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Beyond words: Pragmatic inference in behavioral variant of frontotemporal degeneration

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Abstract

When the message of a speaker goes beyond the literal or logical meaning of the sentences used, a *pragmatic inference* is required to understand the complete meaning of an utterance. Here we study one example of pragmatic inference, called scalar implicature. Such an inference is required when a weaker term “some” is used in a sentence like “Some of the students passed the exam” because the speaker presumably had a reason not to use a stronger term like “all”. We investigated the comprehension of scalar implicatures in a group of 17 non-aphasic patients with behavioral variant frontotemporal degeneration (bvFTD) in order to test the contribution of non-linguistic decision-making ability and the role of prefrontal cortex in supporting the computation of pragmatic inferences. The results of two experiments point to a deficit in producing alternative interpretations beyond a logical reading. bvFTD patients thus prefer the narrowly literal or logical interpretation of a scalar term when they must generate a possible alternative interpretation by themselves, but patients prefer a pragmatic reading when offered a choice between the logical and the pragmatic interpretation of the same sentence. An imaging analysis links bvFTD patients’ spontaneous tendency toward a narrowly logical interpretation with atrophy in ventromedial prefrontal cortex. Our findings are consistent with the *pragmatic tolerance hypothesis*, which proposes that difficulty generating alternative interpretations of an utterance, rather than a frank inability to compute an inference, affects the comprehension of a scalar term.

Keywords

scalar implicature; pragmatic tolerance; bvFTD

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Introduction

Imagine a college professor who says immediately before communicating the grades of an exam to a class:

- (1a) Some of the students passed the exam.

While the semantic meaning of (1a) is compatible with everyone having passed the exam, the professor's choice of words readily conveys information of the sort found in (1b):

- (1b) Not all of the students passed the exams.

This sort of inference, which goes beyond what was explicitly said, is called a *scalar implicature* because the use of a *weaker* term like “some” in (1a) indicates that the speaker had a reason not to use a *stronger* term, like “all”. Scalar implicatures are a good example of *pragmatic inferences* that occur whenever we need to integrate contextual information with linguistic information to completely understand the meaning of a statement.

There is a distinction to be made between the *linguistically encoded meaning* and the *speaker's meaning*. That is, one can determine the linguistically encoded meaning from an utterance by decoding the sentence, i.e. discovering the semantic properties that the grammar relates to its acoustic form. Retrieving the speaker's meaning requires an additional step to understand the message that the speaker is trying to convey. More technically, a sentence like (1a) *underdetermines* the speaker's meaning:

What is meant by this (the underdeterminacy thesis) is that the linguistic semantics of the utterance, that is, the meaning encoded in the linguistic expressions used, the relatively stable meanings in a linguistic system, meanings which are widely shared across a community of users of the system, underdetermines the proposition expressed (what is said). The hearer has to undertake processes of pragmatic inference in order to work out not only what the hearer is implicating but also what proposition she is directly expressing (Carston, 2002).

Scalar implicatures have been the focus of much work in experimental linguistics and particularly experimental pragmatics (e.g., Noveck & Sperber, 2004; Noveck & Reboul, 2008). The earliest studies investigated the computation of scalar implicatures from a developmental perspective (e.g., Noveck, 2001; Papafragou & Musolino, 2003). For example, Noveck (2001) showed that 7-to-10-year-olds do not make scalar inferences in reasoning tasks associated with *some* and *might* to the same degree as adults. In one of Noveck's (2001) experiments, most children accepted sentences such as “Some giraffes have long necks” while adults tended to reject them as false (on the grounds that all giraffes have long necks). This effect has proven to be robust in multiple studies (e.g., Guasti et al., 2005; Pouscoulou, Noveck, Politzer, & Bastide, 2007).

The cognitive processes and the neural basis for this kind of inference making are beginning to be determined. Previous studies pointed to the contribution of a prefrontal network in the processing of a scalar inference. Shetreet and colleagues (Shetreet, Chierchia, & Gaab,

2014) showed a critical role for orbitofrontal cortex (BA 47) in the computation of a scalar inference. BA 47 has been extensively implicated in executive functions like mental flexibility (Abe & Lee, 2011; O'Doherty, Critchley, Deichmann, & Dolan, 2003). In the same study, Shetreet and colleagues found activations in medial prefrontal cortex (BA10), which they linked with the recognition of the mismatch between context and statements. Others have demonstrated the role of medial prefrontal regions in appreciating mismatches on measures of Theory of Mind (Amodio & Frith, 2006; Ferstl & von Cramon, 2002; Rilling, Sanfey, Aronson, Nystrom, & Cohen, 2004; Saxe, 2006).

