccade (Hallett, 1986). Our second set of analyses focused on those conditions in which amnesic participants successfully interpreted the final instruction; these analyses examined participants’ ability to rule out potential competitors during on-line comprehension. These analyses tested for evidence of unresolved competition by analyzing all competitor fixations following critical-word onset.

Identification of targets in visual common ground

Both amnesic and healthy participants rapidly used common ground to successfully interpret the critical instruction as asking about the visually shared referent and not the identical visually privileged object (Fig. 2). An analysis of variance (ANOVA) with condition, epoch, and participant group as factors revealed a main effect of condition due to significantly higher target advantage when common ground ruled out the competitor in the visually unambiguous condition, $F_1(1, 8) = 288.26, p < .0001$; $F_2(1, 17) = 119.25, p < .0001$.¹ A main effect of epoch, $F_1(7, 56) = 16.29, p < .0001$; $F_2(7, 119) = 20.14, p < .0001$, reflected the increase in target fixations following critical-word onset. An epoch-by-condition interaction was significant, $F_1(7, 56) = 11.82, p < .0001$; $F_2(7, 119) = 23.66, p < .0001$, suggesting that the condition effect emerged over time. It is critical to note that planned one-tailed comparisons demonstrated that results in the healthy and amnesic groups did not differ across any of the eight epochs in either condition, $ts < 1.97, ps > .05$.

These results demonstrate that both healthy and amnesic participants distinguish between visually shared and private information as they interpret language on-line. When only one referent of the critical word was in common ground between the participant and the experimenter, and thus the domain of interpretation was restricted, participants directed attention toward the target and away from the competitor object. When two referents of the

¹Hereafter, when violations of sphericity occurred, we report Huynh-Feldt corrected p values; for clarity, unadjusted degrees of freedom are reported. The F_2 statistic is standard for linguistic analyses; it treats item as a random factor.

critical word were in common ground, and thus the domain of interpretation was not constrained, fixations to the target and to the competitor did not diverge.

Identification of targets in linguistic common ground

Both healthy and amnesic participants successfully used linguistic common ground to resolve ambiguities in the experimenter's instructions. However, for the amnesic participants, this was true only in the no-delay condition, with severe deficits following a filled delay (Fig. 3). An ANOVA with condition, epoch, and participant group as factors revealed main effects of both condition, $F_1(1, 8) = 38.60, p < .0001$; $F_2(1, 17) = 61.63, p < .0001$, and epoch, $F_1(7, 56) = 28.53, p < .0001$; $F_2(7, 119) = 75.97, p < .0001$. These main effects were qualified by an epoch-by-group interaction, $F_1(7, 56) = 4.24, p < .01$; $F_2(7, 119) = 12.18, p < .0001$, and a condition-by-epoch interaction, $F_1(7, 56) = 11.00, p < .0001$; $F_2(7, 119) = 15.05, p < .0001$. It is critical to note that a condition-by-epoch-by-group interaction, $F_1(7, 56) = 4.03, p < .05$; $F_2(7, 119) = 5.84, p < .0001$, indicated that the way in which the condition effect emerged over time differed between the two groups.

Planned one-tailed comparisons demonstrated that in the no-delay condition, results from the healthy and amnesic groups did not differ across any of the eight epochs, $t_s < 1.35, p_s > .1$. In the filled-delay condition, however, planned one-tailed comparisons demonstrated that the healthy participants outperformed the amnesic participants between Epochs 4 and 8 (1,000–3,000 ms), $t_s > 2.01, p_s < .05$. The lack of a difference between the groups prior to 1,000 ms may be due to a slight (but nonsignificant) preference for amnesic participants to fixate on the target prior to 1,000 ms.

These results suggest that amnesic participants retain representations of what information is in linguistic common ground only when there is no delay between when they introduce the privileged object into the discourse and the experimenter's instruction to look at it. Following a brief (~40 s) side conversation about another topic (e.g., the shared objects in common ground), the shared information is no longer available to the amnesic participants, and they are unable to determine which object is being referenced by the experimenter.

