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Research report

Comprehension of insincere communication in neurodegenerative disease: Lies, sarcasm, and theory of mind

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ABSTRACT

Comprehension of insincere communication is an important aspect of social cognition requiring visual perspective taking, emotion reading, and understanding others' thoughts, opinions, and intentions. Someone who is lying intends to hide their insincerity from the listener, while a sarcastic speaker wants the listener to recognize they are speaking insincerely. We investigated whether face-to-face testing of comprehending insincere communication would effectively discriminate among neurodegenerative disease patients with different patterns of real-life social deficits. We examined ability to comprehend lies and sarcasm from a third-person perspective, using contextual cues, in 102 patients with one of four neurodegenerative diseases (behavioral variant frontotemporal dementia [bvFTD], Alzheimer's disease [AD], progressive supranuclear palsy [PSP], and vascular cognitive impairment) and 77 healthy older adults (normal controls – NCs). Participants answered questions about videos depicting social interactions involving deceptive, sarcastic, or sincere speech using The Awareness of Social Inference Test. All subjects equally understood sincere remarks, but bvFTD patients displayed impaired comprehension of lies and sarcasm compared with NCs. In other groups, impairment was not disease-specific but was proportionate to general cognitive impairment. Analysis of the task components revealed that only bvFTD patients were impaired on perspective taking and emotion reading elements and that both bvFTD and PSP patients had impaired ability to represent others' opinions and intentions (i.e., theory of mind). Test performance correlated with informants' ratings of subjects' empathy, perspective taking and neuropsychiatric symptoms in everyday life. Comprehending insincere communication is complex and requires multiple cognitive and emotional processes vulnerable across neurodegenerative diseases. However, bvFTD patients show uniquely focal and severe impairments at every level of theory of mind and emotion reading, leading to an inability to identify obvious examples of deception and sarcasm. This is consistent with studies suggesting this disease targets a specific neural network necessary for perceiving social salience and predicting negative social outcomes.

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1. Introduction

Insincere speech is ubiquitous in everyday social interactions, where people make jokes, speak sarcastically, intentionally lie, or are honestly mistaken about reality (Harada et al., 2009). The capacity to correctly interpret these forms of insincere speech is an essential social skill, and inability to do so may result in severely impaired communication (Winner et al., 1998). Two common forms of insincere communication occur when the literal content of a speaker's message contradicts with reality. A speaker who is lying wants to hide their insincerity from the listener, while someone employing sarcasm wants the listener to recognize that they are speaking insincerely. Detecting these insincere statements requires interpretation of the speaker's intention, a complex process relying on integration of semantic and syntactic comprehension, contextual and paralinguistic information processing, pragmatic knowledge, visual perspective taking, emotion reading, and theory of mind (ToM; representing others' beliefs, opinions and intentions).

A lie is a communicative act in which the speaker intentionally withholds information from the listener in order to cause the listener to either abandon a true belief or acquire a false one (Chisholm and Feehan, 1977), and is often used to protect oneself or others (Winner et al., 1998). Watching a deceptive interaction may involve moral reasoning, since lying violates the communication norm of truthfulness (Harada et al., 2009). Although one may correctly identify a lie based entirely on the fact that the truth is being withheld from the listener, additional deliberation about the deceiver's intentions may require more complex emotion reading and ToM processes. The neuroanatomic substrates of comprehending lies involve regions implicated with moral judgment, including anterior temporal and left inferior frontal gyrus (IFG) regions (mediating semantic knowledge about social norms), and rostromedial prefrontal cortex (rmPFC) (involved in reasoning about the moral aspect of a deceptive act). Additionally, lie comprehension uniquely involves activity in bilateral temporoparietal junction (TPJ), an area related to perspective taking, right superior temporal sulcus (STS), and left dorsolateral PFC, regions which may sub-serve the "ability to detect an intent to deceive" (Harada et al., 2009). Patients with right hemisphere lesions, especially in the medial prefrontal cortex (MPFC), demonstrate poor ability to detect lies, which has been attributed to impaired ToM (Stuss et al., 2001; Winner et al., 1998).

Sarcasm is a social mechanism for indirectly conveying criticism or covering up embarrassment in a dramatic or humorous manner, and is perceived as less aggressive and more polite than direct confrontation (McDonald, 1999; Shamay-Tsoory et al., 2005; Winner et al., 1998). In both lying and sarcasm the speaker says the opposite of what they know to be true, and for both, comprehension requires using contextual cues to make an accurate assessment of what the speaker and listener think about the situation (i.e., a belief or opinion). Both may also require additional ToM processing and emotion reading to infer the speaker's intention or emotional state. However, unlike a lie, sarcasm is used to emphasize reality rather than hide it, and the speaker is trying to convey the truth to the listener (Channon et al., 2007; Grice, 1975). There is a unique set of paralinguistic cues in which voice prosody and facial expression can be used to convey sarcasm in the absence of contextual cues, however these are not required for comprehension of sarcasm when sufficient contextual cues are present (Channon et al., 2007; Grice, 1975; Rockwell, 2007). The neuroanatomical substrates of sarcasm comprehension include dorsal and ventral regions of the MPFC including superior frontal gyri (SFG) as well as IFG (with right IFG involved in representing the speaker's intention and integrating information about the speakers' attitudes, intentions and emotions and left IFG involved in integrating ToM and language processing), the temporal poles (implicated in social events-related knowledge and in empathy), posterior parahippocampi (involved in assigning social salience to auditory paralinguistic input), the STS (involved in ToM and semantic processing) and the amygdala (related to perceiving the implicitly conveyed feelings of the speaker) (Channon et al., 2007; Kipps et al., 2009; McDonald and Pearce, 1996; Rankin et al., 2009; Shamay-Tsoory et al., 2005; Uchiyama et al., 2006, 2011).

Neurodegenerative diseases are often manifested by a decline in social comprehension and behavior, especially when they involve degeneration of frontal-insular, anterior cingulate and anterior temporal regions underlying social-cognitive processes. Individuals with the behavioral variant of frontotemporal lobar degeneration (behavioral variant frontotemporal dementia – bvFTD) present with a decline in interpersonal behavior, impaired regulation of personal conduct, emotional apathy, loss of insight (Neary et al., 1998), and "lack of social awareness" (Miller et al., 2003). This disease selectively targets a network of anterior cingulate cortex (ACC) and orbital fronto-insular regions involved in processing emotional salience of stimuli (Seeley et al., 2007), and considered to be part of the "social brain" network (Adolphs, 2010; Brothers, 1990). Correspondingly there is extensive evidence that bvFTD patients perform poorly on tests of ToM, emotional processing, social- knowledge and cognition (Adenzato et al., 2010; Kipps et al., 2009; Rosen et al., 2004; Sturm et al., 2006; Zahn et al., 2009). Alzheimer's disease (AD), which initially targets posterior and medial temporal regions, is associated with progressive cognitive deficits in memory, language, perception, or attention, but not in socio-emotional processes (McKhann et al., 1984; Seeley et al., 2007). Accordingly, patients with AD typically have preserved performance on tests of ToM, social comprehension, emotion reading and regulation, particularly when more general effects of cognitive deficits are accounted for (Goodkind et al., 2010; Lavenu et al., 1999; Rankin et al., 2009; Zaitchik et al., 2004). Progressive supranuclear palsy (PSP) is primarily a motor disorder, with characteristic subcortical pathology resulting in a frontal-subcortical disconnection syndrome (Litvan et al., 1996a). However, clinically this disease often presents as a frontal dysexecutive disorder with bvFTD-like behavioral and personality symptoms such as social disinhibition and apathy (Donker Kaat et al., 2007; Kertesz and McMonagle, 2010; Litvan et al., 1996b; Millar et al., 2006). Vascular cognitive impairment (VCI) is characterized primarily by impairment in attention and executive functioning in the context of vascular lacunes or periventricular white matter disease, but may also include social behavioral features including apathy, emotional lability and social disinhibition (O'Brien et al., 2003).