In the present paper we present two experiments that aim to investigate a specific aspect of pragmatic inference-making (e.g., Davies & Katsos, 2010; Katsos & Bishop, 2011). Arguably the most used paradigm for testing the comprehension of scalar implicatures, especially in the developmental literature, is the binary judgment task. In this task, the participant is asked to express a binary judgment (e.g., true or false) in cases in which an utterance provides an underinformative description of a stimulus picture. Consider the utterance:

(2) "Some of the cats are in the box."

Now, pair this with a pictured array in which all of the cats are in the box. If the utterance is accepted as a good description of the array, the participant is considered to not have computed the scalar implicature. However, the participant might have noticed the mismatch between the utterance and the array but have judged the mismatch not serious enough to require a rejection. In order to support this account, Katsos and Bishop (2011) presented both children and adults with two complementary tasks. The first one was a binary judgment task; in the second task, participants had to choose which array out of four best matched the target utterance (sentence-to-picture-matching paradigm). The results revealed that children accept an underinformative utterance significantly more often than adults in the first task; but when offered a choice among several alternatives, they pick the picture that reflects the pragmatic (scalar) interpretation of the sentence. Katsos and Bishop argued that the results of the two tasks together support their *pragmatic tolerance* hypothesis. In other words, children understand a scalar implicature but they are more *tolerant* than adults to pragmatic violation.

The two experiments we propose here applied Katsos and colleagues intuition about the role that the structure of the task (e.g., binary judgment versus sentence-to-picture-matching) plays in determining the performance of the participants to a clinical population. The aim is to investigate the cognitive and neural basis of the computation of scalar implicatures. We evaluated patients with bvFTD. bvFTD is a neurodegenerative disease associated with progressive frontal and anterior temporal atrophy that results in inappropriate social behavior and executive difficulty (Mendez et al., 2014; Rascovsky et al., 2011). These patients have difficulty on tasks requiring inference-making such as Theory of Mind (Adenzato, Cavallo, & Enrici, 2010; Gregory, Lough, Stone, & Erzinclioglu, 2002; Pardini et al., 2013; Torralva et al., 2007), although inference-making has rarely been assessed explicitly. Nevertheless, imaging studies (Adenzato, Cavallo, & Enrici, 2010; Eslinger et al., 2007; Gregory, Lough, Stone, & Erzinclioglu, 2002; Grossman, 2007; Grossman et al., 2010; Kipps & Hodges, 2006) and autopsy reports (e.g., Brettschneider et al., 2014; Hu et

al., 2007) have shown that bvFTD affects dorsolateral, ventral and medial regions of the frontal lobe, and these regions have been implicated in several fMRI studies of social cognition (e.g., Amodio & Frith, 2006; Enrici, Adenzato, Cappa, Bara, & Tettamanti, 2011; Frith & Frith, 2006; Mitchell, 2009; Saxe, 2006; Van Overwalle & Baetens, 2009) and reasoning (e.g., Bhatt, Lohrenz, Camerer, & Montague, 2010; Meghana Bhatt & Camerer, 2005; Coricelli & Nagel, 2009; Goel, 2007; Prado & Noveck, 2007; Prado et al., 2014; Rypma, Berger, & Genova, 2005).

In the present study, both healthy elderly adults and bvFTD patients were presented with sentences like (2) “Some of the cats are in the box.” In Experiment 1, we asked participants to decide if a sentence like (2) is a good description of one single stimulus array or not. Some arrays illustrated *some but not all* of the cats are in the box, and other arrays illustrated *all* of the cats are in the box. In Experiment 2, we used a sentence-to-picture-matching in which patients were asked to pair a single sentence with one of the two arrays used in Experiment 1. In these simple tasks with minimal task-related resource demands, bvFTD patients are themselves making a pragmatic inference, minimizing the interpretive confounds associated with more complex scenarios.

We expected that bvFTD patients would tend to compute scalar implicatures less often than healthy seniors in Experiment 1, resulting in frequently accepting the logical interpretation of a statement. We also expected that this difference would correlate with decreased gray matter density in ventromedial prefrontal cortex, which would limit bvFTD patients’ ability to flexibly evaluate alternative scenarios that are not explicitly presented to the patients. In Experiment 2 we followed up this interpretation and we expected that bvFTD patients would be able to choose the pragmatically appropriate scenario (e.g., paring the sentence “Some of the cats are in the box” with the picture illustrating that some but non all of the cats are in the box) because the relevant alternative is directly presented to them.

