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IMPAIRED VERBAL COMPREHENSION OF QUANTIFIERS IN CORTICOBASAL SYNDROME

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Abstract

Objective—Patients with Corticobasal Syndrome (CBS) have atrophy in posterior parietal cortex. This region of atrophy has been previously linked with their quantifier comprehension difficulty, but previous studies used visual stimuli, making it difficult to account for potential visuospatial deficits in CBS patients. The current study evaluated comprehension of generalized quantifiers using strictly verbal materials.

Method—CBS patients, a brain-damaged control group (consisting of Alzheimer's Disease and frontotemporal dementia), and age-matched controls participated in this study. We assessed familiar temporal, spatial, and monetary domains of verbal knowledge comparatively. Judgment accuracy was only evaluated in statements for which patients demonstrated accurate factual knowledge about the target domain.

Results—We found that patients with CBS are significantly impaired in their ability to evaluate quantifiers compared to healthy seniors and a brain-damaged control group, even in this strictly visual task. This impairment was seen in the vast majority of individual CBS patients.

Conclusions—These findings offer additional evidence of quantifier impairment in CBS patients and emphasize that this impairment cannot be attributed to potential spatial processing impairments in patients with parietal disease.

Keywords

corticobasal degeneration; number; quantifier; semantic memory

INTRODUCTION

Quantified statements are extraordinarily common in our daily conversations. We often set thresholds or estimate amounts in quantitative domains involving space, time, and money. Typically these quantified statements include a quantifier, which is defined as an adjectival phrase that quantifies a noun. Here we focus on generalized quantifiers – phrases such as “a few” and “many” – that can be applied to virtually any domain of knowledge without restriction due to its content. In formal semantic terms, these phrases serve the function of

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asserting a property about a set and mapping it to a truth value (e.g. in the phrase “less than three hours”, the property is the number of hours and the truth value is whether this time increment falls under the limit “three”). While we know a great deal about the formal semantic properties of generalized quantifiers (Barwise & Cooper, 1981; van Benthem, 1986), we understand little about the neural basis for quantifier comprehension. In this study, we examine deficits in quantifier comprehension using generalized quantifiers conveying relative magnitude in patients with focal neurodegenerative diseases.

Our cognitive model relates comprehension of generalized quantifiers to several components (Figure 1). Among these are magnitude comprehension, a distinct domain of semantic memory. Understanding a quantified statement such as “at least three minutes” entails an ability to understand the magnitude concept underlying the number “three” as a prerequisite to appreciating the meaning of the quantified component of this phrase (Clark & Grossman, 2007). Other components include mapping magnitude concepts to a lexical representation such as “many” or “at least three,” and a syntactic component that can support comparisons such as the relative magnitude of a value across two objects. Substantial work suggests that the intraparietal sulcus plays an integral role in magnitude and number processing (Dehaene, Piazza, Pinel, & Cohen, 2003). Parietal activation is frequently demonstrated in fMRI studies of core numerical processes, for example, such as magnitude judgment of Arabic numerals and dot arrays (Dehaene, Piazza, Pinel, & Cohen, 2003; Piazza, Pinel, Le Bihan, & Dehaene, 2007). Consistent with our hypothesis that a critical component of quantifier knowledge involves magnitude comprehension, we found that healthy adults recruit right parietal cortex during comprehension of generalized quantifiers (McMillan, Clark, Moore, DeVita, & Grossman, 2005; Troiani, Peelle, Clark, & Grossman, 2009).

Patients with corticobasal syndrome (CBS) are significantly impaired on simple measures of number knowledge. This includes difficulty on tasks involving magnitude judgments of pairs of single-digit Arabic numerals or arrays of dots consisting of comparably small cardinalities (Halpern, Clark et al., 2004; Halpern, Glosser et al., 2004). These patients also perform below 50% accuracy on oral addition and subtraction involving single-digit Arabic numerals (Halpern et al., 2003). Finally, patients with CBS have significant difficulty on a “number line” task where they are asked to judge whether an Arabic numeral or a dot array has an intermediate position between two bounding numerals or dot arrays (Koss et al., 2010). We have found parietal cortical atrophy in voxel-based morphometry (VBM) analyses of high resolution structural MRI in these patients (Grossman et al., 2004; Halpern, Glosser et al., 2004; Koss et al., 2010; Troiani et al., 2009). Histopathological abnormalities at autopsy also indicate significant parietal disease in patients with CBS (Murray et al., 2007).

