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By

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Abstract

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This study explores diagnostic differences and neural correlates of emotional language use among neurodegenerative disease groups and healthy controls. Using data from 10-minute dyadic conversations, this study examines how individuals with Alzheimer's disease (AD), behavioral variant frontotemporal dementia (bvFTD), semantic variant primary progressive aphasia (svPPA), non-fluent variant primary progressive aphasia (nfvPPA), and healthy controls differ in the use of emotional language. Text analysis was used to explore diagnostic group differences in emotional language use, and voxel-based morphometry (VBM) was used to explore the neural correlates of emotional language use. Findings suggest distinct patterns of emotional language use across groups, with patients with AD and svPPA using less total emotional language, patients with bvFTD showing increased negative emotional language use, and patients with svPPA showing increased positive emotional language. Neuroanatomical findings indicate that total emotional language use was significantly associated with diminished gray matter volume in the left superior temporal gyrus. Other areas that did not survive corrections for multiple comparisons included lateral temporal regions (right superior temporal gyrus, the bilateral middle temporal gyri, and the left inferior temporal gyrus) and left inferior frontal gyrus, regions associated with generating emotion states, emotion regulation, and semantic processing. This research underscores the potential value of emotional language as a diagnostic tool and provides insights into the underlying brain structures associated with emotional language in neurodegenerative diseases. The implications of these findings are important for both clinical diagnosis and caregiver interventions.

Introduction

What is emotional language?

Say what you mean and mean what you say. This age-old proverb asks us to contemplate if the words we use represent how we truly feel. The affective lexicon is comprised of a myriad of positively (e.g., joyful) and negatively (e.g., angry) valenced emotional language which helps articulate and communicate affective states (Balconi et al., 2015; Clore et al., 1987; Ortony et al., 1987). Numerous scientific studies of emotional language, including those examining positive and negative emotional word use, demonstrate that one's emotional language is correlated with many aspects of the subjective experience of emotion and that emotional language use varies depending on situational and contextual factors (Kahn et al., 2007).

A large body of literature suggests that positive emotional language use is associated with better physical health and well-being (Linton et al., 2021; Pennebaker & Graybeal, 2001; Vine et al., 2020) as well as better mood (Hernandez-Ramos et al., 2022). Greater negative emotional language use, however, is associated with worse mood (Ahmad & Farrell, 2014; Hernandez-Ramos et al., 2022) greater psychological distress, poorer physical health (Vine et al., 2020) and more complicated grief (Diminich & Bonanno, 2014).

Furthermore, situational and contextual factors affect the type of emotional language people use. Two studies found that participants used more positive emotional language when asked to write about positive experiences and more negative emotional language when asked to write about negative experiences (Herbert et al., 2019; Kahn et al., 2007). Other, more complex and difficult contextual factors such as trauma history also influence emotional language use. Individuals with a history of childhood sexual trauma used more negative emotional language than individuals without a history of sexual trauma when asked to write about their thoughts on sex and sexuality (Lorenz & Meston, 2012). Situational factors also affect positive and negative emotional language use. In difficult situations, such as providing care for an ill loved-one, caregivers tend to use more negative emotional language (Ascher et al., 2010; Gupta et al., 2022; Jones et al., 2016). Caregivers who had higher levels of family-conflict used more negative words and those with better family adjustment used more positive words (Robbins et al., 2013). Clinical contexts, such as psychotherapy settings, also have influence on emotional language use. One study found that, during therapy sessions, individuals with greater levels of psychological distress used more negative emotional language than those with lower levels of psychological distress (Shapira et al., 2021). Another study demonstrated that total emotional language use is more frequent during emotionally charged psychotherapy sessions (McCarthy et al., 2017).

Despite the body of research that demonstrates a strong relation between emotional language use and experience as well as context, one study did not find an association between emotional language and participants' subjective ratings of happiness (Sun et al., 2020). This study of college undergraduates used an audio recording device to collect 30-second oral language samples every 10 minutes throughout the day. One limitation, however, was that participants were given the option to erase any recordings they did not want researchers to hear. Thus, it is possible that emotional content was removed, making it difficult to correlate the use of emotional language with subjective emotional experience. Broadly, a large body of literature exists that demonstrates linkages between emotional language and individual experience of emotion. Clearly, research examining emotional language use can provide a unique window into an individual's emotional experience and context.

Methodological considerations for eliciting emotional language

One challenge in evaluating studies of emotional language is that the methodology used to elicit emotional language has varied broadly by such factors as oral or written language, the length of the emotional language sample, and by the paradigm used to evoke the language. Given the diversity in methods to elicit and measure emotional language, there are several important methodological factors to consider.

Written emotional language

A significant portion of the research on emotional language has focused on written words. These writing samples include daily diaries (Pennebaker & Chung, 2011; Pennebaker & Seagal, 1999), essays (Lin et al., 2016; Lorenz & Meston, 2012; Spera et al., 1994), stream of consciousness writing pieces (Vine et al., 2020), blog posts, historical poems (Pennebaker & Stone, 2003) and speeches (Fernández-Cabana et al., 2013; Lester & Mcswain, 2011), as well as suicide notes (Handelman & Lester, 2007). Among these studies, the methods to evoke written language has varied from participants being asked to write about specific topics in a laboratory setting to more observational methods, such as retrospectively collecting poems and letters for analysis.

With the dawn of rapid and brief technological communication, analysis of short writing samples such as text messages (Slatcher et al., 2008), Tweets (Johnsen et al., 2019), social media messages (Brown et al., 2019), Facebook posts (Marengo et al., 2019; Seabrook et al., 2018), and discussion board posts (McDonnell et al., 2020; Pan et al., 2020) have become an increasingly common area of study. These brief excerpts are often evoked naturalistically and studied retrospectively. Several relevant studies have focused on emotional language use as a predictor of mental illness severity and found a significant relation between negative emotional language use and greater symptom severity (Brown et al., 2019; Marengo et al., 2019; Pan et al., 2020). However, one limitation of shorter samples is that emotional language may not be used at all or may be limited in frequency given the brevity of the text.

Spoken emotional language

A smaller body of literature has examined spoken emotional language. It is important to note that written versus spoken contexts are likely to differ in how emotional language is used. Research demonstrates that spoken language often involves more description and greater elaboration than written language (Drieman, 1962). Spoken language is also produced more rapidly and more spontaneously in comparison to written language (Chafe & Tannen, 1987). Given that spoken language is often less planned than written text, emotional language use in spoken language may be more spontaneous and less filtered.

Despite the notable differences in written versus spoken language, relatively few studies have examined emotional language in spoken language. One reason is that examining spoken emotional language is arduous—particularly when the spoken language samples are lengthy. Spoken conversations must be audio recorded and carefully transcribed (Chafe & Tannen, 1987). This process involves the verbatim transcribing of audio recorded content; planning and applying standards for consistency regarding speech disfluencies such as pauses in speech, ums, and other verbal hesitations; as well as chuckles and laughter (Mergenthaler & Stinson, 1992). The level of detail required to adequately prepare transcripts is time consuming and tedious, making it challenging and resource intensive to conduct research using spoken language.

The range of paradigms employed to examine emotional language in spoken samples also varies widely in length and approach across studies. Regarding paradigms, several studies use semi-structured interviews occurring between a trained examiner and a study participant in a laboratory setting (Ahmad & Farrell, 2014; Borelli et al., 2021; Gupta et al., 2022). A disadvantage to this approach is that these studies occur in a laboratory setting, making it difficult to interpret their ecological validity. Fewer studies have examined emotional language use in naturalistic settings. In a naturalistic, non-structured conversation, individuals are likely to respond to the thoughts, cues, and comments of their conversation partner in an ecologically valid way, particularly when they have an existing relationship with the conversation partner. Unlike written text or a formal interview setting, naturalistic conversations involve an exchange of information between participants that may involve a range of complex emotional interactions. For example, a small number of studies have examined emotional language use in psychotherapy sessions, sampling conversations between therapists and patients (Hernandez-Ramos et al., 2022; McCarthy et al., 2017; Shapira et al., 2021). Other studies have examined emotional language use between partners with an existing relationship (e.g., between family members or familial caregiver-patient dyads) (Ascher et al., 2010; Gupta et al., 2022; Robbins et al., 2013). An important advantage of these naturalistic paradigms is that they may be more ecologically valid because individuals may speak more naturally and freely with a loved one or someone with whom they have an existing social or familial relationship. Regardless of the study paradigm used to elicit emotional language use, a majority of studies do not describe the length of the interaction or length of the transcript increasing the difficulty of comparing findings from spoken emotional language.

Measuring and analyzing language use: an evolution of qualitative and quantitative approaches

Qualitative text analysis

In the social psychology and linguistics literatures, one of the earliest methods that arose for analyzing emotional language was discourse analysis. Discourse analysis has been loosely defined over the past 70 years since its introduction, although it is generally described as a qualitative method used to assign meaning to conversations based on the interpretation of language (Harris, 1952). The aim of discourse analysis is to reveal socio-psychological characteristics of an individual who is being analyzed based on their word choice. In discourse analysis, the choice of words used by the study participant is thought to have underlying meaning that can be interpreted by the reader.

Beginning in the 1990s, discourse analysis received a large amount of criticism from the psychological community. Widdowson (1995) described it as inherently subjective, biased, and lacking validity and reliability. Antaki et al. (2008)argued that researchers are often biased by their own moral, political and personal stance. Furthermore, because discourse analysis involves interpretation, some have argued that it is not a true form of analysis, making it particularly difficult to have reliable and valid findings (Stubbs, 1997; Widdowson, 1995).

Given the heterogeneous nature of the discourse analysis approach, other qualitative methods have grown in popularity, such as thematic analysis. Thematic analysis involves examining specific quotes used by the participant with the aim of identifying common themes (Braun & Clarke, 2006). Despite the emphasis placed on using more direct and substantial evidence, such as quotations to support selected themes, there is still a great deal of diversity in methodological approaches to thematic analysis.

One of the most structured approaches to thematic analysis is grounded theory. This approach involves several specific steps aimed at providing clear guidelines to the analysis process: 1) identifying general patterns and themes, 2) refining codes into definitive themes, and 3) describing the central phenomenon from which codes are unified (Gooden & Winefield, 2007).

Despite a more structured approach, there are still several limitations to thematic analysis. Javadi et al. (2016) argued that data collection methods can also bias thematic analysis results, particularly when questions asked, or interviewer guidance emerges as aspects of the theme. There processes can result in potential interviewer bias, such that authors may introduce questions or offer guidance that is later identified as a theme (Javadi & Zarea, 2016). Thematic analysis can also lack reliability and can be inherently biased because it involves the interpretation of others experiences through the subjective lens of the researcher (Javadi & Zarea, 2016). Holloway & Todres et al., 2003 argue that identified themes often lack coherence and consistency.

Additionally, thematic analysis is resource intensive. It often involves reading and re-reading texts several times to identify themes as well specific quotes to support those themes. This process requires a significant amount of time and research staff to conduct. As described above, a minimum of two analysts is recommended; however, larger teams of coders can be helpful for reliability. Given the rigor involved in implementing this methodology, thematic analysis is often conducted on very small sample sizes (Braun & Clarke, 2006).