Experiment 1

2. Methods

2.1 Participants—We studied 17 non-aphasic patients with bvFTD who were diagnosed by board-certified neurologists (DJI, MG) using published consensus criteria (Rascovsky et al., 2011). Patients with other cognitive deficits such as progressive aphasia, visuospatial difficulty or an amnesic syndrome were excluded. Patients with a neurologic condition such as stroke or hydrocephalus, a primary psychiatric disorder, or a medical condition causing cognitive difficulty were also excluded. We also assessed a group of 16 community-dwelling healthy seniors with comparable gender, age and education (age [$t(31) = 0.97$; $p > .9$], gender [$X^2 = 2.972$; $p = .09$], and education level [$t(31) = 0.211$; $p > .8$]) who scored 28 or higher (out of 30) on the MMSE and underwent a screening procedure to ensure absence of any condition, self-reported a negative psychiatric or neurological history, and were not taking any medication that could potentially compromise cognitive performance. Digit span reverse and category fluency (FAS test) were presented to the participants in order to assess possible executive limitations as well as the Boston Naming Test to evaluate patients’ lexical and semantic knowledge. Clinical, demographic, and neuropsychological information

is summarized in Table 1. All subjects participated in an informed consent procedure approved by the University of Pennsylvania Institutional Review Board.

2.2 Materials—In the *experimental* conditions, 24 sentences with the structure “Some X are in the box” were created, where X is the name of a common object (equally often animate and inanimate; e.g., “cats” or “cars”). Each sentence was paired with one of three kinds of picture arrays in order to create three experimental conditions. Every stimulus contained 8 pictures of the target item (e.g., pictures of cats) and 8 pictures of a different item (e.g., pictures of cows). In the *SomeAll* condition, the sentence was paired with an array in which all the 8 target items were represented inside a box while the 8 non-target items were represented outside the box (see figure 1, panel A). In this condition, a sentence like “Some of the cats are in the box” is taken to be an appropriate description of the array from a logical prospective because *Some cats* does not exclude that *All the cats* are in the box. However, this is underinformative because “All the cats are in the box” would have been a more informative description of the array. By contrast, in the *SomeSome* condition, the sentence was paired with an array in which 4 of the target items and 4 of the non-target items were inside the box and the remaining target and non-target items were outside the box (figure 1, panel B). In this condition, a sentence like “Some of the cats are in the box” is an accurate description of the array from both a logical and pragmatic point of view. Finally, in the *SomeNone* condition, the sentence was paired with an array in which all the 8 target items were outside the box while the 8 non-target items were inside the box. Here, “Some of the cats are in the box” is simply an inaccurate description of the array in the condition *SomeNone*.

In the *control* condition, 8 sentences with the structure “All the X are in the box” were also created. 4 sentences were paired with arrays in which all the 8 target items were in the box and all the 8 non-target items were outside the box, making the sentence a logically true description of the array, while 4 sentences were paired with arrays in which all the 8 target items were outside the box and all the 8 non-target items were inside the box. In this case the sentences are inaccurate descriptions. These 8 sentences served as a *control* condition because the quantifier is not open to multiple interpretations. In addition, a *baseline* condition without quantifiers was introduced, pairing a sentence like “There are cats in the picture” four times with arrays in which the target items (e.g., 8 cats) and 8 non-target items were pictured and four times with arrays in which there were no target items (e.g., no cats in the array) but 16 non-target items of two different kinds (e.g., elephants and eagles) were pictured.

Word frequencies across conditions were matched using the “Subtlex corpus of word frequency in American English” (<http://expsy.ugent.be/subtlexus>).

2.3 Procedure—Participants were presented with a booklet in which each page corresponded to an experimental trial. The sentence was printed below the array in order to minimize working memory demands during task performance. While the picture and sentence were available, presentation was followed by the question: “Do you agree?” (see Figure 1, panel A). This question was preferred to other alternatives like: “Is the sentence true or false / correct or incorrect?” because a direct request about the truth-value of the

utterance might have biased participants toward a logical reading of the utterance (e.g., “Some of the cats are in the box” is logically correct also when all the cats are in the box). The experimenter prompted the participant to answer “yes” or “no” to the question. No time limit was imposed on the participant in order to minimize disadvantaging bvFTD patients who are apathetic, and to minimize the risk of biasing patients to respond in a logical manner because of a temporal deadline (see e.g., Bott & Noveck, 2004 for evidence on the effect of time pressure on the computation of scalar implicatures). After the participant replied, the experimenter turned the page to present the following trial. The experimenter recorded the participant’s answer on a separate score-sheet. The order of presentation of the trials was pseudo-randomized in order to mix the various conditions. Prior to the experimental session, we familiarized participants with the stimuli and the experimental procedure by presenting four practice trials that looked exactly the same as the experimental trials. No verbal feedback was provided during the practice trials to avoid feedback that might have biased participants’ performance toward a logical or pragmatic interpretation of the stimuli.