Given the importance of parietal regions in numerical processing, we hypothesized that patients with CBS would demonstrate impaired quantifier comprehension. Previous evaluations of quantifier processing in this patient group have provided support for this hypothesis. Patients with CBS were impaired relative to healthy controls when asked to evaluate quantified statements about pictured visuospatial arrays of familiar objects (McMillan, Clark, Moore, & Grossman, 2006). Because the parietal lobe is also associated with visuospatial processing (Simon, Mangin, Cohen, Le Bihan, & Dehaene, 2002), we performed a more recent study that assessed comprehension of quantified statements about pictured objects presented serially in one location. The use of serially presented stimuli limited the possibility that comprehension deficits could be due to impaired spatial attention (and thus an artifact of experimental design). We found that CBS patients are impaired at assessing phrases that contain quantifiers, even when the pictured objects are presented as a serial array, thus limiting confounds such as reliance on distributed visual processing (Troiani et al., 2009).

However, a potential confound in the assessment of this patient population is a visuospatial impairment due to posterior cortical atrophy. The parietal lobe is important for a variety of cognitive tasks, including both magnitude comprehension and visuospatial attention. Because the stimuli in our previous tasks all had visual components (arrays or serial displays of common objects), we could not definitively rule out the possibility that CBS patients experienced difficulty due to a deficit processing the spatial attributes of the stimulus materials in our previous work. We felt it was important to extend our observations of impaired quantifier comprehension with a method that was minimally confounded by a visuospatial impairment. For this reason, we administered probes of quantified statements using strictly verbal materials. Occasional case studies have reported progressive non-fluent aphasia (PNFA) in patients with CBS (Gorno-Tempini, Murray, Rankin, Weiner, & Miller, 2004; Josephs et al., 2006), and CBS patients with a language disorder were excluded from participation. Participating CBS patients were screened by neurological examination and additional tests of language to insure that language comprehension difficulty could not explain a deficit on this task. To establish the specificity of a quantifier comprehension deficit in CBS, we also examined a brain-damaged control group.

We also probed generalized quantifiers comparatively in 3 separate domains of knowledge, namely temporal (days in a year), spatial (inches in a foot), and monetary (nickels in a dollar). Because the parietal lobe is implicated in visuospatial processing and other aspects of spatial cognition, we additionally sought to determine whether generalized quantifiers are more difficult in spatial domains relative to other domains of knowledge. Greater difficulty in spatial domains compared to temporal and monetary domains would be consistent with a role for a visuospatial imagery deficit in the quantifier comprehension impairment of patients with parietal disease, although our previous work suggested that visuospatial difficulty cannot fully explain the quantifier comprehension deficit in CBS. The observation of a differential impairment in processing in the spatial domain would also be informative for theories of spatial imagery and distributed semantics (Saffran, 2000; Pulvermüller, 2005).

Finally, to minimize the potential confound of degraded knowledge of number in these domains (due to more general cognitive decline in all dementia subtypes), we developed stimuli that focused on highly overlearned facts (e.g. 24 hours in a day, 12 inches in a foot). To control for knowledge differences in these domains, domain-specific factual knowledge was measured and items for which patients could not demonstrate preserved knowledge were removed. A brain-damaged control group was examined the specificity of the quantifier comprehension deficit for CBS. We expected that CBS patients would be impaired in their evaluation of generalized quantifiers presented verbally, even after controlling for potential deficits in their knowledge of these familiar domains and despite preserved language comprehension.

METHODS

Subjects

We examined 32 patients with a neurodegenerative disease and 14 healthy seniors who were right-handed native English speakers. A subset of patients was diagnosed with corticobasal syndrome (CBS, $n=11$). There are presently no published criteria for the clinical diagnosis of CBS, although there are expert recommendations of important diagnostic features (Litvan et al., 2003; Riley, Lang, Litvan, Goetz, & Lang, 2000). We developed criteria based on a review of literature concerned with clinical-pathological diagnosis in CBD including our own autopsy series (Murray et al., 2007). This included apraxia, visual perceptual-spatial difficulty, cortical sensory deficit, and extrapyramidal features such as asymmetric rigidity and dystonia but little resting tremor, that are insidious in onset and gradual in progression.