Fixations on competitor objects

Although amnesic participants successfully identified the target over the competitor in the visually unambiguous and linguistic no-delay conditions, further analyses examined the level of viewing of competitor objects, even when interpretation was successful. Planned one-tailed comparisons of fixations to competitor objects during the period between 200 ms and 3,000 ms following critical-word onset in the visually unambiguous condition demonstrated that amnesic participants made more fixations to the competitor object than did healthy participants, $t(8) = -1.92, p < .05$. In the linguistic no-delay condition, the results between groups did not differ ($p > .05$), although amnesic participants fixated on the competitor object at greater than chance levels ($p = .05$), and healthy participants did not ($p > .05$). The differences in results between the amnesic and healthy participants in these conditions were clearly related to the presence of the competitor, as fixations on the target object in the filler trials did not differ between the groups. Although amnesic participants fixated on the target more than on the competitor within the first second of critical-word onset, the lingering fixations to the competitor suggest that even when interpretation is successful and rapid, hippocampal amnesia may impair the very earliest moments of language understanding, and declarative memory may be critical.

General Discussion

The results of this study demonstrate a clear role for declarative memory in the use of common ground during conversation; they also demonstrate that representations of what information is shared or private can guide real-time language understanding in the absence of declarative memory support. These findings have implications concerning the nature of common-ground representations, and they speak directly to conflicting theoretical views about the kind of memory required in the use of common ground. The findings also provide evidence of deficits in the resolution of competition between visually identical shared and privileged objects during on-line speech processing in individuals with hippocampal amnesia, offering new insights about the possible role of declarative memory in real-time language processing.

According to the classical view, conversational partners represent common-ground information in “reference diaries,” in which explicit memories of events are tagged with information about who jointly experienced that event (Clark & Marshall, 1978, 1981). According to this view, there is a clear role for declarative memory in representations of common ground. The fact that amnesic participants with severe impairments in declarative memory were unable to maintain representations of items in common ground across a brief (~40 s) filled delay is consistent with this view. Given the impairments in the use of common ground evident even with the brief delays used here, it is clear that the usual benefits conferred by common ground to speakers in real-life communication will be compromised significantly in these patients.

More striking and consequential, perhaps, than the amnesic participants’ failure to use common ground following a filled delay was their apparent success at resolving ambiguity in both of the visual conditions and in the linguistic no-delay condition, despite lingering fixations to competitor objects. Although amnesic, these individuals have normal intellectual and reasoning abilities and can take advantage of available information to guide behavior. The amnesics likely relied on external memory cues (see, e.g., Ballard, Hayhoe, & Pelz, 1995) in the visually unambiguous condition and information in the recent-discourse history in the linguistic no-delay condition to assess common-ground status. This result may also provide some support for arguments that there are other nondeclarative routes to forming common ground through priming or associations (Horton & Gerrig, 2005a, 2005b; Pickering & Garrod, 2004).

The pervasiveness of ambiguity in language is one of its most notable characteristics (Altmann, 1998)—in conversation, up to 50% of definite noun phrases are linguistically ambiguous (Brown-Schmidt & Tanenhaus, 2008). The fact that amnesic participants were able to use information available to them to resolve these ambiguities on-line speaks to their ability to rapidly extract information from the environment and apply it to abstract linguistic processes. This finding is in contrast to previous observations of the amnesic patient H. M., who was found to have tremendous difficulty in appreciating linguistic ambiguity (MacKay et al., 1998). The source of the difference is likely related to the use of very different procedures and measures, although H. M.’s comparably worse health, due to years of treatment for epilepsy, is also relevant. It is notable, as well, that the amnesic participants in the study reported here were able to represent items in common ground, suggesting that amnesic participants who learned names for novel shapes in our previous work (Duff et al., 2006) can in fact establish common ground for these names. That these same amnesic participants did not consistently use a definite reference (e.g., “*the* Viking ship”) to signal to their partner that these labels were part of shared knowledge further supports the notion of multiple forms of common ground with representational contributions from distinct memory systems (Duff, Gupta, Hengst, Tranel, & Cohen, 2011).

How successful, then, are patients with severe declarative memory impairment in communication with a conversational partner? There are, of course, many ways to measure success. Amnesic participants did successfully arrive at the correct interpretation of the experimenter's ambiguous instruction. However, although successful, participants had subtle deficits, as evidenced by lingering fixations to competitor objects. The source of this impairment may be the demand that language processing places on representations supporting on-line processing. Neurologically intact adults typically understand spoken (or signed) language with ease, rapidly integrating numerous sources of information (acoustic, syntactic, semantic, and pragmatic) to constrain potential ambiguities (Allopenna et al., 1998; Garnsey, Pearlmutter, Myers, & Lotocky, 1997; Kamide, Altmann, & Haywood, 2003; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). These processes are central to language understanding and have been explored only coarsely in amnesics using explicit tasks and off-line measures that cannot tap the incremental interpretation of words over time (e.g., Duff et al., 2007; MacKay et al., 1998). The current results reveal deficits in the integration of multiple information sources during on-line resolution of linguistic competition, and they allow us to make the strong claim that declarative memory mediation is necessary for on-line resolution of competition in language. In support of this hypothesis are parallel findings from the visual domain that show impairment in amnesic participants even in no-delay and short-delay conditions when mediation of multiple, related representations in real time is required to pick a target among competitors (Barense, Gaffan, & Graham, 2007; Hannula, Tranel, & Cohen, 2006; Warren, Duff, Tranel, & Cohen, 2010).