Direct tests of social cognition are becoming increasingly important for detecting and characterizing social cognition deficits in patients with neurodegenerative disease. In particular, tools now exist to measure comprehension of insincere communication via face-to-face testing (McDonald et al., 2003) and the few studies which examined this ability in neurodegenerative diseases patients found it to be compromised by frontotemporal lobar degeneration (Kipps et al., 2009; Kosmidis et al., 2008; Rankin et al., 2009). Further exploration of these findings may shed light on the social mechanisms underlying these patients' impaired social comprehension and behavior, causing them for instance to have a unique susceptibility to being cheated through scams (McKhann et al., 2001). Thus, the goal of the current study was to examine a large sample of patients with neurodegenerative diseases in order to assess their ability to comprehend social interactions involving lies or sarcasm using bedside cognitive tests. We included patients with diseases known to cause social behavior deficits (bvFTD, PSP, and VCI), as well as a dementia control group with cognitive deficits but minimal impairment in social behavior (AD), and a large sample of healthy older adults. We evaluated the diagnostic specificity of these tests and their relation to real-life social behavior.

We hypothesized that after controlling for general severity of cognitive deficits, 1) patients with bvFTD would demonstrate impairments at all levels of socio-emotional comprehension, including visual perspective taking, belief representation, and emotion reading (in accordance with previous literature), ultimately causing considerably impaired comprehension of lies and sarcasm compared with healthy older adults. 2) PSP and VCI patients, who have less severe real-life social behavior deficits, would demonstrate impairment only on the most complex social comprehension tasks, including belief representation and comprehension of lies and sarcasm. 3) AD patients would not demonstrate significant deficits in comprehension of complex communication, and they were expected to perform normally on realistic emotion reading tasks. 4) Subjects' performance on this face-to-face test would correlate with their real-life empathic abilities and behavior.

2. Methods

2.1. *Participants*

One-hundred and seventy nine subjects participated in the study, including 77 healthy normal controls (NCs) and 102 patients diagnosed with one of four neurodegenerative diseases: 39 patients were diagnosed with bvFTD (Neary et al., 1998), 32 patients met National Institute of Neurological and Communicative Disorders and Stroke and the Alzheimer's Disease and Related Disorders Association (NINCDS-ADRDA) criteria for typical AD (McKhann et al., 1984), 16 were diagnosed with PSP (Litvan et al., 1996a) and 15 had cognitive impairment associated with cerebrovascular disease, with or without dementia (VCI) (O'Brien et al., 2003). NC participants were recruited through recruitment talks and advertisements at the local community and media, and had to have an unremarkable neurological exam and no functional or cognitive indication of dementia to be considered a NC. Patients' diagnoses were determined by a multidisciplinary team of neurologists, neuropsychologists and nurses, following thorough neurological, behavioral, neuropsychological and neuroimaging assessments. Since the experimental tasks were verbally loaded and required intact semantics, we excluded patients who did not speak fluent English or who had primary progressive aphasia with severe comprehension impairment. We additionally excluded patients with corticobasal syndrome, amyotrophic lateral sclerosis, or AD mixed with Lewy body dementia or cerebrovascular disease, whose group size was not large enough to enable inclusion in the statistical analysis. Demographic characteristics of the study participants are presented in Table 1. Each study participant had an informant who completed several paper and pencil questionnaires about the participant and will be described ahead. The study was approved by the Committee on Human Research at the University of California San Francisco (UCSF) and all participants and their informants gave their consent to participate.

Table 1 – Demographic characteristics of study groups, N = 179.

M (SD)	bvFTD $n = 39$	AD $n = 32$	PSP $n = 16$	VCI $n = 15$	NC $n = 77$	F (df)	p-value
Age	61.6 (7.3)[a]	62.3 (9.1)[a]	66.9 (5.1)	75.9 (97)[a]	68.2 (8.9)	10.88 (4,178)	<.001
Sex (M/F)	26/13	17/15	8/8	6/9	32/45	$\chi^2 = 7.25$ (4,179)	ns
Education	15.7 (2.9)[a]	16.3 (2.4)[a]	16.1 (2.6)	16.9 (2.5)	17.6 (2.1)	4.96 (4,178)	<.001
CDR	1.1 (.6)[a]	.8 (.4)[a]	.9 (.7)[a]	.5 (.5)[a]	(.1)	52.09 (4,165)	<.001
CDR sum of boxes	6.4 (3.2)[a]	3.8 (2.5)[a]	6.2 (3.6)[a]	2.8 (3.6)[a]	.1 (.2)	56.33 (4,165)	<.001
MMSE (max = 30)	25.7 (3)[a]	24.4 (3)[a]	26.8 (1.9)[a]	27.1 (3.2)[a]	29.4 (.9)	34.49 (4,178)	<.001
GDS (max = 30)	7.2 (6.4)[a]	6.9 (4.3)[a]	12.6 (6.5)[a]	5.8 (4.2)	3.2 (3.9)	12.44 (4,158)	<.001
NPI total severity	13.3 (5.5)[a]	5.8 (4.5)[a]	10.6 (5.7)[a]	3.8 (4.3)	1 (1.6)	68.13 (4,159)	<.001

Note: Post hoc pair-wise group differences were performed using a Dunnett post-hoc test. AD = Alzheimer's disease, bvFTD = behavioral variant frontotemporal dementia, CDR = Clinical Dementia Rating Scale, GDS = Geriatric Depression Scale, MMSE = Mini-Mental State Examination, NCs = older normal controls, NPI = Neuropsychiatric Inventory, PSP = Progressive Supranuclear Palsy, VCI = Vascular Cognitive Impairment.
a Group differs from NC group at $p < .05$ significance level.

2.2. Social cognition tasks

2.2.1. The Awareness of Social Inference Test (TASIT)

The Social Inference-Enriched (SI-E) subtest of the TASIT (McDonald et al., 2003) included 16 videotaped vignettes of interpersonal interactions involving insincere speech. Half of the videos depicted lies and the remaining videos depicted sarcasm. Correspondingly, the speaker's intention was to either make the listener believe what he/she literally said or to make the listener infer the opposite from it. Each video included additional visual or verbal contextual information (a physical object or a dialog), equally distributed, that helped viewers determine what were the speaker and listener's actual beliefs or opinions. When the contextual cue was a physical object, the listener could not see the object of reference in the deception conditions but could see the object in the sarcasm conditions. For instance, in one of the lie scenarios the speaker carries a plate filled with food, which the listener cannot see, and when asked by the listener if their son had finished his dinner, she replies "yes, he's eaten his dinner alright… he certainly listened to you". Subjects were expected to infer that since the listener could not see that the plate was still full, the speaker intended to deceive the listener. In one of the sarcasm scenarios, the speaker showed the listener a book covered with scribbles. When asked by the listener if a little girl wrote on the book the speaker replied "no, she didn't write on it… you certainly taught her a good lesson". In this case, subjects were expected to infer that since the listener saw the book to which the speaker referred, the speaker's intention was to make a sarcastic remark. When the contextual cue was verbal, the speaker expressed his/her true opinion through a preceding or antecedent dialog which the listener did not hear. When speaking to the listener, the speaker sounded sincere in the deception condition, but was using paralinguistic cues to convey their sarcasm in the sarcasm condition.