2.4 Imaging procedure and analysis—High-resolution volumetric T1-weighted MRI was obtained within 6 months of behavioral testing for 14 bvFTD patients. These patients matched the overall group of patients in age, education and MMSE and gender (age: $t(30) = -0.0015$, $p > .9$; education: $t(30) = -0.6478$, $p > .5$; MMSE: $t(30) = -0.741$, $p > .4$; gender: $X^2 = 4.6253$, $p > .9$). Reasons for exclusion from the MRI study included issues related to health and safety (e.g., metallic implants, shrapnel, claustrophobia), intercurrent medical illness, and lack of interest in participating in an imaging study. MRI volumes were acquired using an MPRAGE sequence from a SIEMENS 3.0T Trio scanner with an 8-channel head coil and the following acquisition parameters: repetition time=1620 msec; echo time=3.87 msec; slice thickness=1.0 mm; flip angle=15°; matrix=192×256, and in-plane resolution=1.0×1.0 mm. Whole-brain MRI volumes were preprocessed using PipeDream (<https://sourceforge.net/projects/neuropipedream/>) and Advanced Normalization Tools (<http://www.picsl.upenn.edu/ANTS/>) using a state-of-the-art procedure described elsewhere (Avants, Epstein, Grossman, & Gee, 2008; Klein et al., 2010). Briefly, PipeDream deforms each individual dataset into a standard local template space. A diffeomorphic deformation was used for registration that is symmetric to minimize bias toward the reference space for computing the mappings, and topology-preserving to capture the large deformation necessary to aggregate images into a common space. Template-based priors are used to guide GM segmentation and compute GM probability, which reflects a quantitative measure of GM density. Resulting images were warped into MNI space, smoothed using a 5 mm full-width half-maximum Gaussian kernel and downsampled to 2 mm resolution.

Permutation-based imaging analyses were performed with threshold-free cluster enhancement (Smith & Nichols, 2009) using the randomise tool in FSL (<http://fsl.fmrib.ox.ac.uk/fsl/fslwiki>). GM density was compared in patients relative to healthy seniors (an independent group of 29 healthy seniors with imaging who matched the patient group for education [$t(41) = 1.25$; $p > .2$], age [$t(41) = 0.332$; $p > .7$] and gender [$X^2 = 2.38$, $p > .1$]). A t-test analysis was run with 10,000 permutations and restricted to voxels containing GM using an explicit mask generated from the average gray matter probability

map of all groups. We report clusters that survived a threshold of $p < .001$ with family-wise error (FWE) correction for multiple comparisons and contained a minimum of 200 adjacent voxels.

To relate behavioral performance to regions of significant GM disease, we used the randomise tool of FSL with TFCE technique as described above but this time we compute a regression analysis between patients' performance in the task and the GM probability in regions of the brain showing cortical thinning with respect to the pool of healthy seniors. Permutations were run exhaustively up to a maximum of 10,000 for each analysis. We report clusters surviving a height threshold of $p < .005$ (uncorrected; considering the sample size this threshold can be considered reliable) and a minimum of 20 adjacent voxels.

3. Results

3.1 Behavioral results—bvFTD patients accepted as appropriate sentences like “Some cats are in the box” in the *SomeAll* condition (i.e. where all of the cats are in the box) more often than healthy seniors. bvFTD patients thus seemed to prefer a logical or literal reading of the quantifier “some” (logical reading in the bvFTD cohort = $.88 \pm .06$; logical reading in the healthy cohort = $.47 \pm .11$). Considering that both bvFTD patients and healthy seniors were consistent in their choice and tend to keep a logical (or a pragmatic) interpretation of the quantifier over the course of the experiment, participants were divided into logical- or pragmatic-readers on the basis of a cutoff of 75%. In other words, if a participant provided a logical interpretation of “some” in more than the 75% of the trials (significantly different from chance according to a binomial test: $p < .05$), she/he was considered a logical reader. By contrast, if the participant provided a logical interpretation of “some” in less than 75% of the trials, she/he was classified as a pragmatic reader. Fourteen (82.3%) of the bvFTD patients fell into the category of “logical readers” while 8 (50%) of the healthy seniors fell in the same category. A chi-square test revealed that the difference between the two groups is significant [$X^2 = 3.882$, $p < .05$; see Figure 2]. Both bvFTD patients and healthy seniors made virtually no errors in the *SomeSome* (bvFTD patients' accuracy = $.95 \pm .03$; healthy seniors' accuracy = 1.0 ± 0), *SomeNone* (bvFTD patients' accuracy = $.94 \pm .02$; healthy seniors' accuracy = $.99 \pm .01$), *Control* (bvFTD patients' accuracy = $.97 \pm .02$; healthy seniors' accuracy = 1.0 ± 0) and *Baseline* (bvFTD patients' accuracy = $.97 \pm .02$; healthy seniors' accuracy = 1.0 ± 0) conditions [Mann-Whitney U test; all $p > .2$].