More recently, researchers have attempted to delineate more specific guidelines for thematic analysis methods in order to improve study reliability and reproducibility (Nowell et al., 2017). These guidelines include setting standards, such as requiring a minimum of two coders to analyze transcripts —and using more standardized data collection approaches, such as a codebook approach, in which researchers code for themes hypothesized a priori (Braun & Clarke, 2021). Standards are also evolving such that authors are now expected to explain how specific decisions about themes are made and to provide quotations as evidence for each decision (Nowell et al., 2017). Another important tenet of proposed thematic analysis principles is a focus on researchers' identifying and acknowledging their own biases and perceptions (Gavin, 2008). Despite this recent aim to standardize thematic analysis practices, there is still significant heterogeneity in the academic literature and no clear agreement among the community on standards (Braun & Clarke, 2006).

Quantitative text analysis

Quantitative, computerized text analysis was introduced to reduce bias and examine emotional language use more efficiently (Tausczik & Pennebaker, 2009). Computerized text analysis, often more simply referred to as text analysis, uses a word count approach in which words are pre-categorized and organized into dictionaries with supraordinate categories (Mehl et al., 2006). Dictionaries are often formed prior to analysis, using judges' ratings on whether or not each word belongs in a pre-determined category. Computerized software has been designed to reference a pre-designed dictionary and categorize words appearing in text samples (Levenson, 1992; Pennebaker & Chung, 2011).

Methodological Considerations. Text analysis methods are highly reliable with studies demonstrating that text analysis methods are comparable to outcomes from expert coders (Alpers et al., 2005; Connelly et al., 2020) and demonstrates high interrater reliability (Bright & O' Connor, 2007). Beyond reliability, there are several other advantages to using text analysis methods. Computerized methods are much faster than using individual coders, making it a more time efficient and cost-effective choice. Furthermore, these methods make analyzing large datasets of text much more feasible (Bright & O' Connor, 2007). Importantly, computerized methods decrease bias, given that the interpretative aspect is greatly reduced.

One of the most commonly used tools for text analysis of emotional language use is the Linguistic Inquiry Word Count (LIWC) program (Pennebaker & Francis, 1996). LIWC has been used as a method of text analysis in hundreds of academic papers, spanning the fields of psychology, sociology, and linguistics, among others. Like other text analysis programs, LIWC uses a word count approach to examine word frequencies and calculates total words spoken (Kahn et al., 2007; Tausczik & Pennebaker, 2009). The software includes several preset dictionaries that can be used to examine a range of types of language, including emotional language.

Despite its nearly ubiquitous use for computerized text analysis software in the field of psychology, there are some limitations to this approach. One challenge is that LIWC is a proprietary, paid software, which limits researchers' ability to access and use this analysis method. Additionally, given that it is proprietary, it does not offer researchers the ability to modify aspects of the analysis, such as how word frequencies are calculated (Pennebaker Conglomerates Inc., n.d.).

Another significant limitation of LIWC is that it does not allow the researcher to take word context into account (Pennebaker Conglomerates Inc., n.d.). As many researchers have identified, word meaning can be notably altered by its context (Seider et al., 2009). For instance, the term "blue" has a markedly different meaning depending on whether an individual states, “I am feeling blue today” or “the sky is blue.” The former statement has obvious emotional significance, whereas the latter does not. Using the LIWC software and the emotion word dictionary, both instances would be categorized into the “sadness,” category and therefore included in the overall sadness word count. Given that there are a multitude of words that have both emotional and non-emotional meanings (Bright & O’ Connor, 2007), lacking the ability to contextualize words, may confound overall word frequency counts. Despite this potentially serious problem, to the best of our knowledge, no study has examined whether context coding improves reliability and validity of text analysis. Further research is needed to determine if this step should be taken when conducting text analysis research.

Another software, Oedipus Text, written by the principal investigator of my lab, Robert W. Levenson (Levenson, 1992) was designed to address this issue of context. Like other word count programs, Oedipus Text leverages a word count approach to calculate word frequencies using dictionaries composed of lexical categories. This software is free and flexible as it offers the opportunity for researchers to design their own dictionaries. Most importantly, this software offers an option to improve the accuracy of word classification by displaying the word in the context and allowing the researcher to choose if it should or should not be included in a category’s overall word count (Seider et al., 2009). Although this approach may improve accuracy, it is arduous, time-consuming, and requires teams of researchers to establish reliability and to conduct the context coding. Although there has been relatively little research examining context coding, reliability of this secondary context coding has been shown to be very high (Connelly et al., 2020; Seider et al., 2009). Additionally, one recent study demonstrated the value of context coding pronouns in comparison to non-context coded samples of pronouns (Heath et al., 2023). Future studies are needed to empirically determine the benefits of context coding emotional language, but there is a much greater likelihood that results yielded will be accurate.

Empirical studies of emotional language

Examining social and emotional language has been a particular area of focus of text analysis research. The use of pronouns (e.g., “we-ness” vs. “I” or” you-ness”) has been shown to serve as proxy of social connectedness, with greater use of “we-ness” being linked with greater marital satisfaction and greater well-being in couples (Connelly et al., 2020; Seider et al., 2009). The study of emotional language use has also been a particular area of focus of text analysis with an emphasis on examining the proportion of words used in different emotional domains such as the usage of positive emotion words, negative emotion words, and total emotion words (Levenson et al., 2008). A number of papers have examined total emotion word usage (Ascher et al., 2010; Gruber & Kring, 2008; Johnsen et al., 2019; Kahn et al., 2007). However, examining emotional valence of word use in the context of positively and negatively valenced words is one of the most common ways to examine emotional language (Ahmad & Farrell, 2014; Ascher et al., 2010; Badr et al., 2016; Borelli et al., 2021; Brown et al., 2019; Carlier et al., 2022; Herbert et al., 2019; Hernandez-Ramos et al., 2022; Hirschmüller & Egloff, 2016; Lin et al., 2016). Some studies have examined the use of discrete emotion words such as happiness words, sadness words, anxiety-related words, among others (Alpers et al., 2005; Diminich & Bonanno, 2014; Gupta et al., 2022; Johnsen et al., 2019; Kahn et al., 2007; Robbins et al., 2013). Using a dyadic, naturalistic conversation between patients with dementia and their caregivers, Ascher et al. (2010) demonstrated the low frequency of discrete emotion word use. Given the relatively low base rate of the use of specific discrete emotion words, many studies collapse these discrete emotion word categories and analyze emotion words by emotional valence or total emotion word count.

The neural substrates of emotional language

Despite the range of studies on emotional language, few studies have examined the neural substrates underlying use of emotional language. Although numerous studies have explored speech production and emotional functioning, few have specifically investigated the neural substrates of emotional language use. Understanding the neural correlates of emotional language provides insight into how the brain processes complex emotional processes, such as generating and producing verbal expressions of emotion.

Examining the neural substrates underlying the production of emotional language is complex. Using emotional language in conversations may involve many aspects of emotional reactivity and processing, including recognizing and labeling another's emotional state, reacting to the conversation with verbal expressions of emotion, and even using emotional language to regulate an internal emotional state.

Neural correlates of language and emotion

Although very few studies have examined the neural correlates of emotional language use, a great deal of research has examined the neural correlates of language production and comprehension, as well as emotional functioning. While studies have shown the importance of the inferior frontal gyrus and anterior insula in speech production, recent work suggests a far more broadly distributed network of areas that support language, including the anterior and middle regions of the left temporal lobe and the angular gyrus (Dronkers et al., 2017; Dronkers & Ivanova, 2023). Wernicke's area and the superior temporal gyrus, more broadly, are regions that are critical for speech perception, thus also supporting language comprehension (Poeppel et al., 2008; Scott et al., 2000). In terms of the neural correlates of emotion, limbic regions such as the amygdala, as well as regions of the prefrontal cortex, have been shown to play an important role in the generation of emotion states (Dixon et al., 2017; Lindquist et al., 2012), and regions such as the dorsolateral prefrontal cortex have been implicated in emotion regulation (Ochsner & Gross, 2005; Silvers et al., 2012).

Methodological considerations: functional neuroimaging approaches

A majority of studies examining the neural correlates of emotional language have involved measuring neural activity using fMRI during emotion word reading or emotion labeling tasks. Ritter et al. (2016) found that participants who were shown negative affect words had greater activation in the bilateral anterior cingulate cortex and the dorsolateral prefrontal cortex as compared to non-affective words. Another study found that positive words were associated with more left-sided dorsolateral prefrontal cortex activation than right (Herrington et al., 2005). An emotion labeling study, in which participants viewed emotional faces and matched an emotion word with each emotional face, found increased activity within the amygdala and ventral anterior insula (Satpute et al., 2016). One fMRI study asked participants to read several emotionally evocative stories and were asked to open-endedly describe how the stories made them feel. The authors found individuals who used more affective language in contrast to non-affective language had greater activation in the bilateral insula and anterior cingulate (Saxbe et al., 2013), regions associated experiencing and feeling emotions (Craig, 2009; Harrison et al., 2010) and emotional awareness (Etkin et al., 2011; Smith et al., 2019). Although these studies provide some insight into the brain regions that may be involved in the processing of emotional language, the methods are diverse, and they do not elucidate the neural correlates underlying emotional language production.

Despite some progress in identifying the functional neural anatomy associated with emotional language, task-based functional neuroimaging studies in healthy individuals have several limitations. First, it is difficult to elicit real-world emotional language use in an MRI scanner. Additionally, neuroimaging studies often identify neural regions that are broadly engaged during fMRI tasks, and these regions may not be specific to emotional language use.

Methodological considerations: neurodegenerative disease models

Lesion studies, including neurodegenerative disease models, can provide unique information about specific neural structures related to the emotional behavior in question (Hillis, 2014). Neurodegenerative diseases, such as frontotemporal dementia (FTD), provide a useful model for studying the neural correlates of emotional language use because a number of brain regions that are involved in both language production and emotion are affected by FTD; therefore, atrophy in these regions can result in both language and/or emotional deficits.

FTD represents a family of neurodegenerative diseases that includes behavioral variant frontotemporal dementia (bvFTD), semantic variant frontotemporal dementia (svPPA), and non-fluent variant primary progressive aphasia (nfvPPA) (Gorno-Tempini et al., 2011), which involves atrophy in key regions of the frontal and temporal regions of the brain. Regarding language functioning, individuals with svPPA and nfvPPA develop dramatic language deficits in contrast to those with bvFTD. Individuals with svPPA are characterized by deficits in semantic knowledge and object naming, whereas individuals with nfvPPA develop difficulties with speech production (Gorno-Tempini et al., 2011). Less is known about emotional language use in FTD, though several studies have demonstrated severe emotional impairments (Eckart et al., 2012; Rankin et al., 2006; Rosen et al., 2006a). Individuals with bvFTD often become apathetic (Barsuglia et al., 2014), are irritable (Peters et al., 2006; Saxon et al., 2017), have diminished empathic responding (Rankin et al., 2006; Shdo et al., 2016), and often express negative emotions towards others (Chiong et al., 2014; Desmarais et al., 2018; Rankin et al., 2011). Individuals with svPPA have a more mixed emotional profile, and some evidence indicates that they develop greater positive emotional reactivity (Shdo et al., 2022a; Sturm et al., 2015a). Less is known about the emotional profile of individuals with nfvPPA. Another commonly known neurodegenerative disease, Alzheimer's Disease (AD), primarily influences memory, but it can also affect some emotional (Cadieux & Greve, 1997) and language processes (Taler & Phillips, 2008).