After viewing each video, subjects answered four yes–no questions about the speaker's intention ("do"), what they intended the listener to comprehend from their speech ("say"), the characters' true belief ("think") and their emotional state ("feel"). Each probe question was scored as correct or incorrect (1/0) yielding a maximal score of 32 for the eight lie items and 32 for the eight sarcasm items.

Subjects additionally viewed five videos depicting sincere social interactions, in which the speaker meant what he/she literally said, with no intention to be deceptive or sarcastic. These were administered as part of the Social Inference-Minimal (SI-M) subtest of the TASIT. Each video was followed by the same probe questions described above, yielding a maximal score of 20 for the five sincere (control) items.

2.2.2. UCSF cognitive Theory of mind test (UCSF cToM)

To assess cognitive ToM/perspective taking ability, subjects viewed eight short videos that involved change of an object's location, in accordance with existing false belief paradigms (Baron-Cohen et al., 1985; Wimmer and Perner, 1983). Each video depicted two characters in a room, both of them aware of an object's location. When one character left the room the remaining character moved the object to a new location. In four of the videos the character that left the room did not see that the object was moved, and thus had a false belief about its location. The character that remained in the room had a true belief about the other character's belief. In the remaining four videos the character that left the room saw that the object was moved, and thus had a true belief about its location. The character that remained in the room did not see that the other character saw the change of location and thus had a false belief about the other character's belief. A narrator explicitly described what was occurring in the movies, thus the information was presented both visually and verbally. Each scenario was followed by one control question ("where is the object now"?) and two ToM questions verifying belief representation/perspective taking (PT) ("where does X think the object is"? and "where does Y think that X thinks the object is"?). Each question was scored as correct or incorrect (1/0), yielding a maximal score of 16 for ToM items and 8 for control items.

2.2.3. The emotion evaluation test (EET)

In an abbreviated form of the TASIT EET (McDonald et al., 2003) participants viewed 14 videos of actors depicting an emotion in a dynamic realistic way, and were asked to choose the emotion displayed by the actor (happiness, surprise, anger, sadness, fear, disgust or neutral).

2.2.4. The comprehensive affect testing system (CATS)

Two subtests of the CATS (Froming et al., 2006) were administered. In the Name Emotional Prosody test participants listened to sentences with an emotionally-neutral meaning, and were required to choose the correct emotional voice prosody that the speaker used (happy, sad, angry, frightened or neutral). In the Affect Matching test participants were asked to determine which of five characters who displayed different emotions was showing the same emotion as that of a target character.

2.2.5. Social-cognitive components summary

We analyzed group differences on the following social-cognitive components (all based on scores derived from the social cognition tasks described above): *Control tasks verifying fulfillment of basic task requirements* (UCSF cToM control items; TASIT SI-M sincere items); *Visual perspective taking* (UCSFcToM PT items; TASIT SI-E "think" probe questions across visual cue items, measuring representation of others' beliefs about objects); *Theory of Mind* (TASIT SI-E "think" probe questions across verbal cue items, measuring representation of others' opinions/mental beliefs; TASIT SI-E "do" probe questions across all items, measuring representation of the speaker's intention); *Emotion reading* (TASIT EET; TASIT SI-E "feel" probe questions across all items; CATS Name Emotional Prosody and Affect Matching); *Comprehension of insincere communication* (TASIT SI-E lie and sarcasm total scores; total scores for each probe question across all lie items and for each probe question across all sarcasm items).

2.3. Neuropsychological tests

Participants were administered a neuropsychological battery, described elsewhere (Kramer et al., 2003), assessing various aspects of their cognition, including general mental status, memory, language, visuospatial, and executive functioning abilities. Tests included the Mini Mental State Examination

(MMSE), California Verbal Learning Test (patients were administered an abbreviated form with 9 items), Benson Figure copying and delayed recall, Fluency (semantic, category and design), abbreviated Boston Naming Test (15 items), Stroop color naming test, abbreviated Trail making test (numbers and days of the week), abstract reasoning (including three similarity items and three proverbs), and the Geriatric Depression Scale (GDS).

2.4. Questionnaires completed by participants' informants

2.4.1. Interpersonal reactivity index (IRI)

The IRI (Davis, 1980) is a 28-item questionnaire that includes four 7-item subscales assessing different aspects of empathy. Informants were asked to rate how well each of 28 statements reflected the current behavior of the study participant on a scale of 1 (does not describe at all) to 5 (describes very well), thus the total score for each subscale ranged from 7 to 35. We analyzed the perspective taking (PT) and empathic concern (EC) subscales, which are most related to real-life social functioning (Davis, 1983). The PT scale measures the ability to consider other peoples' perspective on things (e.g., "the patient is likely to try to understand others better by imagining how things look from their perspective"). The EC scale measures the tendency to be emotionally affected and concerned about distressed others (e.g., "if the patient sees someone being taken advantage of, they feel kind of protective towards them").

2.4.2. Neuropsychiatric inventory (NPI)

The NPI (Cummings et al., 1994) assesses the presence and severity of ten behavioral disturbances that occur among patients with dementia. We analyzed the existence and severity of disinhibition, euphoria, apathy, agitation, depression, anxiety, and irritability.

If a certain behavior was present, the item score ranged from 1 (least severe) to 3 (most severe). A score of 0 was given if the behavior did not exist.

2.5. Data analytic approach

All dependent measures underwent regression diagnostics to identify inappropriately influential data points, as well as to examine the normality, heteroscedasticity, and multicollinearity of residuals. Group differences on potentially confounding covariates were analyzed using a general linear model (SAS PROC GLM) (Table 1). Age, sex, and education were included as standard confounds. MMSE was also used as a proxy for disease severity to equalize this clinical factor across patients in all analyses. Clinical differences in task performance across diagnostic groups in each subscale were investigated using glms controlling for age, sex, education and MMSE, with Dunnett–Hsu post-hoc tests comparing each diagnostic group to the NC group (Table 2).

To evaluate the degree to which patients were actually impaired on each component of social cognition after factoring out elements relating to their other cognitive deficits, an additional set of analyses was performed examining the five main ToM components controlling for age, sex, education, MMSE, and performance on control tasks. The UCSF cToM task was examined controlling for performance on the matched control items for that task. The remaining four SI-E tasks were analyzed controlling for subject performance on the SI-M sincere subtest (Table 3).

3. Results

Continuous dependent variables were examined using kernel density plots of residuals and were found to have normal mildly left-skewed distributions. Based on the medium to large effect sizes seen in the analyses (partial eta-square range for diagnostic group: .10–.33), the analyses were found to be adequately powered to detect group differences even in the smaller groups (Cohen and Cohen, 1983). The results are presented in Table 2.

3.1. Social cognition tasks

3.1.1. Comprehension of control tasks

There were no significant group differences on the UCSF ToM control items score, indicating that all subjects were equally able to track the location of physical objects.

There were no significant group differences on the SI-M Sincere score, indicating that all subjects equally understood literal, truthful remarks.

3.1.2. Visual Perspective Taking

There were significant group differences on both measures of visual perspective taking. Patients with bvFTD ($p = .009$) and AD ($p = .033$) had significantly poorer scores than NCs on the UCSF cToM PT items. When controlling for their performance on the control items, the ADs' performance was not significantly impaired, indicating that only bvFTD patients had an actual ToM deficit on this task. Patients with bvFTD had significantly poorer scores than NCs on the TASIT SI-E "think" questions across visual cue items ($p < .001$), further indicating their impaired ability to represent others' perspective about physical objects (whether they saw them or not).