The CBS patients participating in this study were not aphasic, as determined by a detailed mental status evaluation during the neurological exam performed by an experienced neurologist (MG) using the Philadelphia Brief Assessment of Cognition (Libon et al., 2007), and aphasic patients were excluded from the CBS group of patients. We also examined a brain-damaged control group consisting of patients with several different neurodegenerative conditions. Among the brain-damaged control participants were patients with probable Alzheimer's disease (AD, $n=9$). The basis for this clinical diagnosis was the National Institute of Neurologic and Communicative Diseases and Stroke-Alzheimer's Disease and Related Disorders Association (NINCDS-ADRDA) criteria for AD (McKhann et al., 1984). In addition, the brain-damaged control group included patients with frontotemporal dementia (FTD, $n=11$) diagnosed on the basis of the Lund-Manchester criteria for FTD (The Lund and Manchester, 1994) modified by McKhann et al (McKhann et al., 2001). The latter group included patients with progressive non-fluent aphasia (PNFA, $n=6$) who had effortful, grammatically simplified speech but good word comprehension; and patients with semantic dementia (SD, $n=5$) who had word and object comprehension difficulty. All patients were recruited from the outpatient clinic of the Department of Neurology at the University of Pennsylvania. Clinical diagnoses were made by an experienced, board-certified neurologist specializing in neurodegenerative diseases (MG), and diagnosis was reviewed using two independent raters. The demographic characteristics of these patients are summarized in Table 1. The Mini Mental State Examination (MMSE) was used as an assessment of overall dementia severity. This measures cognition on a 30-point scale by evaluating orientation, anterograde memory, language, executive functioning, and visual construction. To characterize the general language abilities of these patients, we report three language tests in which scores were available for a majority of participants, including the Boston Naming task, a verbal letter naming fluency task (FAS), and a short sentence comprehension task. The mean scores are reported in Table 2. Other causes of dementia were excluded by history, physical exam, serum studies, and structural brain imaging. This study was approved by the Institutional Review Board of the University of Pennsylvania, and all participants and responsible caregivers participated in the informed consent procedure.

Materials and Procedure

Patients were asked to evaluate the truth of 80 brief, aurally-presented statements about highly familiar temporal ($n=32$), spatial ($n=24$), and monetary ($n=24$) domains. These statements contained one of four generalized quantifiers (less than X, more than X, less than half, more than half) that were presented equally often within each domain (e.g. "Forty minutes is more than half of an hour"). Half of the statements were true and half were false. The items were presented in a fixed, pseudo-random order such that there were no more than three consecutive items probing a particular domain. An experimenter presented the statements aurally and with natural intonation contours, and patients answered each question with a verbal "true" or "false".

At the completion of the protocol probing quantifiers, we evaluated patients' background knowledge of the same temporal, spatial and monetary domains with separate judgments of simple, factual statements (e.g. There are 12 inches in a foot: True or False"). Forty statements corresponding to the total number of concepts in the first part of the task (temporal, $n=16$; spatial, $n=12$; and monetary, $n=12$) were presented, half of which were true and half false, and the items were presented in a fixed, pseudo-random order.

To evaluate quantifier comprehension in a manner that is minimally biased by impairments of knowledge in any of the domains tested, we eliminated quantified statements from the statistical analyses of the experimental procedure on an individualized, item-by-item basis. If a participant did not answer correctly both factual questions (one true- "There are 16 ounces in a pound", one false- "There are 12 ounces in a pound") about the numeric

properties of the familiar concept, we eliminated from consideration the corresponding experimental item(s) probing the same concept with a generalized quantifier in the participant. Thus, accuracy in each domain is the proportion of correct items out of domains in which patients demonstrated appropriate background knowledge. The mean number of questions used for each group after correction for lack of knowledge appears in Table 3. There were no significant statistical differences between the number of items discarded or used between the patient groups [temporal, $p=0.156$; monetary, $p=0.367$; spatial, $p=0.310$].

RESULTS

Figure 2 summarizes quantifier judgment performance accuracy for the groups. We found that CBS patients are significantly impaired in their judgments of quantified statements, even after correction for impaired factual knowledge of these familiar spatial, temporal, and monetary domains. This was evident both in analyses of group performance and analyses of individual patient performance profiles. Accuracy for the factual probes is included in Table 2.