Voxel-based morphometry (VBM) is a powerful method for exploring brain-behavior relationships in neurodegenerative disease lesion models. This method allows for precise mapping of brain regions affected by atrophy associated with degenerative processes and their relation to cognitive and emotional functioning (Ashburner & Friston, 2000, 2001). Therefore, it offers a well-suited model for examining the neural correlates of emotional language use. Using a broad sample of neurodegenerative diseases in a VBM study (such as AD, bvFTD, nfvPPA, and svPPA) as well as healthy controls helps capture variance in neural atrophy patterns and can also capture variance in emotional language use given the range of impairment across patient groups.

Beyond its value for studying the neural substrates of emotional language, understanding these neural correlates in neurodegenerative models can elucidate whether changes in emotional language may be related to a disease process, providing insights that can help families better comprehend how degenerative diseases can affect their loved ones' communication.

The Present Study

In the present study, I examined diagnostic group differences in emotional language use were examined in a diagnostically diverse sample of patients with AD, bvFTD, svPPA, nfvPPA and healthy controls. Included as an archival data set, consisting of 10-minute dyadic conversations between a patient with a neurodegenerative disease and their familial caregiver, during which they were asked to discuss an area of conflict. Conversations between 258 dyads were conducted in laboratory research sessions between 2003 and 2019 and were recorded, transcribed, and prepared for text analysis procedures. This study examined group differences and neural correlates of total, negative, and positive emotional language use among individuals with AD, bvFTD, nfvPPA, svPPA, and healthy controls.

Methods

Participants

Participants included 258 caregiver-patient and control-control dyads (AD = 87, bvFTD = 71, svPPA = 43, nfvPPA = 28, and healthy controls = 29) recruited by the Memory and Aging Center at the University of California, San Francisco (UCSF) between 2002 and 2019. Patients were recruited through self-referral, clinician referral, or referral through Alzheimer's Disease Research Centers as part of a larger Program Project Grant (PPG) study at UCSF and all patients received clinical care from providers at the Memory and Aging Center. At UCSF, participants received comprehensive diagnostic testing, including neuropsychological assessment, neurological examination, and structural magnetic resonance imaging (MRI). Testing was administered by a multidisciplinary team of neurologists, psychiatrists, psychologists, and nurses. After thorough review of the above test measures, patient diagnoses were determined by a team of neurologists. All patients met research diagnostic criteria for either AD (McKhann et al., 2011), bvFTD (Rascovsky et al., 2011), svPPA (Gorno-Tempini et al., 2011), or nfvPPA (Gorno-Tempini et al., 2011). Disease severity was measured by the Clinical Dementia Rating Scale (CDR) and the CDR sum of boxes (CDR-Boxscore). Global cognitive impairment was measured by the Mini Mental State Exam (MMSE). The familial caregiver (spouse or partner) of each patient was also recruited and participated in the laboratory tasks (see below).

Healthy control participants were age matched male-female couples recruited from the Bay Area community through advertisements and word of mouth. At the University of California, Berkeley (UCB), all controls were screened by trained clinical psychology graduate students with the CDR and the MMSE. Healthy control participants were included and determined to be free of global cognitive and neurological impairments if they scored 0 on the CDR and 30 on the MMSE.

Procedure

Participants visited the Berkeley Psychophysiology Lab between 2002 and 2019 and completed a battery of tasks to assess emotional functioning, including a social interaction laboratory task, the Conflict Conversation Task. Participant dyads were videotaped throughout all experimental tasks using a remote-controlled, high-resolution video camera that was partially concealed from view. Participants were provided with a lavaliere microphone clipped to their clothing that created a high-quality audio recording of the sessions. Sensors were attached to participants for physiological monitoring (e.g., heart rate, skin conductance). These physiological data, however, were not used for the present study. The Committee for the Protection of Human Subjects at the UCB approved all procedures.

Social Interaction Laboratory Task: Conflict Conversation

Patient and caregiver couples were seated in chairs facing each other and instructed to discuss a topic of ongoing disagreement in their relationship (Levenson & Gottman, 1983). Participants chose a topic of conversation in advance with guidance from the study facilitator. If participants were unable to choose a topic, the facilitator would provide a list of possible topics for participants to discuss (e.g., religion, money, communication, in-law, sex, friends, etc.) Each conversation lasted for 10 minutes. Video and audio signals were routed to a video capture computer that created a digital recording of the session. A backup recording was also made using an SD card recorder.

Transcription

Each video recorded conversation was converted to an audio only, lossless .wav file. Using these files, verbatim transcripts of the 10-minute conversations were prepared by either student Research Assistants at UCB or a HIPAA compliant, commercial transcription service, TranscribeMe. UCB transcribers used a standard USB foot pedal to assist with handsfree pausing and headphones. All text was transcribed using standard transcription procedures (Mergenthaler & Stinson, 1992). Patient and caregiver speech was separated and denoted by a "C:" for caregiver or "P:" for patient. Timestamps were notated in brackets next to each patient or caregiver speech segment (Figure 1). All non-language utterances, such as ums, sighs, and laughter, were denoted in double parentheses so that they could subsequently be excluded from the analysis.

Text analysis of emotional language

All transcripts were processed using Oedipus Text (see above) to identify emotion words spoken by both patient and caregiver (Levenson, 1992; Seider et al., 2009). An emotion word dictionary was developed using the Ortony et al. (1987) criteria for emotion states, exclusively incorporating words that denote clear emotional states while omitting emotion-related words that do not directly refer to emotional states per se (e.g., "baffled", "abandoned"). The dictionary contained 2,162 emotion words comprising approximately 712-word roots along with all possible variations (e.g., love, loves, loving), each of which was assigned to a corresponding discrete emotion category. A total of 18 subordinate discrete emotion categories were used. The discrete emotion categories (with example words) were as follows: *Amusement (e.g., entertain, funny, hilarious), Awe (e.g., admire, astonish, wonder), Content/Relaxed (e.g., calm, comfortable, pleasant), Excitement/Aroused (e.g., ecstatic, enthusiastic, joy) , Love/Affection (e.g., loving, nurturing, romantic), Pride (e.g., confident, proud, smug), Interest/Preference (e.g., curious, interesting, intrigued), Surprise (e.g., astonished, puzzled, stunned), Aggressive (e.g., confronted, fight, violate), Anger (e.g., conflict, frustrated, huffy), Contempt (e.g., condescending, degrading, disdain), Disgust (e.g., gross, revolting, stench), Embarrassment (e.g., blush, shy, timid), Fear (e.g., frightened, horrified, scary), Guilt (e.g., confess, guilty, punished), Jealousy/Envy (e.g., covet, envy, jealousy), Sadness/Grief (e.g., cry, depressed, devastating),* and *Shame (e.g., disgrace, humiliate, intimidated).* Additional information about the construction of the dictionary can be found in Ascher et al. (2010).

The program identified each word in the transcript that was in the emotion word dictionary and displayed the corresponding discrete emotional language category. After making this initial classification, the software depicted the emotion word in context (the preceding sentence, the sentence it occurred in, and the following sentence). A trained coder, blind to diagnostic grouping, determined 1) whether the word was used in an emotional way and 2) if the word was assigned to the appropriate emotion category. This context-coding was done to avoid counting non-emotional homonyms (e.g., "what do you mean,") and phrases (e.g., "down the street") and to ensure the word was assigned to the appropriate emotion category (e.g., if the word "love," were identified it would automatically be classified as an excitement-aroused emotion word; however, if the phrase was "I love tea," then the coder would recategorize the word "love," to the interest-preference category). Additionally, if the coder determined that the word was not used in an emotional way, the word was classified into a "No Code" category. Furthermore, if the word was deemed to be used emotionally but did not fit the initially assigned category, the coder was able to reassign it to any of the other 17 discrete emotion categories, ensuring the appropriate emotional context was selected. Each emotional language category also had an additional category of its negation. For example, a participant might say, "I am not frustrated." In this instance, the emotion word "frustrated" would not fall into the "Anger" category, but rather "Anger (Negated)" category. Negated words were not included in these analyses. To assess reliability, 20% of responses were coded by at least two trained coders.

Figure 1 provides an example of a segment of a patient-caregiver conflict conversation transcript. This figure depicts the word “jealous,” which Oedipus Text would classify in “Jealousy-Envy,” category. Figure 2 shows the Oedipus Text user interface when the word “jealous,” appears in the transcript. Figure 1 also depicts the word “close,” which, without intervention, Oedipus Text would classify into the “Love-Affection category.” However, in this context, “close” is referring to physical proximity and not to a “close relationship,” or “feeling close,” to someone. Given the non-emotional context of this word, the trained coder would select the “no code,” button to remove this from the “Love-Affection,” category. The “no code,” button can be seen in Figure 2.

Emotional language data reduction

Given previous research demonstrating the low base rate of discrete emotional language (Ascher et al., 2010), I aggregated variables into supraordinate categories for primary analyses. Aggregate variables included the following: positive emotional language (amusement, awe, content/relaxed, excitement/aroused, love/affection, pride, interest/preference, surprise), negative emotional language (aggressive, anger, contempt, disgust, embarrassment, fear, guilt, jealousy/envy, sadness/grief, shame), and total emotional language (all positive and negative emotion words). For behavioral data analysis, total emotional language was expressed as a percentage of the total words used. Positive and negative emotional language was expressed as a percentage of the total emotion words used. Thus, for each participant, the following variables were calculated and used in behavioral analyses:

1) total emotional language = total emotion words used / total words used (%)
2) negative emotional language = negative words used / total emotion words used (%)
3) positive emotional language = positive words used / total emotion words used (%)

Discrete positive and discrete negative emotional language use was examined in exploratory analyses. Given the noted low base rates of the discrete emotion words, only emotion word categories with >15-word use instances across the entire sample were included in these exploratory analyses. Therefore, discrete negative emotional language categories examined included aggressive, angry, contempt, disgust, fear guilt and sadness/grief and discrete positive emotional language categories examined included amusement, content-relaxed, excitement-aroused, interest-preference, and love-affection. Discrete emotional language use was also calculated as a percentage (e.g., aggressive word use = aggressive words used/ total emotion words used %).

Additional measures

All additional measures were collected at the UCSF Memory and Aging Center as part of the comprehensive battery described in the procedures section above.

Demographics. Patient age, sex, and education (highest completed) were collected.

Clinical Dementia Rating Scale (CDR). The CDR involves a semi-structured interview, completed with patients and caregivers. The CDR measures cognitive and functional impairment across six domains, including: (a) memory, (b) orientation, (c) judgment and problem solving, (d) community affairs, (e) home and hobbies, and (e) personal care. For each domain, the respondent must select a response on a five-point Likert scale with scores ranging from 0 to 4 (0 = none, 0.5 = very mild, 1 = mild, 2 = moderate, and 3 = severe). The CDR-sum of boxes (Box) score is obtained by summing each of the domain box scores, with scores ranging from 0 to 18. The CDR is a reliable and well validated measure of dementia severity (Burke et al., 1988; Morris, 1997).