Partial correlations (controlling for age, sex, education, and MMSE) indicated that cToM PT score was significantly related to SI-E lie score, $r = .32$, $p < .001$, but not to SI-E sarcasm score (though a non-partial correlation between these variables was highly significant). SI-E "think" probe score across visual cue items was significantly related to both lie, $r = .46$, $p < .001$, and sarcasm, $r = .45$, $p < .001$.

3.1.3. Theory of mind

There were significant group differences on both ToM measures. Patients with bvFTD ($p < .001$) and with PSP ($p = .007$) had significantly poorer scores than NCs on the TASIT SI-E "think" questions across verbal cue items, indicating impaired ability to represent others' verbalized opinions/beliefs. Also, patients with bvFTD ($p < .001$) and with PSP ($p = .015$) had significantly poorer scores than NCs on the TASIT SI-E "do" questions across all items, indicating impaired ability to comprehend others' intentions. A follow up analysis looking at responses to the "do" items on visual versus verbal items indicated that PSP patients were only impaired at comprehending the speaker's intention on the verbal cue items ($p = .034$) but not on the more explicit visual cue items. bvFTD patients, however, were equally impaired on both conditions.

Table 2 – Social cognition tasks performance across groups (N = 179).

M (SD)	bvFTD $n = 39$	AD $n = 32$	PSP $n = 16$	VCI $n = 15$	NC $n = 77$	F (df)	p-value	Effect size (DX partial eta-square)
Control tasks								
UCSF cToM: control items (max = 8)	7.5 (1.1)	6.9 (1.5)[a]	7.4 (.7)	7.7 (.6)	7.9 (.3)	1.83 (8,156)	ns	
SI-M: sincere (max = 20)	15.4 (3.6)	14.9 (3.6)	14.7 (4.2)	14.5 (4.1)	16.8 (3.1)	1.75 (8,178)	ns	
Visual PT tasks								
UCSF cToM: PT items (max = 16)	12.8 (3.4)[b]	12.1 (3.5)[a]	13.9 (2.5)	14.3 (2.8)	15.6 (.8)	2.83 (8,156)	.027	.07
SI-E: "think" score across visual cue items (max = 8)	4.9 (1.7)[b]	5.9 (1.4)	6.1 (.7)	5.9 (1.6)	6.9 (.9)	7.74 (8,178)	<.001	.15
ToM tasks								
SI-E: "think" score across verbal cue items (max = 8)	5.3 (1.5)[b]	6.4 (1)	6 (1)[a]	6.7 (1.4)	7.3 (0.8)	14.84 (8,178)	<.001	.26
SI-E: "do" score across all items (max = 16)	9.3 (2.1)[b]	11.9 (2.2)	11.3 (2.4)[a]	12.1 (2.8)	13.7 (1.8)	18.55 (8,178)	<.001	.30
Emotion reading tasks								
EET: emotion recognition (max = 14)	6.8 (2.5)[b]	9.8 (2.1)	9.9 (2.3)	9.6 (2)	11.5 (1.9)	18.04 (8, 174)	<.001	.30
SI-E: "feel" score across all items (max = 16)	9.5 (2)[b]	10.3 (1.5)	11.8 (2.1)	11.3 (2.5)	12.8 (1.6)	7.7 (8,178)	<.001	.15
CATS emotion prosody (Z-score)	−1.7 (1)[b]	−.8 (1.1)	−1.4 (.9)[b]	−1.5 (.8)[a]	0 (1)	13.24 (8,156)	<.001	.26
CATS affect matching (Z-score)	−1.7 (1.3)[b]	−1.3 (1)[a]	−2.2 (1.7)[b]	−1.2 (1.2)	0 (1)	9.61 (8,156)	<.001	.21
Comprehension of insincere communication: TASIT SI-E								
SI-E lie "think" score (max = 8)	4.9 (1.5)[b]	5.8 (1.3)	5.5 (.7)[a]	6.2 (1.7)	6.9 (.9)	8.69 (8,178)	<.001	.17
SI-E lie "say" score (max = 8)	5.1 (1.9)[b]	5.9 (1.5)	5.7 (1.5)	6.6 (1.4)	7 (1.2)	4.49 (8,178)	.002	.10
SI-E lie "do" score (max = 8)	6.1 (1.3)[b]	6.7 (.9)	6.7 (1)	7 (1)	7.3 (1)	5.38 (8,178)	<.001	.11
SI-E lie "feel" score (max = 8)	5.1 (1.9)[a]	5 (1.4)	5.8 (1.7)	6.2 (1.7)	6.8 (1.3)	1.78 (8,178)	ns	
SI-E lie total score (max = 32)	21.1 (4.6)[b]	23.5 (3.4)	23.7 (3.4)[a]	26 (4.6)	28 (3.4)	8.15 (8,178)	<.001	.16
SI-E sarcasm "think" score (max = 8)	5.3 (1.6)[b]	6.5 (1.2)	6.6 (.7)	6.4 (1.2)	7.3 (.7)	13.3 (8,178)	<.001	.24
SI-E sarcasm "say" score (max = 8)	3.9 (1.7)[b]	5.5 (1.8)	5.1 (1.8)	5.4 (2.2)	6.5 (1.5)	10.72 (8,178)	<.001	.20
SI-E sarcasm "do" score (max = 8)	3.3 (1.6)[b]	5.2 (2)	4.6 (2.4)	5.1 (2.2)	6.4 (1.4)	12.27 (8,178)	<.001	.22
SI-E sarcasm "feel" score (max = 8)	4.4 (1.5)[b]	5.3 (1)	6 (1)	5.1 (1.4)	5.9 (1.2)	6.92 (8,178)	<.001	.14
SI-E sarcasm total score (max = 32)	16.9 (4.3)[b]	22.5 (4.4)	22.3 (4.4)	22 (6.2)	26.1 (3.3)	20.9 (8,178)	<.001	.33

Note: F-statistic and p-values are for overall diagnostic group differences controlling for age, sex, education and MMSE score. Post hoc pair-wise group differences were performed comparing each patient group's least squares mean with the NC mean using a Dunnett–Hsu test. DX = diagnostic group, EET = TASIT emotion evaluation test, SI-M = TASIT Social Inference-Minimal test, SI-E = TASIT Social Inference-Enriched test.
a Group differs from NC group at $p < .05$ significance level.
b Group differs from NC group at $p < .001$ significance level.

Partial correlations indicated that SI-E "think" probe score across verbal cue items was significantly related to both lie, $r = .51$, $p < .001$, and sarcasm, $r = .46$, $p < .001$, total scores. SI-E "do" probe score was significantly related to both lie, $r = .48$, $p < .001$, and sarcasm, $r = .78$, $p < .001$, total scores as well.

3.1.4. *Emotion reading*

There were significant group differences on all measures of emotion reading: TASIT EET, SI-E "feel" questions across all items, CATS emotion prosody and affect matching tests. bvFTD patients had significantly poorer scores than NCs on all

Table 3 – ToM components and diagnostic groups' impairment information.