The present research explored questions about the interface of memory and language in the most basic form of language use (i.e., conversation). Our approach to these questions provided insights not only about the role of declarative memory in using common ground, but also its role in the on-line resolution of competition during language processing and possibly beyond. We have demonstrated that successful use of common ground across time requires the maintenance of declarative memory representations. We have also documented that individuals with declarative memory impairment can form and use representations of items in common ground, as long as this information remains readily available. Finally, we have provided initial, tantalizing evidence that hippocampal mediation is necessary for the resolution of competition in on-line tasks. Deficits in amnesics in on-line language processing (i.e., even in the absence of any imposed delays) open up questions about unexpectedly significant challenges they may face in real-world language abilities. Future research will show what other aspects of language processing and other cognitive domains might be similarly sensitive to amnesia and hence dependent on declarative memory processes.

Acknowledgments

Funding

This research was supported by grants from the National Institute of Mental Health (R01 MH062500) to Neal J. Cohen and the National Institute of Neurological Disorders and Stroke (P50 NS19632) to Daniel Tranel.

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Fig. 1.

Examples of the displays viewed by participants (left column) and the experimenter (right column) in the visual common-ground conditions. Each display consisted of a 3×3 grid of cubbyholes with a fixation cross in the center. Objects shared between the participant and the experimenter were presented in open cubbyholes in the top row. Objects that could be seen by only the participant or only the experimenter (i.e., privileged objects) were hidden by closed cubbyholes in the display's bottom row and middle row, respectively. In visually unambiguous displays (a), a target object (in this example, the cactus) was presented once among the shared objects and once among the participant's privileged objects. In visually ambiguous displays (b), a target object (in this example, the giraffe) was presented twice among the shared objects. The same displays used in the visually ambiguous condition were also used in the two linguistic common-ground conditions.

Fig. 2.

Results for the visual common-ground conditions: proportion of fixations to targets and to competitor objects as a function of time. Time 0 is the onset of the critical word. Results are shown separately for healthy comparison participants in (a) the visually unambiguous condition and (b) the visually ambiguous condition and for amnesic participants in (c) the visually unambiguous condition and (d) the visually ambiguous condition.

Fig. 3.

Results for the linguistic common-ground conditions: proportion of fixations to targets and to competitor objects as a function of time. Time 0 is the onset of the critical word. Results are shown separately for healthy comparison participants in (a) the no-delay condition and (b) the filled-delay condition and for amnesic participants in (c) the no-delay condition and (d) the filled-delay condition.

Table 1

Demographic and Neuropsychological Data for Participants With Amnesia

Participant	Demographic characteristics			Neuropsychological scores				
	Etiology	Sex	Age	Damaged brain area	WAIS-III FSIQ	WMS-III GMI	Boston Naming Test	MAE Token Test
2363	Anoxia	M	53	Hippocampus	98	73	58	44
1846	Anoxia	F	46	Hippocampus	84	57	43	41
2563	Anoxia	M	54	Hippocampus	102	75	52	44
2308	HSE	M	53	Medial temporal lobe	98	73	52	44
1951	HSE	M	57	Medial temporal lobe	105	57	49	44

Note: Neuropsychological scores include Full Scale IQ (FSIQ) from the Wechsler Adult Intelligence Scale—Third Edition (WAIS-III; Wechsler, 1997a), General Memory Index (GMI) from the Wechsler Memory Scale—Third Edition (WMS-III; Wechsler, 1997b), score on the Boston Naming Test from the Boston Diagnostic Aphasia Examination (Goodglass & Kaplan, 2000; maximum score = 60), and score on the Multilingual Aphasia Examination (MAE; Benton, Hamsher, & Sivan, 1994; maximum score = 44). HSE = herpes simplex encephalitis; M = male; F = female.