3.2 Imaging results

The analysis of GM density in bvFTD patients relative to healthy seniors revealed significant atrophy in bilateral dorsolateral, medial, and ventromedial prefrontal regions and insula, as well as atrophy in anterior and inferior temporal cortex. (Figure 3 and Table 2). We related the probability of accepting a logical reading in the condition *SomeAll* to GM atrophy using a regression analysis. The results revealed a significant association of the behavioral measure with ventromedial prefrontal cortex (vmPFC; BA 11; see Figure 3 and Table 2).

4. Interim Discussion

In Experiment 1, we investigated the understanding of a scalar term employing a binary judgment task in which participants were presented with a pictured array and an utterance, and we asked participants to judge whether the utterance is a good description of the array. The results suggested that patients with bvFTD tend to accept an underinformative utterance as a good description of the array significantly more often than healthy seniors. Use of the quantifier “some” thus is not incompatible with a picture showing that all of the target objects are in a box. However, the quantifier “some” is less informative than the quantifier “all” when describing a picture with all of the target objects in a box. In other words, bvFTD patients appeared to have difficulty computing a scalar implicature, and adopted a narrow, literal or logical interpretation more often than controls. These results cannot be easily explained by language-related impairments because the bvFTD patients were not aphasic. Moreover, the analysis of the control condition showed that bvFTD patients appear to have good comprehension of the quantifier terms per se, since they do not differ from healthy seniors when a sentence containing “some” is paired with arrays in which some or none of the cats are in the box or when the target sentence containing “all” is paired with an array in which all or none of the cats are in the box. These results would be compatible with observations suggesting that bvFTD patients have difficulty computing inferences in daily interactions. This would encompass interactions involving perspective-taking such as empathy and irony, and the interpretation of metaphor. In Experiment 2, we examine whether difficulty with this spectrum of human interactions is due to an impairment computing pragmatic interpretations or to greater *tolerance* of pragmatic violations.

The imaging analysis indicates that bvFTD patients’ preference for a narrower, logical reading of a scalar term correlates with reduced GM density in vmPFC. Previous work has noted difficulty on tasks requiring inference-making such as Theory of Mind (Adenzato et al., 2010; Gregory et al., 2002; Pardini et al., 2013; Torralva et al., 2007) and fMRI studies of social cognition have implicated vmPFC in Theory of Mind measures (e.g., Amodio & Frith, 2006; Enrici, Adenzato, Cappa, Bara, & Tettamanti, 2011; Frith & Frith, 2006; Mitchell, 2009; Saxe, 2006; Van Overwalle & Baetens, 2009). Taken together, these findings appear to suggest that vmPFC disease in patients with bvFTD compromises the inference-making component of their social interactions.

Experiment 2

We performed a second experiment to assess an alternate hypothesis to explain bvFTD patients’ performance. This follow-up study is based on a two-alternative, forced-choice, sentence-picture matching task. Here, a sentence like “Some of the cats are in the box” was presented with two arrays to the individuals participating in Experiment 1, and they were asked to choose one of the two arrays that is best described by the sentence. In this case, participants did not need to generate possible alternative interpretations. Thus, the load on both executive resources and perspective-taking should decrease, potentially making the “pragmatic” interpretation of the sentence more accessible to every participant. From this perspective, bvFTD patients’ deficit may not be due to an inability to make pragmatic inferences, but instead may be related to limited flexibility in their ability to consider that

there may be more than one interpretation of a situation. If true, then we might expect that bvFTD patients, like healthy seniors, would prefer to match a sentence like “Some of the cats are in the box” with the array in which some but not all the cats are in the box.

2. Methods

2.1 Participants—The same participants who took part to Experiment 1 were also presented with Experiment 2.

2.2 Materials—The same materials employed in Experiment 1 were recombined, generating a different set of stimuli for Experiment 2. In this case, two arrays were paired with a single sentence in order to provide a choice between two interpretations of the utterance. A total of 24 sentences were presented to participants. In the *experimental* condition, 8 sentences began with the quantifier “some,” as in “Some of the cats are in the box,” and sentence was paired with two arrays - one consistent with a pragmatic interpretation of the quantifier (e.g., some but not all the cats are in the box), and one consistent with a strictly logical interpretation of the quantifier (e.g., all the cats are in the box) (Figure 1, Panel C). In the *control* conditions, another 8 sentences began with the quantifier “all”, as in “All the cats are in the box”, and these were paired with two arrays, one in which all the target objects were in the box and one in which some but not all of the target objects were in the box. Another 8 sentences did not contain a quantifier and began with “there”, as in “There are cats in the picture”, and in this case only one of the two pictured arrays included the target objects. Two alternatives were preferred to the four alternatives that Katsos and Bishop presented in their study because the choice between too many options might overwhelm patients’ working memory.