Level	Other's thought content	Modality of presentation	Construct	Test score	Impaired groups, when controlling for other cognitive deficits
1	Knowledge of objective facts	Explicitly verbalized and presented	Visual PT (explicit)	UCSF cToM: PT items	bvFTD
2	Knowledge of objective facts	Implicitly presented	Visual PT (implicit)	SI-E: "think" score across visual cue items	bvFTD
3	Mental opinion	Explicitly verbalized	ToM	SI-E: "think" score across verbal cue items	bvFTD; PSP
4	Mental intention	Implicitly presented	ToM	SI-E: "do" score across all items	bvFTD; PSP[a]
5	Emotion	Implicitly presented	Emotion reading	SI-E "feel" score across all items	bvFTD

Note: Group impairment was determined using GLM controlling for age, sex, education, MMSE, and the control task score (UCSF cToM PT score controlling for UCSF cToM control score, SI-E scores controlling for SI-M sincere score), with Dunnett–Hsu post-hoc tests.
a PSP patients were only marginally impaired in inferring the mental intention on verbal cue items ($p = .072$) but not on visual cue items (ns).

tests (p's $< .001$). PSP and VCI patients had significantly poorer scores than NCs on the CATS emotion prosody task ($p < .001$ and $p = .019$, respectively). Patients with PSP as well as those with AD had significantly poorer scores than NCs on the CATS affect matching task ($p < .001$ and $p = .049$, respectively).

Partial correlations indicated that EET score was significantly related to both lie, $r = .47$, $p < .001$, and sarcasm, $r = .47$, $p < .001$, total scores. CATS emotion prosody score was related to both lie, $r = .28$, $p < .001$, and sarcasm, $r = .45$, $p < .001$, and so was CATS affect matching ($r = .38$, $p < .001$ and $r = .32$, $p < .001$, respectively).

3.1.5. *Comprehension of insincere communication*

There were significant group differences on all SI-E scores, excluding the "feel" probe question score across lie items. Patients with bvFTD were significantly impaired on all measures of insincere communication comprehension (overall lie and sarcasm task scores, as well as each of the probe questions) compared with NCs (all p's $< .001$, except $p < .05$ on "feel" probe questions across lie items). PSP patients performed significantly poorer than NCs on their overall lie task score ($p = .026$) and on "think" probe questions across lie items ($p = .030$). However, when controlling for their performance on the sincere task, their lie comprehension score was no longer significantly impaired.

Table 3 summarizes the performance of patients with different neurodegenerative diseases on the various ToM components examined in the study (when controlling for their performance on the control tasks).

3.2. *Neuropsychological, neuropsychiatric and emotion sensitivity characteristics of patients who succeeded or failed to comprehend insincere communication*

We computed a Z-score for each patient (one for lie and one for sarcasm score) based on the mean and standard deviation (SD) of the NC sample. We used a cut- point of $Z \leq -1.5$ to indicate task failure and divided the patient group based on whether each patient (1) passed or failed the lie task, and (2) passed or failed the sarcasm task. We did not include NCs in this analysis in order to minimize a diagnostic group effect. The pass/fail groups were compared with regard to their demographic, neuropsychological, neuropsychiatric, and emotion sensitivity scores using GLMs, conducted separately for lie and sarcasm. The results are presented in Table 4 (neuropsychological and demographic data) and Table 5 (neuropsychiatric and emotion sensitivity data).

3.2.1. *Lie comprehension*

Patients who failed to comprehend lies had lower MMSE and higher Clinical Dementia Rating Scale (CDR) scores compared with patients who passed the task. On neuropsychological testing, when controlling for disease severity, they had poorer scores on tests of verbal fluency and abstract reasoning, spatial cognition, and most measures of executive functioning: working memory (digits backward), letter and design fluency, and cognitive control (Stroop interference). They also had poorer performance on emotion reading tests (not including prosody), and their informants rated them as more disinhibited and apathetic.

3.2.2. *Sarcasm comprehension*

Patients who failed to comprehend sarcasm had lower MMSE scores, and higher CDR scores compared with patients who passed the task. On neuropsychological testing, when controlling for disease severity, they had poorer scores on tests of naming and abstract reasoning, verbal episodic memory and phonemic fluency. They had poorer performance on tests of emotion reading, including emotion prosody, and reported more depressive symptoms than patients who passed the test. They were also rated by informants as less empathic, and more disinhibited, euphoric, and apathetic.

3.3. *The relationship between comprehension of lies and sarcasm to real-life measures of empathy and neuropsychiatric symptoms*

The relationship between lie and sarcasm scores and informants' ratings of empathy and neuropsychiatric-behavioral symptoms was examined with partial correlation analyses, controlling for age, sex, education and MMSE. Pearson correlation coefficients were used to calculate the relationship with the IRI EC and PT subscale scores (each ranging from 5 to 35), and Spearman correlation coefficients were used to calculate the relationship with the NPI disinhibition, euphoria, apathy, agitation, depression, anxiety and irritability subscale scores (each ranging from 0 to 3).

Partial Pearson correlations revealed that both lie and sarcasm overall task scores had significant positive correlations with IRI PT ($r = .33$, $p < .001$ and $r = .30$, $p < .001$, respectively), as well as with IRI EC ($r = .39$, $p < .001$ and $r = .30$, $p = .024$), indicating that people with better social comprehension on this face-to-face testing had better emotional perspective taking and empathic concern in real life.

Partial Spearman correlations revealed that both lie and sarcasm scores were negatively correlated with NPI ratings of disinhibition ($r = -.22$, $p = .006$ and $r = -.33$, $p = .001$, respectively), euphoria ($r = -.17$, $p = .036$ and $r = -.38$, $p < .001$), and apathy ($r = -.31$, $p < .001$ and $r = -.41$, $p < .001$). Sarcasm score was also negatively correlated with agitation ($r = -.19$, $p = .020$). Neither lie nor sarcasm scores correlated with depression, anxiety or irritability.

4. Discussion

Our results suggest that subjects in the early stages of bvFTD, PSP, VCI, and AD can understand literal, truthful remarks as well as healthy older adults can. However, as hypothesized, patients with bvFTD were impaired on tests of fundamental social-cognitive processes involved in detecting insincere speech, including visual perspective taking, belief representation, and emotion reading, leading to poor comprehension of both lies and sarcasm. PSP patients showed some deficits as well, performing poorly on complex ToM tests requiring them to represent others' opinions and intentions, but not on visual perspective taking where the facts of the situation were directly observable. Cerebrovascular and AD patients did not demonstrate impaired social-cognitive processing or difficulty comprehending insincere communication when overall cognitive deficits were accounted for.

Table 4 – Neuropsychological and demographic characteristics of patients who passed or failed the lie and sarcasm tests (N = 102).