We examined these observations statistically with a mixed-model analysis of variance (MANOVA) of quantified statement judgment corrected for factual knowledge, using a between-subjects factor of group (3 – healthy senior controls, CBS patients, brain-damaged control patients with AD and FTD) and a within-subjects factor of knowledge domain (3 – temporal, spatial, monetary). This revealed a significant main effect for group [$F(2,44)=7.73$; $p=0.001$] and a significant main effect of the knowledge domain [$F(2,88)=5.77$; $p=0.004$], but no group X knowledge domain interaction effect. T-tests revealed that CBS patients [$p<0.001$] and the brain-damaged control group [$p=0.01$] are both worse than healthy senior control subjects. Also, CBS patients were significantly less accurate than the brain-damaged controls [$p<0.05$].

We evaluated individual patient profiles for quantifier judgments, following correction for errors of knowledge, by converting each patient's performance to a z-score based on the judgments of healthy seniors. This analysis underlined greater difficulty in CBS patients compared to the brain-damaged control population. The mean ($\pm$ S.D.) z-score for CBS patients' quantifier judgments was $-5.65 (\pm 2.5)$, while the mean ($\pm$ S.D.) z-score for the brain-damaged control population was $-3.03 (\pm 4.7)$. Using a z-score threshold of -1.96 (equivalent to a two-tailed p-value of 0.05), we found that 10 (90.9%) of 11 CBS patients are significantly impaired at judging quantified statements. By comparison, we observed significantly impaired performance in only 9 (45.0%) of 20 brain-damaged controls. These proportions differed significantly [$\chi^2(1)=7.56$; $p<0.01$].

CBS patients were disproportionately impaired in their quantifier comprehension relative to brain-damaged controls, even though CBS patients performed equally or better than the brain-damaged control group on several standard tests of language, and their quantifier comprehension was unrelated to performance on these language measures. To evaluate group differences in performance on the language measures, we converted individual patient's performance to a z-score based on normative data. We used chi-squared and Mann-Whitney nonparametric tests to compare groups on language measures (Table 2). Overall, using a z-score threshold equivalent to $p<0.05$ ($z<-1.96$), proportions of CBS patients differed significantly from SD patients impaired on BNT, sentence comprehension, and FAS [$\chi^2(1)=6.24$; $p<0.05$; $\chi^2(1)=5.18$; $p<0.05$; $z=-2.052$; $p<0.05$, respectively]. A significant difference was also observed between proportions of CBS patients impaired on the BNT, as compared to AD patients [$\chi^2(1)=4.77$; $p<0.05$]. Finally, CBS patients were significantly more fluent than PNFA patients on the FAS task ($z=2.195$; $p<0.05$). Interestingly, when the brain damaged control group's accuracy scores were correlated with the language measures,

significant correlations emerged between total accuracy in the quantifier task and the category fluency (Correlation coefficient=.691; $p<.001$) and syntactic comprehension (Correlation coefficient=.557; $p<.01$) measures. There was no correlation between accuracy on the quantifier task and any of the language measures for the CBS patients.

We did not find a significant group X knowledge domain interaction effect, but we investigated performance in each domain specifically to determine whether the CBS patients are particularly disadvantaged in their judgments of spatial concepts. However, these analyses showed that CBS patients' were equally impaired in all three domains and their deficit could not be attributed to differential difficulty judging quantifiers in any one domain of knowledge. Of particular interest, CBS patients do not have greater difficulty within the spatial domain. Thus, neurodegeneration in posterior parietal regions does not necessarily entail greater difficulty with semantic concepts that include a spatial component. Table 3 summarizes performance on the quantifier probes and factual probes of each domain of knowledge. We found that CBS patients are worse than controls in their accuracy judging quantifier probes for each domain of knowledge [all p -values significant at least at the $p<0.05$ level]. CBS patients were also worse than the brain-damaged controls in the monetary domain [$p<0.01$]. However, there were no statistical differences within either patient group for performance accuracy between the 3 domains.