Mini Mental State Exam (MMSE). The MMSE is a reliable and valid tool for measuring of cognitive impairment (Folstein et al., 1975; Tombaugh & McIntyre, 1992). Cognitive functioning is examined across several domains: 1) memory, 2) orientation, 3) attention, 4) language, and 5) visuospatial construction. The measure includes 30 items, each consisting of 1 point. A total score is provided ranging from 0-30, with lower scores indicating greater cognitive impairment. Scores between 25-30 indicate normal cognition, 21-24 indicate mild dementia, 10-20 moderate dementia, 9 points or lower is severe dementia.

Aims & Hypotheses

Aim 1. To identify diagnostic group differences in emotional language use.
Question 1a: *Do patients with bvFTD use less emotional language than patients with AD, nfvPPA, svPPA, and healthy controls?*
Hypothesis 1a**.** Of the total words spoken, patients with bvFTD will use less total emotional language (regardless of emotional valence) than patients with AD, nfvPPA, svPPA, and healthy controls.

Rationale. Patients with bvFTD develop severe deficits in emotional functioning. Research has shown that these patients become apathetic (Barsuglia et al., 2014) and lose empathy toward others (Rankin et al., 2006; Shdo et al., 2016). Diminished use of emotional language has been demonstrated in other clinical populations that demonstrate apathy and low levels of empathy (e.g., autism spectrum disorder; Lartseva et al., 2015). Therefore, patients with bvFTD will use less emotional language than other neurodegenerative disease groups and healthy controls.

Question 1b: *Do patients with bvFTD use more negative emotional language than patients with AD, nfvPPA, svPPA, and healthy controls?*
Hypothesis 1b**.** Of the total emotion words spoken, patients with bvFTD will use a greater proportion of negative emotion words than patients with AD, svPPA, nfvPPA, and healthy controls.

*Rationale***.** Research has demonstrated that patients with bvFTD are often irritable (Peters et al., 2006; Saxon et al., 2017) and engage in socially inappropriate behaviors, such as making insulting remarks to others (Chiong et al., 2014; Desmarais et al., 2018; Rankin et al., 2011). This negative emotional behavior may be expressed through greater use of negative emotional language in contrast to other neurodegenerative disease groups and healthy controls.

Question 1c: *Do patients with svPPA use more positive emotional language than patients with AD, bvFTD, nfvPPA, and healthy controls?*
Hypothesis 1c**.** Of the total emotion words spoken, patients with svPPA will use a greater proportion of positive emotion words than patients with AD, bvFTD, nfvPPA, and healthy controls.

*Rationale***.** Recent studies demonstrate that individuals with svPPA have heightened positive emotional experience and behavior (Shdo et al., 2022a; Sturm et al., 2015a) in contrast to healthy controls or other neurodegenerative disease groups. Therefore, individuals with svPPA may also express heightened positive emotion in their use of language, such that they will use more positive emotional language than other neurodegenerative disease groups.

Aim 2. To identify the neural correlates of emotional language in neurodegenerative disease.
Question 2a: Which brain regions show significant atrophy in relation to lower total emotional language use?
Hypothesis 2a**.** Less use of emotional language will be associated with bilateral atrophy in the amygdala.

Rationale. Significant research demonstrates the role of the bilateral amygdala in the subjective experience of emotion, regardless of valence (Anderson & Phelps, 2002). Additionally, fMRI studies of healthy individuals show that the amygdala is linked to processing of emotion words regardless of valence (Hamann & Mao, 2002). Therefore, the amygdala may play an important role in the overall use of emotional language.

Question 2b: Which brain regions show significant atrophy in relation to negative emotional language use?
Hypothesis 2b**.** Greater negative emotional language use will be associated with atrophy in the ventromedial prefrontal cortex (vmPFC).

*Rationale***.** Diminished gray matter volume in the vmPFC, has been associated with impulsive behavior, including increased expression of anger and frustration (Blair, 2016; Chester et al., 2017). Therefore, negative emotion, expressed through negative emotional language use, may also be associated with atrophy in this region.

Question 2c: Which brain regions show significant atrophy in relation to positive emotional language use?
Hypothesis 2c***.*** Greater use of positive emotional language will be associated with atrophy in left temporal regions.

*Rationale***.** Recent research demonstrates that neurodegenerative disease patients with greater atrophy in left anterior temporal structures and the superior temporal gyrus (STG), report greater positive emotional reactivity, including heightened positive emotional experience and increased smiling behavior (Shdo et al., 2022a). Therefore, positive emotion, expressed through positive emotional language, may also be associated with atrophy in these left temporal regions.

Statistical Analyses

Preliminary analyses

All statistical analyses were completed in R. Prior to examining group differences all data were screened for normality, including examining skewness and kurtosis. Normality screenings of the dependent variables revealed that the distribution of positive emotional language use and negative emotional language use was non-normal. Of the total emotion words spoken, a high frequency of participants used 100% positive words and 0% negative emotion words. Given the censored nature of this data (skewed data with a high frequency of 1's or 0's), Tobit regression models were selected to examine group differences in negative emotional language use and positive emotional language use, as they are well-suited to accommodate censored data effectively (Austin et al., n.d.; Sigelman & Zeng, 2000). Normality screenings of the discrete negative emotional language categories and discrete positive emotional language categories were also conducted, revealing skewed but not censored data. Thus, log transformations were applied to correct for non-normality.

I also examined diagnostic group differences in key potential confounding variables (e.g., age, gender, MMSE, and CDR-Boxscore). Diagnostic group differences in age, MMSE, CDR-Box, and total emotional language were compared using ANOVAs. Diagnostic group differences in gender were examined using a chi-squared test. Potential confounding variables that significantly differed across diagnostic groups were considered for inclusion in later analysis as covariates. Given that multicollinearity among confounding variables can distort the effects of individual variables, correlations among potential confounders were assessed using Pearson's correlations. When significant correlations were detected ($p < 0.05$), one of the correlated variables was excluded to mitigate the effects of multicollinearity.

Analyses of diagnostic group differences

ANOVAs with Tukey post-hoc comparisons were used to examine diagnostic group differences in total emotional language use. When significant effects were found, I assessed the robustness of these effects using an additional follow-up ANOVA, adjusting for potential confounding variables that were found to have statistically significant differences across groups (e.g., age and CDR-Boxscore). To account for multiple comparisons, Benjamini–Yekutieli corrections were used (Benjamini & Yekutieli, 2001). Tobit regression models were used to examine diagnostic group differences in positive emotional language use and negative emotional language use. Given that the independent variable, diagnosis, was categorical, diagnostic groups were dummy coded for analysis. Pairwise comparisons were conducted using a series of Tobit models, with each diagnostic category sequentially set as the reference. Exploratory analyses were conducted using ANOVAs with Tukey post-hoc comparisons to examine group differences in discrete negative and discrete positive emotional language categories.

Neuroimaging Data Analysis

Imaging Acquisition and Image Preprocessing

Study participants (n = 222) underwent a 1.5-T, 3-T, or 4T research quality structural MRI at the UCSF Memory and Aging Center as part of the comprehensive diagnostic battery described in the participants section above. Scans were conducted within 90-120 days of completing the conflict conversation task. All patients had scans within 90 days, although healthy controls may have had scans up to 120 days before or after completing the conflict conversation task. Six participants did not have scans within 90-120 days of the testing and thus were not included in the analysis.

One hundred forty structural MRIs were acquired on a 3.0 Tesla Siemens (Siemens, Iselin, NJ) TIM Trio scanner equipped with a 12-channel head coil located at the UCSF, Neuroscience Imaging Center using volumetric MPRAGE (160 sagittal slices; slice thickness, 1.0 mm; FOV, 256 × 230 mm2 ; matrix, 256 × 230; voxel size, 1.0 × 1.0 × 1.0 mm3 TR, 2,300 ms; TE, 2.98 ms; flip angle, 9°); 23 structural MRIs were acquired on a 4T Bruker MedSpec system with an 8-channel head coil controlled by a Siemens Trio console, using an MPRAGE sequence (192 sagittal slices; slice thickness, 1 mm; FOV, 256 × 224 mm2 ; matrix, 256 × 224; voxel size, 1.0 × 1.0 × 1.0 mm3 ; TR, 2,840 ms; TE, 3 ms; flip angle, 7°); 10 structural MRIs were acquired on a 1.5T Siemens Magnetom VISION system (Siemens, Iselin, NJ), equipped with a standard quadrature head coil, using a MPRAGE sequence (164 coronal slices; slice thickness, 1.5 mm; field of view (FOV), 256 × 256 mm2 ; matrix, 256 × 256; voxel size, 1.0 × 1.5 × 1.0 mm3 ; repetition time (TR), 10 ms; echo time (TE), 4 ms; flip angle, 15°).

Although images were collected using different acquisition hardware as described above, previous studies have demonstrated that structural neuroimaging analyses using different hardware have robust effects (Abdulkadir et al., 2011) and are unlikely to cause artifacts at the level of strict statistical thresholds. Additionally, to address the potential impact of varying magnet strengths, magnet strength was included as a covariate in all analyses to control for its influence

All scans were visually inspected for poor scan quality and movement artifacts at the time of collection. Statistical parametric mapping SPM12 default parameters were used to preprocess each image, with the exception of a light clean-up procedure in the morphological filtering step. Preprocessing involved segmenting the T1-structural images into gray matter, white matter, and cerebrospinal fluid and next spatially normalizing them into MNI space (Ashburner & Friston, 2005). Intersubject registration was optimized by warping each participant's image to the Montreal Neurological Institute (MNI) template created from 151 healthy control participants. Spatially normalized, segmented, and modulated gray matter images were smoothed using an 8 mm full width at half-maximum Gaussian Kernal.

Neuroimaging analyses

All VBM analyses included age, gender, magnet strength, total intracranial volume (TIV), and total words spoken as covariates in each design matrix, correlating the raw emotion word count (e.g., total emotion words, negative emotion words, and positive emotion words) with smoothed gray matter volume using a one-tailed t-contrast. All patient groups and healthy controls were included in the analysis Results were considered significant at $p < .001$ with a cluster size > 30 mm^3. To assess the robustness of these effects, a multiple comparisons correction was conducted at $p_{FWE} < 0.05$ based on custom-fit error distribution and clustering based on 1,000 permutations. On any significant findings, a co-atrophy error check was conducted in which each patient group (AD, bvFTD, nfvPPA, and svPPA) was parameterized and added to the model (each diagnostic group was parameterized using 1 for the diagnosis of interest and 0 for the remaining diagnoses) to adjust for potential diagnostic group effects. Images were overlaid using MRIcron (http://people.cas.sc.edu/rorden/mricron/index.html) on an MRI average brain based on the gray and white matter MNI templates used for preprocessing. Statistically adjusting for diagnosis is a conservative error check and has a high likelihood of weakening real relations; therefore, findings must be considered in context of the main effects results.