M (SD)	Pass lie ($n = 55$)	Fail lie ($n = 47$)	F-value	p-value	Pass sarcasm ($n = 42$)	Fail sarcasm ($n = 54$)	F-value	p-value
Demographics								
Age	65.4 (9.9)	64.1 (8.5)	.48 (1,101)	ns	63.7 (9.6)	65.6 (9)	1.06 (1,101)	ns
Sex (M/F)	27/28	30/17	$\chi^2 = 2.23$	ns	21/24	36/21	$\chi^2 = 2.77$	ns
Education	16.2 (2.6)	16 (2.7)	.09 (1,101)	ns	16.7 (2.5)	15.7 (2.7)	3.97 (1,101)	.049
Disease severity								
MMSE (max = 30)	26.6 (2.6)	24.6 (3.1)	12.41 (1,101)	<.001	26.7 (2.1)	24.9 (3.4)	9.36 (1,101)	.003
CDR	.7 (.5)	1.1 (.6)	14.49 (1,93)	<.001	.8 (.6)	1 (.6)	2.64 (1,93)	ns
CDR sum of boxes	3.9 (3)	6.5 (3.4)	16.52 (1,93)	<.001	3.8 (3.3)	5.9 (3.3)	8.58 (1,93)	.004
Neuropsychological functioning								
Language								
Abbreviated BNT (max = 15)	12.6 (2.9)	12.1 (3.3)	.05 (4,95)	ns	13.5 (1.7)	11.4 (3.5)	11.93 (4,95)	<.001
Semantic fluency (animals)	13.4 (5.8)	9.3 (4.1)	9.26 (4,97)	.003	12.6 (5.9)	10.6 (5)	1.24 (4,97)	ns
Abstract reasoning (max = 6)	2.9 (1.5)	1.8 (1.3)	7.92 (4,88)	.006	3.1 (1.6)	1.9 (1.3)	13.21 (4,88)	<.001
Verbal memory								
CVLT short form 10 min recall (max = 9)	4.3 (3.1)	3.5 (2.3)	0 (4,90)	ns	5.3 (2.6)	2.9 (2.4)	10.48 (4,90)	.002
CVLT recognition discriminability (max = 100%)	76.1 (25)	66.4 (28.3)	.3 (4,90)	ns	80.1 (21)	65 (29.1)	3.15 (4,90)	ns
Visuospatial memory								
Benson Figure delayed recall (max = 17)	7.2 (4.4)	5.7 (4.4)	.98 (4,95)	ns	7.5 (2.3)	5.8 (4.2)	.98 (4,95)	ns
Benson Figure delayed recognition (1/0)	37/15	28/16	$\chi^2 = .62$	ns	30/12	35/19	$\chi^2 = .47$	ns
Visuospatial								
Benson Figure copy (max = 17)	13.6 (3.1)	12.8 (4)	.06 (4,95)	ns	12.8 (4.1)	13.6 (3.1)	3.31 (4,95)	ns
Number location (max = 10)	8.2 (1.7)	6.8 (2.7)	6.74 (4,95)	.011	7.4 (2.3)	7.7 (2.3)	.86 (4,95)	ns
Executive functioning								
Digit span forward	6 (1.5)	5.3 (1)	1.91 (4,86)	ns	5.9 (1.3)	5.5 (1.3)	.06 (4,86)	ns
Digit span backward	4.3 (1.4)	3.5 (1)	4.32 (4,96)	.041	4.1 (1.4)	3.8 (1.2)	0 (4,96)	ns
Modified trails speed (lines/min)	17.2 (13.4)	10.1 (9.9)	3.31 (4,91)	ns	16.9 (15.7)	11.8 (8.4)	1.18 (4,91)	ns
Phonemic fluency (d-words/min)	10.8 (4.8)	7.2 (4.2)	8.42 (4,97)	.005	10.6 (4.6)	8 (4.8)	4.12 (4,97)	.045
Design fluency (designs/min)	7.6 (3.5)	4.9 (3.1)	9.44 (4,96)	.003	7 (3.5)	5.8 (3.5)	.84 (4,96)	ns
Stroop interference (words/min)	33.7 (16)	23.8 (13.9)	4.29 (4,83)	.042	29.4 (11.5)	29.5 (18.5)	1.20 (4,83)	ns

Note: F-statistics are derived from general linear models of neuropsychological scores controlling for age, sex, and MMSE. BNT = Boston Naming Test, CDR = Clinical Dementia Rating Scale, CVLT = California Verbal Learning Test, MMSE = Mini-Mental State Examination.

As expected, subjects with poor comprehension of lies and sarcasm were rated by their informants as demonstrating poorer empathic concern and emotional perspective taking abilities, and more disinhibition, euphoria and apathy in real life. Thus, failure to comprehend complex social interactions may exacerbate patients' poor social self-monitoring and aberrant social behavior. These results also suggest that directly testing patients' ability to comprehend insincere speech provides ecologically valid information about interpersonal sensitivity and social behavior outside of the exam room. Such testing may be sensitive and specific to early bvFTD, and to a lesser degree to other tauopathies with characteristic frontal-subcortical involvement such as PSP.

4.1. *Fundamental social-cognitive processes involved in comprehending insincere speech: perspective taking, Theory of mind, and emotion reading*

Traditional theories of communication suggest that listeners initially use semantic information to understand the literal meaning of speech, and then use pragmatic processes to understand the speaker's intention in a particular context (Grice, 1975). Gibbs (1999) has argued that pragmatic processing is essentially involved in both stages: we use primary pragmatic information (common associative knowledge about the world) to literally interpret a saying (e.g., when someone says "my plate is full", we use primary pragmatic information to recognize that plates are typically filled with food). We then use secondary pragmatic information such as specific contextual information to determine the implication of the saying in a given situation (e.g., when someone says "my plate is full" while purposefully showing us their empty plate, we may infer that they are being sarcastic). Similarly, if a child says "my plate is empty" while trying to disguise his full plate, we may infer that they are trying to be deceptive. Thus, detection of both lies and sarcasm strongly relies on processing contextual, secondary pragmatic information in the form of visual or verbal cues.

Both lie and sarcasm tasks in this study required several interdependent processes representing increasing levels of cognitive complexity. First, subjects applied basic semantic/linguistic and primary pragmatic knowledge to interpret the literal meaning of the speaker's words. While this can be affected by neurodegenerative disease, our patients likely did not fail to comprehend insincere communication due to

Table 5 – Neuropsychiatric, emotion sensitivity and empathic abilities of patients who passed or failed the lie and sarcasm subtests (N = 102).

M (SD)	Pass lie (n = 55)	Fail lie (n = 47)	F-value	p-value	Pass sarcasm (n = 34)	Fail sarcasm (n = 49)	F-value	p-value
Neuropsychiatric symptoms (informant ratings)								
NPI total severity	8.8 (5.8)	10.4 (6.7)	1.58 (4,87)	ns	7.8 (6.1)	10.7 (6.1)	6.72 (4,87)	.011
NPI disinhibition	1 (1)	1.4 (1.1)	5.77 (4,87)	.019	.8 (.9)	1.4 (1.1)	11.20 (4,87)	.001
NPI euphoria	.6 (.9)	.7 (.9)	.47 (4,87)	ns	.4 (.7)	.8 (.9)	9.12 (4,87)	.003
NPI apathy	1.3 (.9)	1.9 (1)	5.17 (4,87)	.026	1.1 (1)	1.8 (.9)	10.34 (4,87)	.002
NPI agitation	.7 (.8)	.8 (1.1)	.98 (4,87)	ns	.6 (.8)	.9 (1)	2.28 (4,87)	ns
NPI depression	.5 (.8)	.4 (.7)	.15 (4,87)	ns	.4 (.7)	.4 (.7)	.10 (4,87)	ns
NPI anxiety	.7 (.8)	.7 (.9)	.16 (4,87)	ns	.7 (.8)	.7 (.9)	.02 (4,87)	ns
NPI irritability	.9 (1)	.9 (1.1)	.06 (4,87)	ns	.9 (1)	.9 (1.1)	.01 (4,87)	ns
GDS (depression self rating)	7.9 (6.5)	7.5 (5)	.06 (4,85)	ns	9.4 (6.4)	6.4 (5)	4.61 (4,85)	.035
Emotion sensitivity and empathy								
TASIT EET (max = 14)	9.7 (2.5)	7.4 (2.4)	15.78 (4,97)	<.001	10.2 (2.1)	7.5 (2.5)	26.03 (4,97)	<.001
CATS emotion prosody (Z-score)	−1.1 (1)	−1.5 (1.1)	1.86 (4,81)	ns	−0.8 (1.1)	−1.7 (.8)	14.03 (4,81)	<.001
CATS affect matching (Z-sore)	−1.1 (1.1)	−2.1 (1.3)	9.91 (4,81)	.002	−1 (1)	−2 (1.3)	10.48 (4,81)	.002
IRI PT (informant ratings)	18 (7)	15.5 (6.7)	1.77 (4,83)	ns	19 (6.8)	15.1 (6.5)	6.94 (4,83)	.010
IRI EC (informant ratings)	23.5 (6.8)	20.1 (7.4)	3.36 (4,84)	ns	24.9 (5.9)	19.6 (7.5)	12.33 (4,84)	<.001