As in Experiment 1, the stimuli were organized in a booklet, with the two arrays next to each other and the sentence in the center-bottom of the page. We counterbalanced across trials the left/right order of the arrays picturing the logical or the pragmatic interpretation of the sentence in the target condition as well as the arrays picturing the correct or the incorrect interpretation of the sentence in the conditions containing *all* or *there*.

3. Procedure

The task was presented to the participant following the same, untimed procedure employed for Experiment 1. In this case participants were prompted to indicate which one of the two arrays is a better match with the sentence. The order of presentation of Experiment 1 and Experiment 2 was counterbalanced across participants.

4. Results

4.1 Behavioral results—In the *experimental* condition, bvFTD patients and healthy seniors equally preferred the pragmatic interpretation over the strictly logical one since both groups chose the array in which *some but not all* of the target objects were in the box more often than the array in which all the target objects are in the box (bvFTD = $.79 \pm .07$; healthy seniors = $.99 \pm .01$). As in Experiment 1 we divided the participants into “logical” and “pragmatic” readers using a cut-off of 75% of strictly logical answers. 16 (94.12%) of the bvFTD patients fell into the category of “pragmatic readers” and 16 (100%) of the healthy

seniors fell in the same category. A chi-square test revealed no significant difference between the bvFTD patients and healthy seniors [$X^2 = 0.971$; $p > 3$]. In the conditions with “all” and “there”, bvFTD patients as well as healthy seniors made virtually no mistakes [*All*: accuracy bvFTD = $.97 \pm .02$; accuracy Healthy seniors = $.99 \pm .01$; *There*: accuracy bvFTD = $.97 \pm .02$; accuracy Healthy seniors = 1 ± 0] and a Mann-Whitney test confirmed that the difference in accuracy between the two groups is not significant [*All*: Mann-Whitney U = 120; $p > 5$; *There*: Mann-Whitney U = 120; $p > 5$]. Since the analysis of the performance in the task revealed no significant difference between the two groups, we did not perform a regression analysis relating bvFTD patients’ performance to GM atrophy.

5. Interim Discussion

In Experiment 2, we diminished executive demands and mental flexibility was less necessary because the participant did not need to generate an alternative interpretation of the sentence. Under these conditions, the performance of bvFTD patients did not differ from the performance of healthy seniors in Experiment 2. Thus, it seems that bvFTD patients are not impaired at computing a scalar implicature per se, and they recognize and accept the optimal, “pragmatic” interpretation of an utterance when the pragmatic interpretation is made available to them.

General discussion

In the present study we were interested in investigating the extent to which bvFTD patients are able to derive a scalar implicature. A scalar implicature is a simple case of pragmatic inference that requires participants to take into account information external to the narrow, linguistic information derived from a sentence. This kind of inference is commonly involved in daily conversation. Our clinical intuitions are that bvFTD patients often have difficulty deriving a speaker’s intended meaning. bvFTD patients’ difficulties in social interactions have been attributed to deficits in intention-recognition or decision-making and limited executive resources (Adenzato et al., 2010; Gregory et al., 2002; Pardini et al., 2013; Torralva et al., 2007). When asked to interpret a scalar implicature spontaneously, our findings were consistent with this hypothesis about bvFTD patients’ behavior. Thus, using a simple task that directly ascertains a patient’s inference-making with few resource demands, we found that bvFTD patients prefer a literal, narrowly logical interpretation in their understanding of a scalar term. This was associated with disease in vmPFC. However, in a second task where bvFTD patients were not required to generate several alternate interpretations themselves, we found that patients’ performance does not differ from that of controls. Thus, bvFTD patients do not appear to have a deficit in computing an inference per se.

Instead, the present results appear to be more consistent with the findings of Katsos and colleagues (2011). Thus, bvFTD patients may be considered more *tolerant* of pragmatic violations than healthy seniors and not necessarily unable to compute a scalar implicature, as Katsos and colleagues proposed for children (Katsos & Bishop, 2011). We discuss the basis for our findings below.