Results

Preliminary Analyses

Table 1 displays demographic and clinical data for each diagnostic group. No significant differences were found between diagnostic groups in-terms of gender. However, diagnostic groups differed in age $F(4, 253) = 13.52$, $p < .001$, levels of cognitive impairment (MMSE) $F(4, 240) = 21.02$, $p < .001$ and dementia severity (CDR-Boxscore) $F(4, 247) = 44.68$, $p < .001$. Tukey post-hoc comparisons of age indicated that patients with AD were younger than healthy controls ($p < .001$). Patients with bvFTD were significantly younger than patients with nfvPPA ($p < .01$), svPPA ($p < .001$), and healthy controls ($p < .001$). Patients with nfvPPA were significantly younger than healthy controls ($p = .045$) and patients with svPPA were significantly younger than healthy controls ($p <.01$). Tukey post-hoc comparisons of MMSE indicated that patients with AD ($p < .001$), bvFTD ($p < .001$), nfvPPA ($p < .001$), and svPPA ($p < .001$) had significantly greater cognitive impairment than healthy controls. Patients with AD had significantly greater cognitive impairment than patients with bvFTD ($p < .001$), nfvPPA ($p <.01$), and svPPA ($p < .001$). Tukey post-hoc comparisons of CDR-Boxscore indicated that patients with AD ($p < .001$), bvFTD ($p < .001$), nfvPPA ($p < .001$), and svPPA ($p < .001$) had greater dementia severity scores than healthy controls. Patients with AD had greater dementia severity than patients with nfvPPA and lower dementia severity than patients with bvFTD ($p < .01$). Patients with svPPA had greater dementia severity than patients with nfvPPA ($p = .027$) and lower dementia severity than patients with bvFTD. Pearson correlations revealed that MMSE and CDR-Boxscore were moderately correlated ($r(241) = -.41$, $p < .001$, 95% CI [-0.51, -0.30]), indicating multicollinearity. Consequently, to minimize data redundancy and enhance model accuracy, CDR-Boxscore was retained as the covariate instead of MMSE. Thus, in follow-up analyses I included age and dementia severity as covariates.

Significant diagnostic group differences were found in total word use and remained significant when covarying age and CDR Boxscore $F(4, 245) = 14.5$, $p < .001$. Tukey post-hoc comparisons revealed that healthy controls used more total words than patients with AD ($p < .01$), bvFTD ($p < .001$) and nfvPPA ($p < .001$). Additionally, patients with svPPA used more words than patients with bvFTD ($p < .001$) and nfvPPA ($p < .001$) and patients with AD ($p < .01$) used fewer total words than patients with nfvPPA and bvFTD ($p < .05$).

Aim 1. To identify diagnostic group differences in emotional language use.

Group differences in total emotional language

I hypothesized that patients with bvFTD would use less total emotional language than other patient groups and healthy controls. ANOVA results, revealed a significant diagnostic group differences in total emotional language use $F(4, 253) = 3.33$, $p =.01$ (Figure 3). Tukey post-hoc comparisons with Benjamini–Yekutieli corrections revealed that patient's with svPPA ($M_{diff} = -4.77$, SE = 0.002, $p = .01$) and

AD (M_{diff} = -4.69, SE = 0.002, *p* < .01) used less total emotional language than healthy controls[1]. Contrary to the hypothesis, there were no significant differences in total emotional language use by patients with bvFTD in comparison to healthy controls or any other diagnostic group. Main effects remained significant when covarying for age and CDR-Boxscore *F*(4, 245) = 3.24, *p* = .01 and tukey post-hoc comparisons with Benjamini–Yekutieli corrections continued to show that patient's with svPPA (*p* = .02) and AD (*p* < .01) used less total emotional language as compared to healthy controls.

Group differences in negative emotional language

I hypothesized that patients with bvFTD would use more negative emotional language than other patient groups and healthy controls. Tobit regression analysis, adjusted using Benjamini–Yekutieli corrections and with bvFTD as the reference group, revealed that patients with bvFTD used significantly more negative emotional language than patients with svPPA (β = 0.20, SE = 0.08, *z* = -2.43, *p* = .02) and patients with nfvPPA (β = 0.29, SE = 0.10, *z* = -2.79, *p* < .01), which was consistent with the hypothesis (Figure 4A).

To explore pairwise comparisons among other groups I conducted additional tobit models adjusted using Benjamini–Yekutieli corrections, sequentially setting different diagnostic groups as the reference. Pairwise comparison revealed that patients with svPPA (β = -0.27, SE = 0.10, *z* = -2.83, *p* < .01), nfvPPA (β = -0.36, SE = 0.12, *z* = -3.14, *p* < .01), and AD (β = -0.18, SE = 0.08, *z* = -2.20, *p* = .03) use less negative emotional language than healthy controls. All pairwise comparisons remained significant when covarying for age and CDR-Boxscore with the exception that patients with AD no longer significantly differed from healthy controls in negative emotional language use.

Group differences in positive emotional language

I hypothesized that patients with svPPA would use more positive emotional language than other patient groups and healthy controls. Tobit regression analysis, adjusted using Benjamini–Yekutieli corrections and with svPPA as the reference group, revealed that patients with svPPA used significantly more positive emotional language than patients with bvFTD (β = 0.22, SE = 0.09, *z* = 2.48, *p* = .01) and healthy controls (β = 0.29, SE = 0.11, *z* = -2.76, *p* < .01) (Figure 4B).

To explore pairwise comparisons among other groups I conducted additional tobit models adjusted using Benjamini–Yekutieli corrections, sequentially setting different diagnostic groups as the reference. Pairwise comparisons revealed that patients with nfvPPA (β = -0.38, SE = 0.13, *z* = -3.05, *p* < .01) and AD β = -0.20, SE = 0.09, *z* = -2.16, *p* = .03) used significantly more positive emotional language than healthy controls. Patients with bvFTD used less positive emotional language than patients with nfvPPA (β = -0.31, SE = 0.11, *z* = 2.79, *p* < .01). All pairwise comparisons remained significant with the exception that patients with AD no longer significantly differed from healthy controls in positive emotional language use.

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[1] A committee member requested an exploratory analysis to examine potential underlying cognitive and emotional factors that may drive group differences in total emotion word use (%). Four exploratory mediation analyses were conducted to examine if single word object naming *(Boston Naming Test; BNT),* semantic knowledge *(Peabody Picture Vocabulary Test; PPVT),* memory *(California Verbal Learning Task; CVLT-2)* and/or empathy *(Interpersonal Reactivity Index – Empathic Concern; IRI-EC)* individually mediated the relationship between total emotion word use (%) and diagnosis in separate models. A subsample of 149 patients had complete data across these measures (AD = 56, bvFTD = 48, nfvPPA = 19, svPPA = 26). Only one healthy control had complete data and was thus excluded from the analysis. Mediation analyses were conducted using the lavaan package in R (Rosseel, 2012). The mediation models tested potential direct and indirect effects of the cognitive and emotional factors on the use of total emotion words (%). Model fit was evaluated based using Hu & Bentler (1999) suggested cutoffs of comparative fit index (CFI) ≥ 0.95, root-mean-square error of approximation (RMSEA) ≤ 0.06, and standardized root-mean-square residual (SRMR) ≤ 0.08 as indicative of good overall fit. Model fit was determined good for each of the four models based on cutoffs of comparative fit index (CFI) ≥ 0.95, root-mean-square error of approximation (RMSEA) ≤ 0.06, and standardized root-mean-square residual (SRMR) ≤ 0.08 as indicative of relatively good overall fit. No significant direct, indirect, or total effects were identified in any of the four mediation models. Given that the initial ANOVA findings for hypothesis 1a demonstrated group differences in comparison to controls, it is difficult to determine how these results would change if complete healthy control data was available.

Exploratory analysis: group differences in discrete positive and negative emotional language use

I conducted exploratory analyses to examine group differences in discrete negative and discrete positive emotional language use for each emotional language category with > 15 instances of usage. ANOVAs of discrete negative emotions revealed significant differences in contempt language use across diagnostic groups $F(4,19) = 3.24$, $p = .03$ (Figure 5). Tukey post hoc comparisons revealed that patients with AD ($p = .02$) used more contempt words than healthy controls.

ANOVAs of discrete positive emotions revealed significant group differences in content-relaxed words $F(4,86) = 3.78$, $p < .01$, interest-preference words $F(4,177) = 2.84$, $p = .03$, and excitement aroused words $F(4,43) = 5.31$, $p <.01$. Tukey post hoc comparisons revealed that patients with AD ($p = .02$) and svPPA ($p < .01$) used significantly more content-relaxed words than healthy controls (Figure 6). Tukey post hoc comparisons revealed that patients with AD used significantly more interest-preference words than healthy controls ($p = .03$). Tukey post hoc comparisons revealed that patients with nfvPPA used significantly more excitement-aroused words than patients with AD ($p = .01$), bvFTD ($p < .01$), svPPA ($p = .02$), and healthy controls ($p < .01$).

Aim 2. To identify the neural correlates of emotional language in neurodegenerative disease.

Neural correlates of total emotional language

I hypothesized that less total emotional language use would be associated with bilateral atrophy in the amygdala. Contrary to this hypothesis, whole-brain VBM analysis revealed that less total emotional language use was associated with smaller volumes in several regions ($p < .001$, uncorrected), including bilateral temporal regions, the left inferior frontal gyrus, bilateral parietal regions and left occipital regions. One cluster in the left superior temporal gyrus (STG) withstood correction at the $p_{FWE} = .05$ level and remained significantly associated with less total emotional language use when adjusting for diagnosis (MNI Coordinates: x = -52, y = -12, z = -2; Figure 7, Table 2).

Neural correlates of negative emotional language

I hypothesized that greater negative emotional language use would be associated with atrophy in the vmPFC. Contrary to this hypothesis, whole-brain VBM analysis indicated a trend-level association indicating that greater negative emotional language use was associated with smaller volume in the lingual gyrus. This region did not withstand corrections at the ($p_{FWE} = .05$) and was not significant when adjusting for diagnosis (Table 2).

Neural correlates of positive emotional language

I hypothesized that greater positive emotional language use would be associated with atrophy in left temporal regions. Contrary to this hypothesis, there were no significant regions ($p < .001$, uncorrected) that were associated with greater positive emotional language use.

Discussion

The present study examined emotional language use and its neural correlates across a range of neurodegenerative diseases including, AD, bvFTD, nfvPPA, and svPPA as well as healthy controls. Results revealed significant diagnostic group differences in total, negative, and positive emotional language use as well as significant anatomical correlates for total and negative emotional language use. Below, I discuss each set of findings in additional detail.

Diagnostic group differences in emotional language use

Results indicate that patients with AD and svPPA used less total emotional language than healthy controls. When examining positive and negative emotional language use, results indicate that patients with bvFTD used more negative emotional language and less positive emotional language than patients with svPPA and healthy controls. Additionally, patients with svPPA used more positive emotional language and less negative emotional language than patients with bvFTD and healthy controls. Similarly, patients with AD and nfvPPA used more positive emotional language and less negative emotional language than healthy controls.

bvFTD

Although findings did not support hypothesis 1a, that patients with bvFTD would use less total emotional language, results did align with hypothesis 1b, suggesting that patients with bvFTD did indeed exhibit greater use of negative emotional language than healthy controls and other patient groups. These findings are consistent with research that demonstrates heightened irritability (Laganà et al., 2022), anger (Miki et al., 2016), and aggression (Liljegren et al., 2015, 2018) in patients with bvFTD, highlighting the potential clinical relevance despite variability in models using different reference groups. Much of this research focuses on informant reported behaviors. Thus, using an objective measure of emotional language use in a laboratory setting, our study suggests that enhanced negative emotion is also expressed in verbal communication that occurs when discussing an area of conflict with a familial caregiver. Although I hypothesized that patients with bvFTD would use less total emotional language overall, given that apathy is a key feature of the disease, it is possible that context of the conflict conversation with a caregiver may elicit more aggression and irritability, resulting in increased total emotional language use as well as heightened use of negative emotional language.