Note: F-statistics derived from general linear models, controlling for age, sex and MMSE. CATS = Comprehensive Affect Testing System, EC = Empathic Concern Subscale, GDS = Geriatric Depression Scale, IRI = Interpersonal Reactivity Index, NPI = Neuropsychiatric Inventory, PT = Perspective Taking subscale, TASIT EET = The Awareness of Social Inference Test: Emotion Evaluation Test.

primary semantic processing deficits. We excluded patients with aphasia who could not fulfill the initial requirements of the task, and more importantly, found no significant group differences in response to a control task verifying comprehending sincere speech. Thus, our subjects did not appear to have significant deficits in comprehending the literal meaning of the conversations they viewed, nor did they appear to lack the pragmatic knowledge to comprehend the series of events in the sincere videos.

Next, subjects had to identify contextual information occurring around the speaker's words. In the visual cue items, they had to attend to the physical object to which the speaker referred, and observe who could directly see that object. We found no significant group differences in response to a control task verifying how well the subjects could track the location of a physical object, indicating that all subjects were equally able to perceive this information. Also, performance on a standard visual perception task was equal between patients who failed or passed the tasks, suggesting they were equally able to process the contextual visual cues, had they paid attention to them. Although there were some minor differences between the pass and fail groups on a spatial perception task, it did not seem to affect their otherwise intact performance on sincere items that were as contextually complex as the insincere items. Thus, subjects did not appear to differ in their perception of the visual cues. However, subjects did differ in their ability to represent the knowledge of the speaker and the listener about the physical object (i.e., visual perspective taking). bvFTD patients had poor ability to represent other people's knowledge of these objective facts, whether they were implicitly presented to them (as determined by their responses to the "think" probes on SI-E visual cue items) or when they were explicitly, verbally presented to them (determined by their responses to the cToM task PT items).

In the verbal cue items, subjects had to attend to the additional information stated before or after the main conversation in order to accurately represent the speaker's verbalized opinion. bvFTD and PSP patients had impaired performance on questions measuring this ability ("think" probes on verbal cue items). Thus, although patients generally performed equivalently on both visual cue items and verbal cue items (i.e., bvFTD patients failed both, while VCI and AD patients failed neither), PSP patients showed a dissociation between these two abilities. Though they did not have difficulty representing others' knowledge when the information was explicitly presented visually, they were impaired at representing others' explicitly stated opinions.

In addition, to correctly identify the emotional state of the speaker, subjects were also required to read the vocal and facial emotional cues, which can provide additional information to help them determine the overall attitude of the speaker. While other groups had difficulty on static emotion tasks (e.g., CATS), only the bvFTD patients failed when the emotional stimuli were presented in an ecologically realistic, dynamic and multimodal manner (EET), and they were the only group who had trouble understanding characters' implicitly presented emotions during insincere speech on the SI-E task.

Finally, after processing the literal speech elements and contextual cues, then representing the beliefs, opinions and emotional states of the protagonists, subjects had to infer the speaker's intention. bvFTD patients in our study likely failed to ultimately comprehend the intentions behind insincere speech (deception or sarcasm) due to deficits in each of these preceding social-cognitive processes. Thus, perspective taking, ToM and emotion reading, are essential for correct interpretation of others' complex indirect speech. PSP patients who only had difficulties with representing other's opinions on the verbal cue items correspondingly had poor ability to infer the speaker's intentions in the verbal cue condition, but not in the visual cue condition.

In addition to social-cognitive deficits, our data show that patients who failed to comprehend both lies and sarcasm had poor scores on tests of abstract reasoning and fluency/generation compared with patients who passed the tests. It has been suggested before in the pragmatic linguistics literature that when subjects initially interpret the literal meaning of a saying, they employ abstract thinking and generate different possible linguistic meanings for a specific utterance, and that based on contextual information they then select the appropriate meaning for that utterance in a specific context (Thomas, 1995). Accordingly, our findings suggest that better abstract reasoning and generation abilities are associated with more accurate comprehension of insincere speech.

Also, though not directly tested in this study, comprehension of lies and sarcasm both may rely on acquired social knowledge. Over the course of development people gradually acquire concepts for lying (Strichartz and Burton, 1990) and sarcasm (Filippova and Astington, 2008) and increasingly apply them in order to make accurate inferences about real-life situations. This knowledge may be jeopardized in neurodegenerative diseases that specifically target social semantic knowledge. Patients with bvFTD typically have varying degrees of temporal involvement (Whitwell et al., 2009), thus some may have impoverished social conceptual knowledge, which is mediated in part by the right lateral anterior temporal lobe (Zahn et al., 2009). Accordingly, the temporal poles have been directly implicated in the ability to comprehend sarcasm (Rankin et al., 2009; Uchiyama et al., 2006) and lies (Harada et al., 2009). It is possible, therefore, that patients with atrophy in this region might have difficulties recognizing these social acts partly due to degradation of the very concepts of lying or sarcasm.

4.2. *Lie detection involves sensitivity to social norm violations*

Detecting interpersonal deception uniquely entails sensitivity to a violation of the conversational "maxim of quality" which assumes that all speakers are being truthful (Grice, 1975). A lie is considered to be a morally- and value- loaded form of speech (Lee, 2000), and its detection requires awareness of social and moral norms, or "conventionality". It also requires detection of the deceiver's intention (Harada et al., 2009), which is common to comprehending both lies and sarcasm. This presents an interesting contrast with other dementia patients who may have benefited from their intact sensitivity to violations of social norms ("conventionality"), ultimately scoring better on this test than bvFTD patients, despite equivalent cognitive deficits. Although patients who failed to detect that one person was deceiving another had more functional impairment (higher CDR and lower MMSE scores), analyses were performed controlling for any differences in disease severity across subjects, and these diagnostic group differences still remained significant. Thus, the "awareness to conventionality" aspect is another social-cognitive component that is likely to be impaired in patients who fail to detect interpersonal deception, i.e., patients with bvFTD.

4.3. *Sarcasm comprehension can rely on paralinguistic and emotional cues*

The visual cue vignettes in the SI-E task were designed so that the viewer could determine the intention of the speaker based entirely on the contextual cues provided. Thus, even a viewer without any sensitivity to the paralinguistic elements of sarcasm should have been able to derive the correct interpretation from the contextual cues alone. However, in the verbal cue vignettes, the sarcasm scenes also included additional, sometimes subtle paralinguistic cues which facilitated correct inference about the speaker's intention. Sarcastic remarks are often accompanied by specific facial expressions, including greater gaze aversion (Williams et al., 2009) and a pattern of vocal prosody unique to sarcasm (Rockwell, 2007). Thus, it is likely that patients with poorer sensitivity to such paralinguistic features, such as those who are also impaired at emotional prosody detection, could not recognize the sarcastic nature of the insincere remarks. Indeed, patients who failed to comprehend sarcasm had significantly poorer emotion prosody scores compared with patients who passed the task, but there was no such group difference with regard to the lie task, indicating that detection of paralinguistic cues such as voice prosody is more relevant to sarcasm than lie comprehension.