An important advantage of our task over some previous assessments of bvFTD patients is that we tested inference-making in a manner that minimizes task-related resource demands: we used a simple task where all materials were available during the entire procedure, and patients were always given two clear, simple alternative response choices. From the perspective of the *pragmatic tolerance* interpretation, we can evaluate other data showing difficulties in bvFTD patients. Consider the difficulties observed in bvFTD patients' attempts to understand linguistic phenomena such as figurative (e.g., ironic or metaphorical) language. The interpretation of a metaphor or of an ironic statement requires a listener to go beyond the literal meaning of an utterance and to take into consideration other possible interpretations (Clark & Gerrig, 1984; R. J. Gibbs & Gerrig, 1989; Grice, 1975; Sperber & Wilson, 1986; Spotorno & Noveck, 2014). Figurative language is arguably a more complex case of pragmatic inference that requires additional world knowledge beyond the literal linguistic utterance as well as metarepresentational skills (Gildea & Glucksberg, 1983; Sperber & Wilson, 2008; Wilson & Sperber, 2012). From the perspective, it is not unreasonable to propose that the different instances of pragmatic inferences share the same basic mechanisms. Studies of the comprehension of figurative language in bvFTD patients (e.g., Rankin et al., 2009; Shany-Ur et al., 2012), usually ask participants to interpret an utterance without explicitly providing the pragmatic/figurative interpretation as we did in Experiment 1. Therefore, it is possible that bvFTD patients' difficulty in interpreting figurative language derives not from an inability to interpret metaphoric or ironic language per se, but instead from their difficulty in generating relevant alternative interpretations as well as to their greater tolerance of pragmatic violations as we propose for the case of scalar implicature.

We hypothesize that the limited sensitivity of bvFTD patients to pragmatic inference may be due in part to their difficulty generating relevant alternative interpretations of an utterance. However, the basis for this difficulty is not clearly established by our study. One possibility is related to a general limitation in mental flexibility that may be seen on measures or reversal learning. Patients with bvFTD have difficulty on such tasks (Freedman et al., 2013), and this may limit patients from spontaneously generating an alternate interpretation of a scalar implicature containing the word "some." A second, related, possibility is that bvFTD patients have a social cognitive deficit with perspective-taking and recursive reasoning that interfere with the computation of a scalar implicature (Adenzato et al., 2010; Gregory et al., 2002; Healey et al., 2015; McMillan, Rascovsky, Khella, Clark, & Grossman, 2012; Pardini et al., 2013; Torralva et al., 2007). In the absence of an explicit alternative, the comprehension of the scalar term in Experiment 1 strongly depends upon an individual's ability to go beyond the linguistic code. Previous developmental studies (e.g., Pouscoulous, Noveck, Politzer, & Bastide, 2007) showed that task features, like the use of an action-based task (e.g., "bring me the box containing *all/some* tokens") or the inclusion of distractors (e.g., unrelated items on the scene), can facilitate or prevent children from computing the pragmatic inference. Thus, bvFTD patients might tend to accept the literal interpretation of a scalar term because this is the only possibility they are able to process. A third possibility, which is again suggested by the developmental research (e.g., Barner, Brooks, & Bale, 2011; Foppolo, Guasti, & Chierchia, 2012; Gualminia, Craina, Meronia, Chierchiab, & Guastib, 2001), is that the lack of pragmatic inference derives from the absence of an automatic link

between the lexical entry of the weaker term *some* and the stronger term *all*. Thus, the explicit presentation of the two alternative scenarios (Experiment 2) should facilitate the activation of the lexical link between *some* and *all*. This should allow the participant to see the possibility of computing the scalar implicature. Although, our experiment cannot completely exclude this possibility, one of the key feature of bvFTD is that patient's linguistic abilities are largely spared (Rascovsky et al., 2011). Therefore, we consider unlikely that a deficit at lexical level can block the computation of a scalar implicature in bvFTD patients. Another possible explanation is that bvFTD patients may prefer the most obvious, literal interpretation of an utterance without considering the risk associated with an incorrect interpretation. In this context, bvFTD patients appear to have minimal self-evaluation (Massimo et al., 2013; Rosen et al., 2010), and thus they may be less likely to evaluate the reasonableness of their responses. Likewise, they may have limited concern about the reward associated with a correct response or a penalty associated with an incorrect response (Grossman et al., 2010; McMillan, Clark, Gunawardena, Ryant, & Grossman, 2012). Additional work is needed to evaluate these possibilities.

The imaging analysis shows a correlation between bvFTD patients' performance in Experiment 1 and atrophy in vmPFC. This is in line with the results of several fMRI studies showing increased activation in vmPFC during pragmatic inference-making (Basnáková, Weber, Petersson, van Berkum, & Hagoort, 2013; Eviatar & Just, 2006; Rapp, Leube, Erb, Grodd, & Kircher, 2004; Spotorno, Koun, Prado, Van Der Henst, & Noveck, 2012). Unfortunately, the level of control or ceiling performance in Experiment 2 did not allow us to examine the neuroanatomic correlates of their performance when given choices. Additional work will be needed to evaluate the neuroanatomic basis for bvFTD patients' ability to select the optimal, pragmatic interpretation of an utterance.