AD

Compared to healthy controls and other patient groups, patients with AD exhibited less total emotional language, but more positive emotional language and less negative emotional language. Although I did not initially hypothesize that AD would use less total emotional language, these findings are consistent with research that demonstrates language impairment and word finding difficulties in the early stages of AD (Croot et al., 2000; Emery, 2000; Martin & Fedio, 1983). Thus, these factors may contribute to diminished total emotional language use. Similarly, I did not hypothesize that patients with AD would have greater positive emotion word use, yet a large body of literature has demonstrated heightened positive emotion in AD including, greater interpersonal warmth (Sollberger et al., 2014), heightened emotional empathy (Sturm et al., 2013), greater positive emotional reactivity (Fernandez-Aguilar, 2021; Fredricks, 2018), euphoria (Cummings, 1997), and increased mutual gaze (a form of prosocial connection) (Sturm et al., 2011). Furthermore, research suggests a “positivity bias,” in AD such that individuals with AD are better at recognizing and remembering and positive emotional stimuli (Sava et al., 2017; Werheid et al., 2011). Our results support this large body of extant literature and contribute that positive emotional language use also appears to be enhanced in AD.

svPPA

Patients with svPPA exhibited a similar pattern of emotional language use to patients with AD, demonstrating overall less total emotional language use, but greater positive and less negative emotional language use. Although I did not initially hypothesize that patients with svPPA would use less total emotional language than other groups, degeneration in the left anterior temporal lobes has been associated with the loss of semantic knowledge (Bonner & Price, 2013; Gorno-Tempini et al., 2004; Snowden et al., 2018). Emotional language may be a nuanced aspect of semantic knowledge that is affected with degeneration in this area. The finding that patients with svPPA exhibited greater positive emotional language use than other groups is consistent with hypothesis 1c, supporting previous research that demonstrates enhanced positive emotional reactivity (Sturm et al., 2015b), experience (Shdo et al., 2022b), and behaviors (Midorikawa et al., 2017) in svPPA. One possibility is that enhanced positive emotional language use in svPPA is due to the diminished negative emotional language such that as patients become more impaired in using negative language, positive language becomes more dominant, increasing its proportion despite lower total emotional language use. Overall, the current findings contribute to this literature, indicating that positive emotional language is also enhanced in svPPA.

nfvPPA

Although I did not initially set fourth specific hypotheses about emotional language use in nfvPPA, I found that patients with nfvPPA did not show significant differences in total emotional language use but did show greater positive emotional language and less negative emotional language usage. Emerging research suggests that these patients also exhibit greater emotional reactivity to positive stimuli (Balconi et al., 2015; Fletcher et al., 2015) and increased positive emotional behaviors (Midorikawa et al., 2017).

Neural correlates of emotional language use

Total Emotion Words

I found a linear relation between total emotional language use and gray matter volume in the left superior temporal gyrus. Of note, only the left superior temporal gyrus was significant with family-wise error corrections. I also found trend level findings between total emotional language use and gray matter volume in other lateral temporal regions including the right posterior superior temporal gyrus, bilateral middle temporal gyrus, and left anterior inferior temporal gyrus as well the left anterior inferior frontal gyrus. Lateral temporal structures are involved in a range of social and emotional processes including recognizing the emotions of others through interpreting voice prosody (Ethofer et al., 2006), reading emotional facial expressions (Rosen et al., 2006b), and deciphering emotional meaning of gestures and physical cues (Ross & Olson, 2010). The ability to interpret and understand other's emotion states based on behavior, is likely to constitute key to emotional responding, including generating emotional language in response to these cues. The lateral temporal lobes also play an important role in the semantic representation of social concepts, semantic processing (Visser et al., 2010; Zahn et al., 2009), and sentence comprehension (Binney et al., 2010; Dronkers et al., 2004). Processing others' language and understanding social information is likely key for generating emotions and responding with emotional language. Taken together, these regions are likely to play an important role in interpreting emotional states of others, processing socioemotional and semantic concepts, and generating emotion states that would be associated with emotional language use. These processes may all contribute to the use of emotional language in the context under investigation here (i.e., conversations with the caregiver). Another region identified at a trend level, the left inferior frontal gyrus, is well known for its role in speech production (Indefrey, 2000; Ishkhanyan et al., 2020; Koechlin & Jubault, 2006). Additionally, some research has demonstrated its role in emotion regulation (Grecucci et al., 2013; Naor et al., 2020). Emotion regulation is a process often used when responding to the emotion states of others and in response to heightened emotional experience (English et al., 2017; Gross, 2013). Diminished volume in this region may impair the ability to appropriately comprehend, regulate, and subsequently produce emotional language.

I initially hypothesized that negative emotional language use would be associated with volume in the vmPFC. However, I found that greater negative emotional language use was associated with diminished gray matter volume in only one area, the lingual gyrus. These results did not withstand atrophy correction for family-wise error correction and thus should be interpreted with caution. The lingual gyrus is an occipital region, typically considered a visual processing region (Bogousslavsky et al., 1987). One study, however, found a relation between the lingual gyrus and the processing of negative visual stimuli (Kehoe et al., 2013). Therefore, this region may be involved in processing negative visual and contextual information that occurs during a conflict conversation, such that dysfunctional processing of this information may result in frustration, increasing negative emotional language use that is necessary to understand to generate negative emotional language.

Contrary to hypothesis 2c, that greater positive emotional language use would be associated with atrophy in temporal lobe regions, I did not find any gray matter volumes that were significantly associated with greater positive emotional language use. These null findings suggest that there may not be specific brain regions associated with positive emotional language use.

For both positive and negative emotional language use, it is possible that findings are weak because generating positive and negative emotional language may involve more distributed networks across the brain, rather than localized areas, making it difficult to link these emotions to specific changes in gray matter volume. Furthermore, a fundamental assumption of VBM analysis is linearity in the relation between variables; however, the relation between brain volumes and the use of positive or negative emotional language may not be linear. Rather, there may be optimal ranges of emotional language use, such that both excessive and minimal use of emotionally valanced words could be related to diminished brain volume.

Clinical Implications

This work has several clinical implications, including possible use for enhancing clinical diagnosis and for educating caregivers about possible changes in emotional communication. For instance, the distinct patterns of emotional language use identified in this study may aid clinicians in refining diagnostic criteria, particularly for detection of subtle emotional changes that may precede other more noticeable symptoms. Given the rapid development of technology and advances in collecting language samples and analyzing text, the ability to collect natural language samples is increasing. This advance could make it easier to implement our findings in routine clinical practice, allowing for more dynamic and responsive assessments of patients over time. Findings that emotional language use differs across diagnostic groups suggests that emotional language use may be a valuable tool in the differential diagnosis of disease types. This finding could lead to more personalized treatment plans and targeted interventions, improving patient management and outcomes.

This study also has implications for caregivers. Caregivers of patients with bvFTD often have worse health outcomes (Lwi et al., 2017). Understanding that increased negative emotional language use is characteristic of the disease, may help caregivers cope with negative emotional language in conflict situations. Psychoeducation and health education programs could use these insights to teach coping strategies that are tailored to the communication styles that emerge as the diseases progress. Awareness of this may help caregivers notice negative emotional language use and deescalate their behavior appropriately, potentially improving the emotional environment and reducing caregiver stress.

Strengths and weaknesses

This study has several strengths. To my knowledge, it is the first to examine diagnostic group differences in emotional language use based on an objective measure of emotional language usage during naturalistic conversations between patients and their caregivers. It uses a relatively large sample size and provides valuable information about the nature of emotional language use in disease groups and from a neuroanatomical perspective.

A key limitation is the cross-sectional design, which limits the ability to examine how emotional language use changes with disease progression. Changes in emotional language use over-time may differ across diagnoses or may become more pronounced in later disease stages.

Regarding the neuroanatomical findings, results were relatively weak, with only the left superior temporal gyrus surviving family-wise error correction, when examining total emotional language use. As mentioned previously, the study assumes a linear relation between brain volume and emotional language use, which may contribute to weaker findings. Additionally, the study utilized voxel-based morphometry (VBM) to identify structural correlates of emotional language, which may limit the ability to detect distributed brain network interactions that are potentially more critical in emotional language processing.

Future directions

There are several future directions that would enhance and broaden this line of research. First, given the variability in findings related to negative emotional language use when different diagnostic groups were used as reference, future research should aim to replicate these findings with a larger sample size. To examine how emotional language use changes with disease progression, future research could use longitudinal methods to examine changes over time. Additionally, future studies could examine the dyadic nature of emotional language over the course of a conversation to determine if patients vs. caregivers drive total, positive, or negative emotional language use. Although I did not analyze caregiver emotional language use, future research could examine whether patient language use is influenced by caregiver language use. Finally, future studies could also examine if different contexts such as group settings or with care providers yields similar findings.

Regarding the neuroanatomical findings, future research should aim to replicate these results with a larger sample size, given that most of our findings did not survive rigorous error corrections. Future research should also examine if a possible nonlinear relation might explain the minimal significant findings in our study and could employ analysis methods that can capture more complex, potentially curvilinear relationships. Future research is also needed to better explore potential mechanisms underlying the relationship between decreased emotional language use and regions known to support semantic knowledge and involved in sentence comprehension, such as the left anterior temporal lobe. While I have demonstrated this association, it remains unclear if the diminished use of emotional language is because using emotional language inherently requires semantic knowledge. Additionally, it is unclear why structures involved in sentence comprehension should pertain to emotional language use specifically, and future studies should further explore this. Lastly, given the relatively weak findings in this study, future research should explore the relations between emotional language use and distributed brain networks to potentially uncover more robust and comprehensive neural correlations.

Conclusions

This study explored emotional language use across a range of neurodegenerative diseases, including AD, bvFTD, nfvPPA, and svPPA as well as healthy controls. It found significant differences in total, negative, and positive emotional language use across groups, highlighting different patterns of verbal emotional expression by diagnosis. These patterns may be useful both diagnostically and therapeutically. Additionally, I examined the neural correlates of emotional language use, finding some links between specific brain regions and the production of emotional language. The findings, indicate that the left superior temporal gyrus may play a role in generating emotional language, which is a key part of social interactions. Although significant associations between negative or positive emotional language use and specific brain volumes did not survive conservative error corrections, this pattern may indicate more distributed network involvement or non-linear relationships that future research should investigate. Taken together, these findings enhance understanding of emotional communication in neurodegenerative diseases and could help inform both clinical practices (e.g., differential diagnosis) and caregiver strategies (e.g., behavioral management) related to these neurodegenerative diseases.