Significant difficulty with quantifiers in CBS patients could not be easily attributed to impairments in their knowledge of familiar temporal, spatial, and monetary domains. A MANOVA with a group (3) X factual domain (3) design showed a significant overall difference between groups for the factual probes [$F(2,44)=7.28$; $p=0.002$]. This was due to worse performance in CBS patients [$p<0.01$] and the brain-damaged control patients [$p<0.01$] relative to healthy seniors. However, there was no statistical difference in performance on factual probes between the two patient groups [$p=0.267$]. This performance pattern was seen for factual probes of each domain of knowledge as well [temporal, $p=0.258$; spatial, $p=0.402$; monetary, $p=0.430$].

DISCUSSION

We found that patients with CBS are significantly impaired in their ability to evaluate quantified statements probing familiar domains of knowledge. We observed a quantifier comprehension deficit in the vast majority of individual CBS patients, and their impairment was more prominent than in patients suffering from other neurodegenerative diseases. This deficit was present even after we corrected for any impairment in knowledge of the familiar domains that we probed. The protocol involved only verbal judgments of verbal material, so it is unlikely that the quantifier deficit in CBS can be explained by a visuospatial impairment. Moreover, there was no differential impairment for quantifiers of visuospatial knowledge compared to monetary and temporal domains, suggesting that a deficit in visuospatial imagery is unlikely to account for CBS patients' deficit. The CBS patients were not aphasic, and thus a language impairment is unlikely to explain the deficit in these patients. We discuss the quantifier comprehension deficit in CBS in greater detail below.

Previous work has shown a deficit for magnitude comprehension in patients with CBS. These patients have significant difficulty judging the relative magnitude of two single-digit numbers or two small arrays of dots (Halpern, Glosser et al., 2004), they are impaired in their ability to perform basic calculations such as adding two numbers together (Halpern et al., 2003; Halpern, Glosser et al., 2004), and they cannot determine whether an Arabic numeral or an array of dots fits between two bounding quantities (Koss et al., 2010). Previous work also demonstrated a deficit evaluating quantified statements about visuospatial arrays of familiar colored objects (McMillan et al., 2006). Other work

confirmed this deficit in quantifier comprehension even when visuospatial representations of objects were presented serially (Troiani et al., 2009). We argued that a deficit for magnitude comprehension is the basis for their impaired quantifier comprehension, and attributed this deficit to parietal lobe atrophy. However, we could not rule out that their difficulty is due to a deficit appreciating the visuospatial properties of the object arrays that they were judging. Patients with parietal lesions frequently demonstrate impaired visuospatial processing, and fMRI studies of healthy adults associate visuospatial processing with parietal activation (Mesulam, 1999; Simon et al., 2002). The present study evaluated CBS patients on a strictly verbal task that does not depend on spatial perception. Despite the absence of any visuospatial properties in the presented stimuli, CBS patients were still significantly impaired.

CBS patients were no more impaired in their judgments of factual statements about these domains than patients with other neurodegenerative diseases, and yet their performance with quantified statements about these accurately judged facts was significantly worse than that of brain-damaged controls. This suggests that limited knowledge of these factual domains cannot fully explain their difficulty with quantifiers. We specifically corrected for knowledge of the probed domains on an item-by-item basis in each individual patient to ensure that participants have the underlying knowledge base (e.g. they are aware of the number of inches in a foot), with the understanding that an additional probe of quantifiers in this domain would be meaningless if the patient has no baseline understanding of the particular unit system of the stimulus.

Patients with CBS were impaired in their quantifier comprehension, even though the CBS patients participating in this study do not have aphasia. To confirm that the impairment in CBS is not due primarily to a language deficit, we evaluated a brain-damaged control group consisting of two subgroups of progressive aphasic patients - those with PNFA or SD (for review, see Grossman, 2010). PNFA patients present with impaired grammatical processing and associated left inferior frontal cortex atrophy. SD is a disorder of semantic memory that is most prominent for word and object knowledge, due to left temporal lobe atrophy (Bonner et al., 2009; Hodges & Patterson, 2007; Patterson, Nestor, & Rogers, 2007). Preserved comprehension of number knowledge and quantifiers has been previously documented in SD (Cappelletti, Butterworth, & Kopelman, 2006; Cappelletti, Butterworth, & Kopelman, 2001; Cipolotti, Butterworth, & Denes, 1991), and number knowledge has been doubly dissociated from object knowledge in CBS and SD (Halpern, Glosser et al., 2004). Some CBS patients may have PNFA that involves grammatical comprehension difficulty (Gorno-Tempini et al., 2004; Josephs et al., 2006), but patients with this pattern of language difficulty were excluded from this study.