Several limitations must be taken into account in interpreting the present results. First of all, while our measure examined the patients' direct participation in a measure requiring inference-making, the tasks we used did not directly test pragmatic inferences in real-world exchanges. In other words, the set up of the study might have biased participants toward a logical interpretation of the utterances, even though bvFTD patients may have been as likely as controls to compute pragmatic inferences in daily conversations. A related caveat is that several healthy seniors also tended to prefer a logical interpretation of the scalar terms in Experiment 1. Thus, although controls spontaneously adopted a literal interpretation much less often than did bvFTD patients, the tolerance to pragmatic violation appears to not be an exclusive feature of bvFTD patients but may also exist in healthy aging. Variability in the performance of healthy adults was also found in previous studies of scalar implicatures (Bott & Noveck, 2004; Shetreet et al., 2014). However, this variability suggests further questions. It would be important to investigate the relation between typical aging and the ability of compute pragmatic inferences at both cognitive and neural level. Moreover, the similarities and the differences between the subgroup of healthy seniors who accept the literal interpretation of a scalar term and the bvFTD's patients with similar performance deserve further investigation. Unfortunately, the present experiments do not allow us to explore these questions and future work will be needed to investigate individual differences in

pragmatic inference-making as well as the differential the impact of bvFTD and typical aging on *literal readers*.

Conclusion

With these caveats in mind, the findings of the present study appear to provide useful insight into the cognitive and neural basis of pragmatic inference-making. The two experiments explored the hypothesis that bvFTD patients have greater pragmatic tolerance, resembling that seen in children by Katsos and colleagues. Here, bvFTD patients showed a spontaneous tendency to interpret a scalar term in a narrowly logical and highly literal manner, and this may have been driven by difficulty generating alternative interpretations rather than by a frank deficit in computing the inference. We suggest that the same explanation might be extended to other linguistic and behavioral phenomena in bvFTD that require inference-making, such as metaphorical and ironic language and perspective-taking in daily interactions.

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- bvFTD patients prefer the logical interpretation of a scalar term.
- bvFTD patients do not generate possible alternative interpretation by themselves.
- Patients' tendency toward a logical reading correlates with GM atrophy in vmPFC.
- bvFTD patients prefer a pragmatic reading when they have the choice.

Figure 1.

Example of experimental materials. Panel A: example of an item in the *SomeAll* condition of experiment 1. Panel B: Example of a target item in the Experiment 2.

Figure 2.

Behavioral results of the Experiment 1. Panel A: Probability of providing a logical answer in the condition *SomeAll*. Panel B: Percentage of participants in each group who have been categorized as *logical* or *pragmatic* readers.

Figure 3. Significant gray matter atrophy in bvFTD patients (blue and green) and regression analysis relating the probability of providing a logical answer in the *SomeAll* condition of Experiment 1 to reduced gray matter density (green; peak: 16 34 -20).

Table 1

Mean ($\pm$ SEM) demographic and neuropsychological data for patient and control groups.

Demographic/ Clinical Measure	Patients (N=17)	Healthy Seniors (N=16)
Age (years)	63 (2)	63 (2)
Education (years)	16.2 (0.7)	16.0 (0.5)
Gender (female / male)	2 / 15	6 / 10
MMSE score (max = 30)	24.9 (1.0)	29.5 (0.2)
Disease duration (years)	3.5 (0.6)	--
Digit span backward	3.7 (0.3)	--
Verbal category fluency (words/minute for 3 target letters) ^I	20 (3)	--
Boston Naming Test (BNT; max = 30)	25 (1)	--

Note:

* significant difference between the two groups;

^I data available for 16 out of 17 patients.

The patient group differed from healthy seniors in their MMSE score [$t(31) = -4.468$; $p < .001$].

A: Regions with reduced gray matter density in the bvFTD cohort respect to the group of healthy seniors. C: Regions of reduced gray matter density in patients with bvFTD that relate to the probability of giving a logical answer in the *SomeAll* condition of the Experiment 1.

Table 2

A: Reduced GM (BA) bvFTD <Healthy seniors	L/R	p value	MNI Coordinates		
			x	y	z
Inferior frontal gyrus (45–47)	R	.001	38	8	2
Ventromedial prefrontal cortex (11)	L/R	.001	10	20	–20
Thalamus	R	.001	16	–34	0
Superior temporal gyrus (21)	L	.001	–30	–32	–2
Prefrontal gyrus (10)	L	.001	–20	46	24
C: Results of the regression analysis in the bvFTD cohort (BA)					
Ventromedial prefrontal cortex (BA 11)	L/R	.001	16	34	–20

Note. BA, Brodmann area; MNI, Montreal Neurological Institute