Figure 1. Conflict Conversation Transcript Example.

C: [00:25] You want to go first on why you want another dog?
P: [00:33] I want another dog because it will be my dog.
C: [00:37] [I am] feeling ***jealous****... because... you had... you had Ollie as your dog...*
P: [00:43] Yeah.
C: [00:50] Dog? How about a stuffed animal...? the reason I don't want another dog is I'd have to walk... take two walks... it'd be four walks a day. We'd have... there'd be probably initial turmoil... getting the food separated and all that stuff. We don't have... a trainer living ***<u>close</u>*** *by us... to mediate the initial stuff. And I think I have my plate full right now, and I don't want to be dealing with a second dog. We just got the house fixed up. And you know what happens.*

Note. Excerpt of a transcript from a conflict conversation between a patient and caregiver dyad. Words in **bold** represent emotion words that are in an appropriate context. Words in **<u>bold and underlined</u>** represent words that do not have an emotional context and would therefore need to be recoded as “no code.”

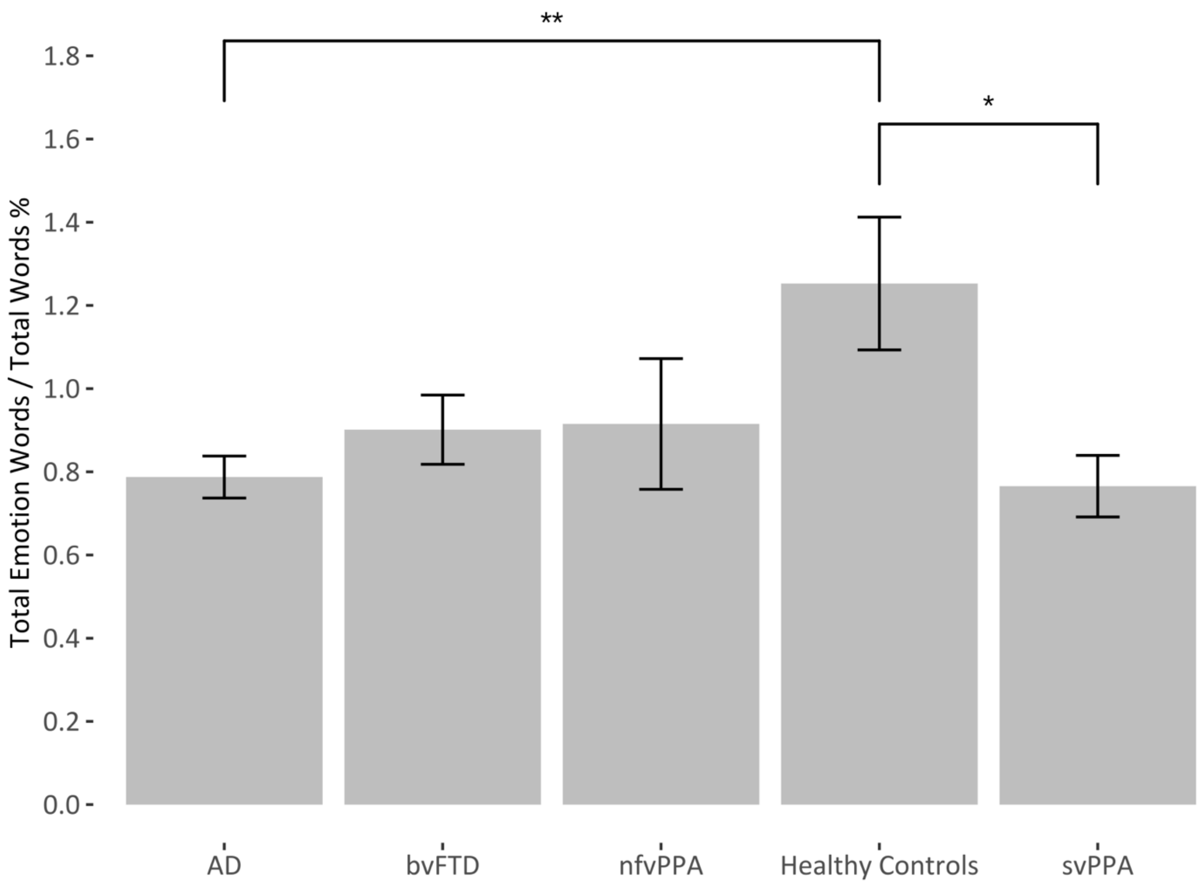
Figure 2. Oedipus Text User Interface.

Note. The interface depicts a portion of a transcript in which “Jealous,” was identified and categorized into the “Jealousy-Envy,” category. All emotion categories are depicted. The user interface also shows options to “ok,” this selection or to “negate,” or “no code.”

	AD	bvFTD	nfvPPA	svPPA	Healthy Controls	Test Statistics for Group Differences	p-value	Effect Size (η^2)
N	87	71	28	43	29	-	-	-
Age	70 (.90)[a]	67 (.96)[bhi]	73 (1.48)[ch]	73 (.96)[di]	79 (1.17)[abcd]	$F(4, 253) = 13.52$	<.001	0.18
Sex (M/F)	53/34	49/22	13/15	27/16	12/17	$X^2(4) = 8.88$	0.06	0.06
Education	16.4 (.33)	16.2 (.34)	16.9 (.53)	16.8 (.42)	17.0 (.35)	$F(4, 251) = 0.62$	0.65	0.01
MMSE	21.5 (.56)[aefg]	25.4 (.48)[be]	24.9 (1.08)[cf]	25.3 (.57)[dg]	29.6 (.11)[abcd]	$F(4, 240) = 21.02$	<.001	0.26
CDR Box Score	4.5 (.21)[aef]	6.0 (.35)[behi]	2.0 (.37)[cfhj]	3.7 (.38)[dij]	0.0 (.00)[abcd]	$F(4, 247) = 44.68$	<.001	0.42
Total Words Spoken	756 (425)[aef]	563 (391)[bei]	433 (238)[cfj]	915 (424)[ij]	1061 (334)[abc]	$F(4, 253) = 15.07$	<.001	0.19

Table 1. Characteristics of participants by group. For age, education, MMSE, CDR Box Score, and CDR Total the values indicate mean (standard deviation). For sex, the values indicate the frequency of male/female sex identification. Effect Size is reported as eta squared. Means with common superscripts are significant at p<.05. Superscripts represent significant group differences a p<.05: [a]=AD vs healthy controls, [b]=bvFTD vs healthy controls, [c]= nfvPPA vs healthy controls, [d]=svPPA vs healthy controls, [e]=bvFTD vs AD, [f]=nfvPPA vs AD, [g]=svPPA vs AD, [h]=nfvPPA vs bvFTD, [i]=svPPA vs bvFTD, [j]=nfvPPA vs svPPA.

Note: AD= Alzheimer's disease; bvFTD, behavioral variant frontotemporal dementia; CDR Box Score, Clinical Dementia Rating Scale (sum of boxes); CDR Total, Clinical Dementia Rating Scale total score; MMSE, Mini-Mental State Examination; nfvPPA, non-fluent variant primary progressive aphasia; svPPA, semantic variant primary progressive aphasia.



ANOVA of groups $F(4, 253) = 3.33$, $p < .05$

Figure 3. Total emotional language use by diagnostic group.

Note: * = $p < .05$, ** = $p < .01$. Error bars represent +1/- standard error of the mean. All group comparisons conducted using Tukey post hoc comparisons.

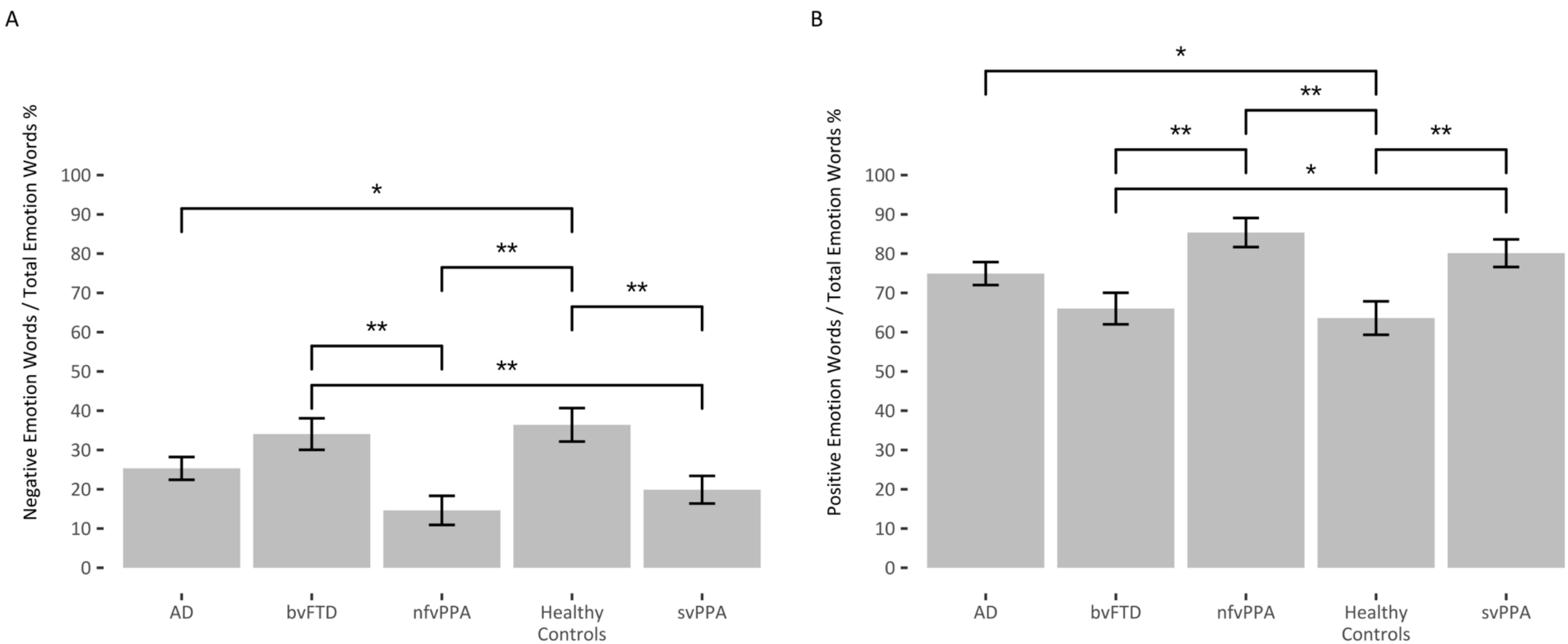
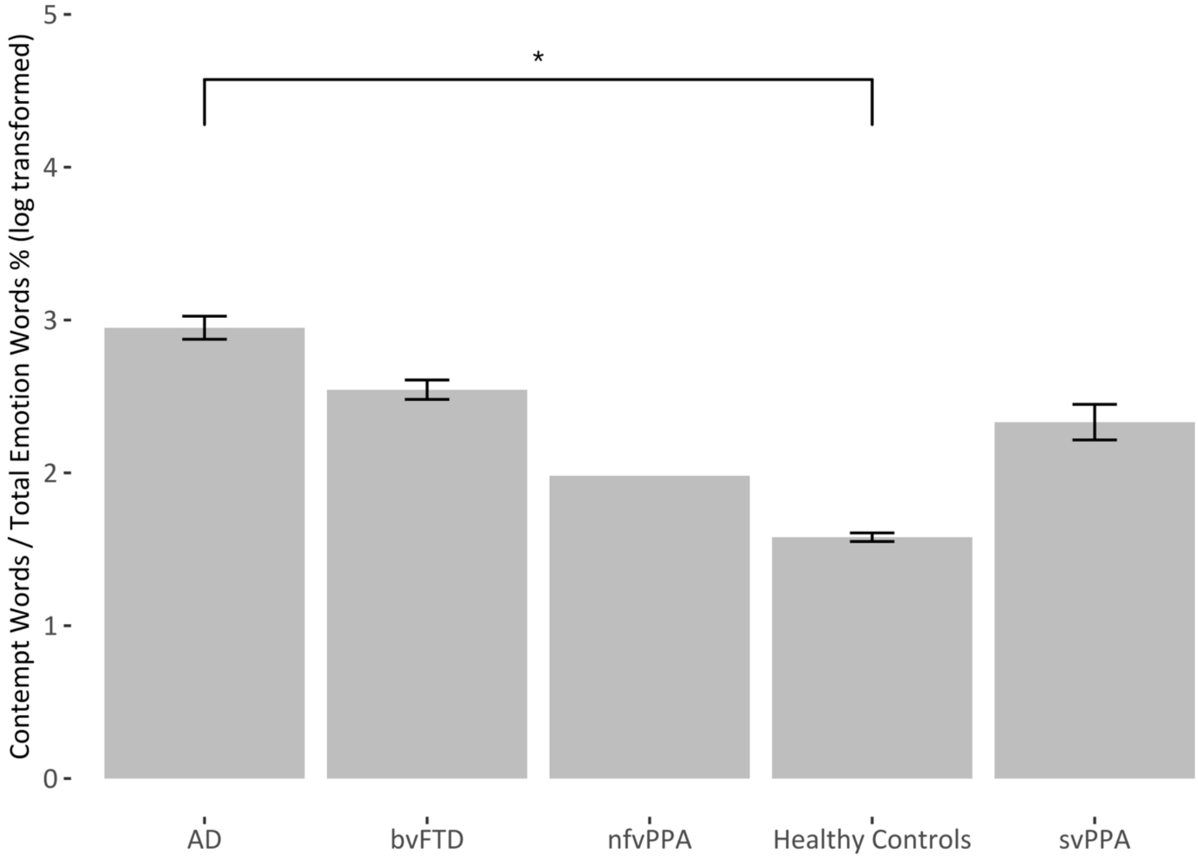