We also collected three language comprehension measures on most of the participating patients. This included evaluations of lexical access, verbal fluency, and sentence comprehension abilities. CBS patients were more fluent (as determined by the FAS letter fluency task) than the brain-damaged control group and more fluent than the PNFA group, and were better at lexical and sentence processing tasks than patients with SD. CBS patients did not differ statistically from controls on the sentence processing task, and also did not differ statistically from PNFA and AD patients in their performance on the sentence processing measure. Additionally, while the brain-damaged control group's performance on the quantifier task was significantly correlated with language measures, CBS patients' performance did not reveal a similar relationship between these measures. However, sentence comprehension is complex and difficulty on this task may be due to any of several impairments: This study was not powered to make comparisons and assess correlations with each individual subgroup of patients and we therefore cannot rule out limited power in the

correlation analysis. Additional work is needed to specify the basis for performance on this task in CBS.

While generalized quantifier comprehension may depend in part on number knowledge, there may be additional language characteristics of a quantifier that contribute to quantifier comprehension difficulty in CBS despite their generally minor language impairments. One possibility is that generalized quantifiers like “at least X” do not refer to a definite quantity but instead refer to a relative range of values. This “relative” property of quantifiers may play a role in the quantifier comprehension difficulty of CBS since it entails comprehension of an indefinite quantity (Barwise & Cooper, 1981; van Benthem, 1986). Additional work is needed to examine the difference between definite and indefinite quantifiers in the comprehension deficit of CBS patients.

CBS patients appeared to have a relative disadvantage compared to brain-damaged controls for quantifier judgments in the monetary domain. One possibility is that this may be due in part to a difference in storage of knowledge of these domains, similar to differences observed in storage of addition or multiplication facts versus subtraction. Concepts such as days in the week, months in the year, quarts in a gallon, and inches in a foot are all memorized during early education. However, the number of pennies in a quarter may not be as well-rehearsed and thus may rely more heavily on online number processing, similar to subtraction.

Neuroimaging assessments of patients with CBS show significant parietal cortical atrophy (Grossman et al., 2004; Halpern, Glosser et al., 2004; Koss et al., 2010; Troiani et al., 2008). Parietal disease is confirmed by regional assessments of the density of histopathologic abnormalities at autopsy (Murray et al., 2007). The observation of impaired quantifier comprehension in CBS is consistent with previous functional neuroimaging studies of healthy adults (McMillan et al., 2005; Troiani et al., 2008) associating quantifier comprehension with parietal cortex. PNFA and SD patient groups both have relatively preserved parietal cortex (Gorno-Tempini et al., 2004; Grossman et al., 2004; Nestor et al., 2003). From this perspective, progressive aphasics with FTD may have performed relatively accurately with probes of quantifier comprehension because their disease does not compromise number knowledge and quantifier concepts that depend on parietal cortex. Additional work is needed to relate comprehension of verbal quantifiers directly to parietal atrophy in CBS.

Several caveats should be kept in mind when considering these observations. This study focused on generalized quantifiers where meaning is determined in part by quantity, but logical or Aristotelian quantifiers such as “some” and pragmatically determined quantifiers such as “many” also must be assessed, in addition to other factors that determine how quantifiers are used in daily conversation. For example, recent evidence suggests that the logical quantifiers like “some” and “all” are relatively preserved in patients with CBS (Troiani et al., 2009). This class of quantifiers may rely on a simple form of perceptual logic that does not depend on parietal cortex. Other related factors remain to be investigated in CBS, such as non-numerical qualifiers and comprehension of relative statements. With these caveats in mind, our observations are consistent with the claim that quantifier comprehension is significantly impaired in CBS, and this deficit cannot be easily explained by aphasia or visuospatial difficulties. As in our previous work (McMillan et al., 2006; Troiani et al., 2008), we hypothesize instead that quantifier comprehension is due in part to their deficit processing the magnitude component of a quantifier (Halpern et al., 2003; Halpern, Glosser et al., 2004; Koss et al., 2010) related to their parietal disease (Grossman et al., 2004; Halpern, Glosser et al., 2004; Koss et al., 2010; Murray et al., 2007; Troiani et al., 2009).