Also, a central aspect unique to the sarcasm scenarios was that the speakers were portrayed as being angry or unhappy about something, and used sarcasm to communicate their displeasure to the listener. bvFTD was the only patient group with significantly poorer scores on questions referring to the speaker's feelings ("is he/she annoyed"?). Correspondingly, patients who failed to comprehend sarcasm were rated by their informants as having poorer emotional perspective taking and empathic concern compared with patients who passed this task. Indeed, it has been proposed before that one needs to acknowledge the sarcastic speaker's feelings to fully understand his or her sarcastic intentions (Shamay-Tsoory et al., 2005). Our results suggest that patients with decreased emotional sensitivity and empathic abilities are less likely to infer that someone is using sarcasm to convey a (typically) negative emotion. Interestingly, the study groups did not significantly differ in responding to the "feel" probe question on the lie task, showing that consideration of the speaker's emotion in order to understand their intention is more central to comprehending sarcasm than lies.

4.4. *Clinical implications*

Patients with bvFTD are known to have a progressive decline in their ability to comprehend others and interact with them, losing their basic sense of social- and self-awareness early in the disease (Miller et al., 2003; Neary et al., 1998). Previous research on social cognition in bvFTD has demonstrated deficits on various aspects of ToM (Adenzato et al., 2010) and emotion reading abilities (Rosen et al., 2004), but in this study we show in detail how these patients fail at distinct levels of a cascade of increasingly complex social-cognitive processes, including visual perspective taking, ToM, and emotion reading, leading them to ultimately misinterpret lies and sarcasm. A previous study found relatively preserved sarcasm comprehension in bvFTD patients, but only when it was conveyed with simpler paralinguistic cues, which are primarily interpreted using structures in the temporal lobe (Rankin et al., 2009). Here we demonstrated that ability to comprehend sarcasm from more complex contextual cues is clearly deficient in bvFTD. Anatomic heterogeneity within bvFTD is a confounding factor across studies characterizing social cognition and behavior, because patients meeting clinical criteria for bvFTD have highly divergent degrees of temporal versus frontal atrophy (Whitwell et al., 2009). Thus, in addition to the distinction between types of sarcasm studied, the different results between the two studies could be related to cohort inclusion and diversity factors.

In this study we demonstrated that even when bvFTD patients are given all necessary information to detect that someone is lying, they are unable to do so. This likely reflects one aspect of their decreased ability to attend to salient, socially significant cues, which is thought to depend on connectivity in a right fronto-insular intrinsic network that is selectively targeted by this disease (Seeley et al., 2009). bvFTD patients tend to make more "risky" decisions on a gambling task measure of decision making (Torralva et al., 2007), and a recent study found that patients with bvFTD were impaired at judging whether a social act was acceptable only when it had a negative valence, but not in a positive social setting (Grossman et al., 2010). In both of these studies, patients' decreased sensitivity to the negative outcome of their decisions was linked to volume in the ventromedial prefrontal cortex (VMPFC). This evidence supports a role for this region in evaluating the specifically negative consequences of social decisions, and by extension may be relevant to bvFTD patients' insensitivity to rule violations such as lies.

These findings have practical implications for patients as well. Because bvFTD patients are unable to differentiate between sarcastic and sincere speech, and thus may interpret sarcastic sayings literally, caregivers should be cautioned against using such speech with these patients. In addition, the finding that bvFTD patients cannot recognize blatant lies due to a specific series of social-cognitive failures is consistent with clinical observations that these patients are frequently victimized in economic deception and scam attempts (McKhann et al., 2001). Greater vigilance by caregivers and doctors, as well as attention to this problem from public policymakers, may be required to better protect these vulnerable patients.

Social cognition in PSP has not been widely examined, though a recent study reported impaired emotion recognition in PSP patients (Ghosh et al., 2009). We found that PSP patients had poorer lie comprehension scores than NCs, though not to the same extent as patients with bvFTD. This difference did not remain significant after controlling for their ability to comprehend sincere interactions, thus their impairment on the test appeared to be primarily an effect of general difficulty with complex cognitive processing, rather than a specific deficit in comprehending ToM and insincere communication. Still, analysis of the specific components of ToM, controlling for performance on the control tasks, indicated that PSP patients had difficulty representing others' explicitly verbalized opinions, but not others' knowledge of facts that were visually presented to them. Correspondingly, they had poor ability to infer the speaker's intentions in the verbal cue condition but not in the visual cue condition. These results suggest PSP patients may have some mild but significant focal deficits in social cognition, which is consistent with research showing that they often demonstrate behavioral and personality changes, and executive dysfunction on testing, hypothesized to occur as a result of disconnection between subcortical structures to the PFC (Donker Kaat et al., 2007; Grafman et al., 1990).

Patients with AD, who do not show the loss of emotional salience network function seen in bvFTD (Seeley et al., 2007), were relatively unimpaired on this task. Although formally these patients showed deficits on some of the visual perspective taking and emotion reading tasks, these likely corresponded with general cognitive deficits, because these deficits did not remain significant when controlling for performance on the control tasks. This provides evidence consistent with previous literature suggesting that this group does not have profound deficits in social cognition and behavior, and may actually experience an accentuation of social sensitivity in the early stages of their disease due to paradoxical hyperactivation of the salience network (Zhou et al., 2010).

Historically, changes in socio-emotional behavior in neurodegenerative diseases have been assessed through primarily indirect and subjective methods. While informants' ratings of patients' behavior have yielded valuable data (Mega et al., 1996; Petry et al., 1988; Rankin et al., 2003, 2005), they are nevertheless limited by their dependence on informants of varying reliability. Development and validation of direct, objective measures of socio-emotional functioning in patients with neurodegenerative disease are becoming increasingly valuable as indicators of clinical status and predictors of real-life behavior in these conditions. Our finding that sensitivity to lies and sarcasm correlates with clinically important behavioral features suggests that this face-to-face test may be used as a more objective clinical proxy for measurement of real-life social dysfunction.

4.5. *Conclusions*

Because this study was designed to investigate social-cognitive processes in patients with neurodegenerative diseases, some of which are fairly rare, group sizes were necessarily small in some instances. While this was a clear limitation to the study, the observed effect sizes in this sample were very large, suggesting that the study design allowed adequate power to investigate these models. While no anatomic data was included in this study, directly examining the neural substrate of these deficits would be a valuable future investigation to further elucidate the neurologic and cognitive mechanisms involved in comprehension of lies and sarcasm.

In summary, patients with bvFTD demonstrate impaired comprehension of sarcastic and deceptive speech, due to faulty representation of others' opinions, intentions, and emotions. PSP patients evidence more isolated ToM deficits, and AD and cerebrovascular disease patients do not appear to have focal deficits in these aspects of social cognition, though performance on these complex tasks worsens with general cognitive decline. Even early in their disease course, bvFTD patients show a markedly decreased sensitivity to violations of communication rules in the form of lies. This is consistent with growing evidence that bvFTD specifically targets a neural network sensitive to salient social-emotional information such as the potential for a behavior to result in negative consequences, and that this network is less affected by other neurodegenerative diseases. Patients' performance on these objective tests of social cognition correlates highly with their real-life social behavior, including their tendency to behave empathically and to take others' perspective, suggesting such tests may be useful as objective measures of social functioning.

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