Figure 4. Negative emotional language use (panel A) and positive emotional language use (panel B) by diagnostic group.

Note: All group comparisons were conducted using Tobit regression, with each diagnostic group set sequentially as the reference. P-values were adjusted using the Benjamini–Yekutieli method to control for multiple comparisons. * = $p < .05$, ** = $p < .01$. Error bars represent +1/- standard error of the mean.



ANOVA of groups $F(4,19) = 3.24$, $p = .03$

Figure 5**.** Percentage of contempt emotion words to total emotion words by diagnostic group.

Note: Data were log transformed to address skewness in the distribution. All group comparisons conducted using Tukey post hoc comparisons. * = $p < .05$. Error bars represent +1/- standard error of the mean. Only one patient with nfvPPA used contempt words, thus there are no error bars for this patient group

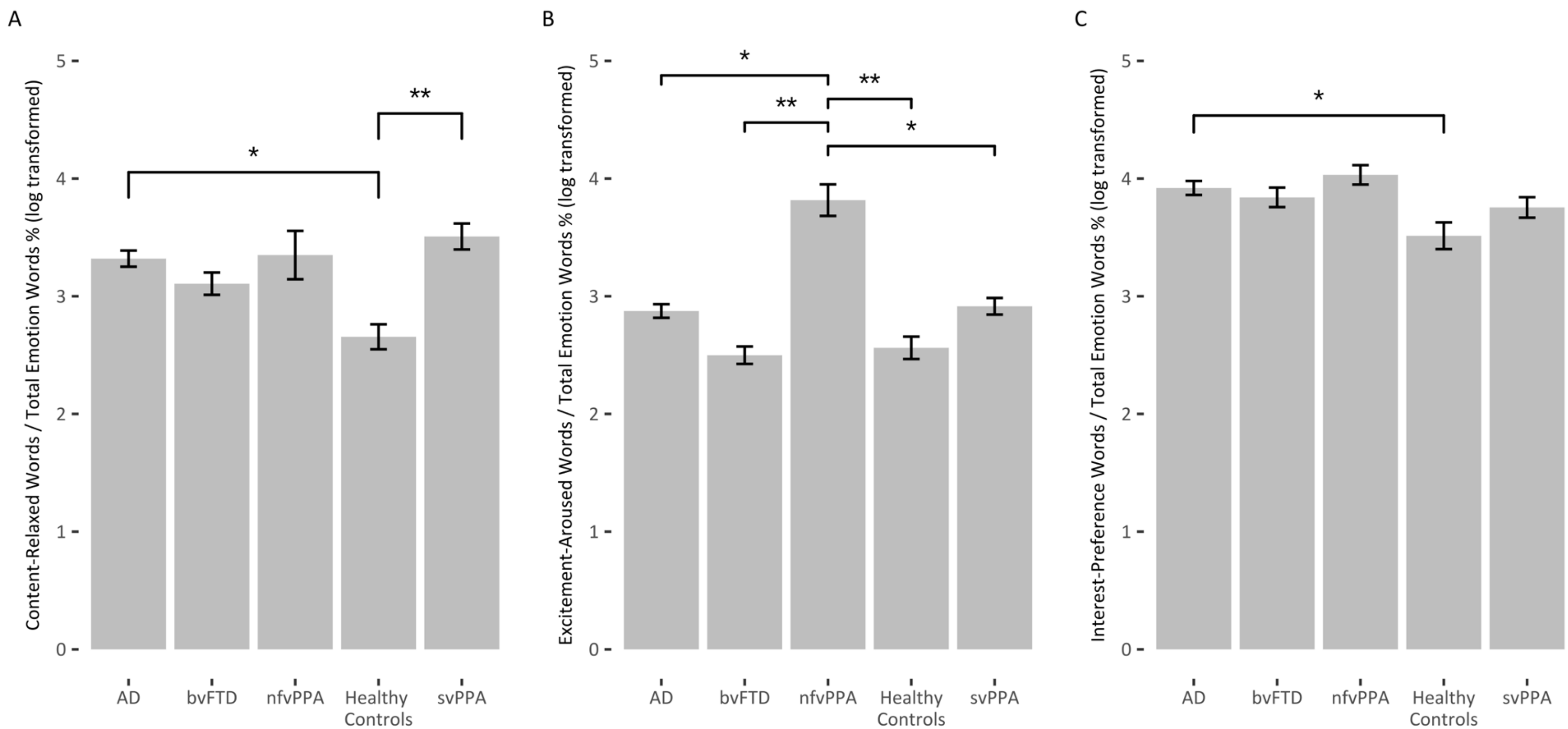


Figure 6. Positive language use by diagnostic group (Panel A: Content-Relaxed words, Panel B: Excitement-Aroused words, and Panel C: Interest-Preference Words).

Note: Data were log transformed to address skewness in the distribution. All group comparisons conducted using Tukey post hoc comparisons. * = $p < .05$, * = $p < .01$. Error bars represent +1/- standard error of the mean.

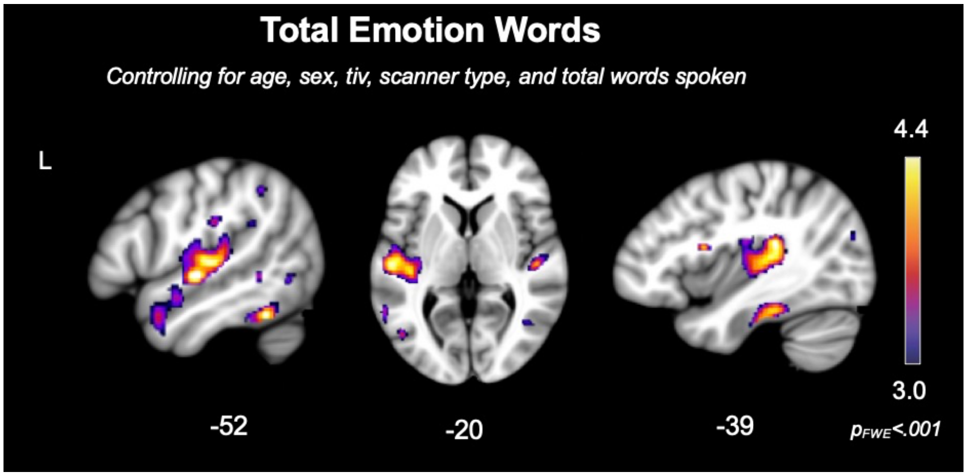


Figure 7. T-score maps of brain areas for which greater atrophy was associated with less total emotional language use, when controlling for age, gender, tiv, magnet strength, and total words spoken. Regions in the left and right superior temporal gyrus, the left and right middle temporal gyrus, and the left inferior frontal gyrus among other regions were associated with less total emotional language use. A cluster in left superior temporal gyrus was also significant with family wise error correction ($p_{FWE} < .05$).

Note: Results presented at $p < .001$ uncorrected.

Anatomical Region	Cluster Volume (mm³)	MNI coordinates			Maximum T Score
		x	y	z	
Total Emotional Language Use					
Left Superior Temporal Gyrus*†	3343	-52	-12	-2	4.81
Left Inferior Temporal Gyrus	1379	-51	-50	-22	4.48
Right Superior Temporal Gyrus†	670	40	-30	16	4.12
Left Middle Temporal Gyrus	377	-57	-28	-15	4.13
Left Middle Temporal Gyrus	114	-52	8	-24	3.58
Right Middle Temporal Gyrus	111	-44	-58	22	3.64
Left Lingual Gyrus	91	-14	-66	-8	3.65
Left Middle Occipital Gyrus	71	-46	-70	3	3.62
Left Angular Gyrus	55	-44	-68	33	3.72
Left Supramarginal Gyrus	49	-54	-22	26	3.68
Left Inferior Frontal Gyrus	45	-39	9	16	4.05
Left Middle Occipital Gyrus	42	-34	-82	20	3.33
Right Postcentral Gyrus	33	57	-14	22	3.62
Negative Emotional Language Use					
Right Lingual Gyrus†	31	18	-80	0	3.49

Table 2. Whole brain voxel-based morphometry analyses, controlling for age, sex, scanner type, and total intracranial volume (tiv) revealed that smaller volumes predominately in the left superior temporal gyrus were associated with greater total emotional language use.

Note: Montreal Neurological Institute (MNI) coordinates (x, y, z) reported for maximum T-score for each cluster. All results are significant at $p < .001$, uncorrected. * = Results significant at $p_{FWE} < .05$. † = results remained significant when controlling for diagnosis. Cluster sizes smaller than 30 mm^3 were excluded.

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