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FIGURE 1.
SCHEMATIC REPRESENTATION OF COMPONENTS CONTRIBUTING TO
QUANTIFIER COMPREHENSION

FIGURE 2.
MEAN (S.D.) PERFORMANCE ACCURACY JUDGING QUANTIFIERS

TABLE 1MEAN ($\pm$ S.D.) CLINICAL AND DEMOGRAPHIC CHARACTERISTICS OF PARTICIPANTS¹

	AGE	EDUCATION	MMSE
CONTROLS	68.0 (8.1)	16.0 (3.6)	29.5 (0.7)
CORTICOBASAL SYNDROME	65.5 (9.0)	14.6 (2.4)	24.3 (2.3)
FRONTOTEMPORAL DEMENTIA	70.1 (8.5)	15.3 (3.0)	23.1 (5.5)
ALZHEIMER'S DISEASE	74.2 (10.3)	14.0 (2.4)	23.6 (5.0)

TABLE 2

MEAN ($\pm$ S.D.) SCORES FOR LANGUAGE MEASURES¹

	FAS (#/minute)	OSC (max=12)	BNT (max=15)
Normative Score	34.8 (12.8)	10 (2)	14 (2)
CORTICOBASAL SYNDROME	30 (14)	9 (2)	14 (1)
FRONTOTEMPORAL DEMENTIA AND ALZHEIMER'S DISEASE CONTROLS	18 (15)	8 (3)	11 (5)
FRONTOTEMPORAL DEMENTIA (SD)	12 (12)	6 (4)	7 (6)
FRONTOTEMPORAL DEMENTIA (PNFA)	14 (10)	9 (2)	12 (4)
ALZHEIMER'S DISEASE	25 (19)	9 (3)	11 (3)

NOTE

¹Boston Naming Test (BNT) (Short Version) (Kaplan, Goodglass, & Weintraub, 1983): Lexical access was investigated using an abbreviated version of the Boston Naming Test consisting of 15 line drawings selected from the full test. Scores were available for 8 of the 11 CBS patients and 19 of 20 patients in the brain-damaged control group. We report average naming accuracy. Verbal Letter Naming Fluency (FAS) (Benton & Hamsher, 1989; Mickanin, Grossman, Onishi, Auriacombe, & Clark, 1994): Lexical knowledge, retrieval, and executive resources were measured in a task where subjects name as many words beginning with the letters 'F', 'A', and 'S' in 60 s each. Scores were available for 8 of the 11 CBS patients and 19 of 20 patients in the brain-damaged control group. We report the average number of unique responses beginning with the target letter in 60 s. Oral Sentence Comprehension Test (OSC) (Grossman et al., 1996): Participants responded to a simple oral question about the agent of the action of four grammatically simple sentences containing a subject-verb-object structure (e.g., "The nice, tall girl chased the friendly boy."), and eight length-matched grammatically complex sentences featuring a subject-relative or object-relative embedded clause (e.g., "The friendly boy that the girl chased was nice."). The sentence was read twice and could be repeated if requested by the patient. Scores were available for 8 of the 11 CBS patients and 19 of 20 patients in the brain-damaged control group. We report the average total number of probes with an accurate response.

MEAN (+S.D.) PERCENT ACCURACY FOR QUANTIFIER AND FACTUAL PROBES IN EACH DOMAIN OF KNOWLEDGE; MEAN (+S.D.) NUMBER OF QUESTIONS USED TO CALCULATE ACCURACY AFTER CORRECTION FOR KNOWLEDGE

TABLE 3

	QUANTIFIER PROBES			FACTUAL PROBES		
	TEMPORAL	SPATIAL	MONETARY	TEMPORAL	SPATIAL	MONETARY
CONTROLS	98.2% (3.0) 15 (1)	83.5% (10.6) 11 (1)	93.8% (6.6) 11 (1)	99.1% (2.2)	94.6% (7.1)	98.9% (2.9)
CORTICOBASAL SYNDROME	70.9% (14.3); 13 (3)	66.8% (23.3) 8 (2)	69.8% (13.0) 10 (2)	89.3% (8.9)	79.8% (14.1)	87.5% (8.5)
FRONTOTEMPORAL DEMENTIA AND ALZHEIMER'S DISEASE	80.2% (22.8) 14 (2)	74.5% (24.4) 9 (2)	82.8% (19.8) 10 (2)	93.2% (9.2)	85.8% (14.7)	91.0% (12.0)