

A Systematic Review of the Quantitative markers of speech and language of the Frontotemporal Degeneration Spectrum and their potential for cross-linguistic implementation

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ABSTRACT

Frontotemporal dementia (FTD) is a neurodegenerative disease spectrum with an urgent need for reliable biomarkers for early diagnosis and monitoring. Speech and language changes occur in the early stages of FTD and offer a potential non-invasive, early, and accessible diagnostic tool. The use of speech and language markers in this disease spectrum is limited by the fact that most studies investigate English-speaking patients. This systematic review examines the literature on psychoacoustic and linguistic features of speech that occur across the FTD spectrum across as many different languages as possible. 76 papers were identified that investigate psychoacoustic and linguistic markers in discursive speech. 75% of these papers studied English-speaking patients. The most generalisable features found across different languages, are speech rate, articulation rate, pause frequency, total pause duration, noun-verb ratio, and total number of nouns. While there are clear interlinguistic differences across patient groups, the results show promise for implementation of cross-linguistic markers of speech and language across the FTD spectrum particularly for psychoacoustic features.

Keywords: FTD, PPA, PSP, CBS, ALS-FTD, biomarkers, speech, language

1. INTRODUCTION

Frontotemporal dementia (FTD) gives rise to a spectrum of clinical phenotypes with variable degrees of speech and language pathology (Moore et al., 2020; Rohrer et al., 2015). All variants of primary progressive aphasia (PPA) by definition present with prominent abnormalities of speech and/or language (Gorno-Tempini et al., 2011), but the FTD spectrum as a whole is strongly associated with such impairments. In behavioral variant FTD (bvFTD), word retrieval, comprehension, reading, writing, verbal and non-verbal semantic knowledge, as well as prosody of speech are impaired, while motor speech and repetition abilities remain generally preserved (Geraudie et al., 2021; Samra et al., 2023). On the other side of the spectrum, progressive supranuclear palsy (PSP) and corticobasal syndrome (CBS) have been more often associated with motor speech impairments such as apraxia of speech and dysarthria, though more recent research also shows impairment in language abilities, such as confrontation naming, fluency, sentence comprehension and production (Peterson et al., 2019). Meanwhile, FTD combined with amyotrophic lateral sclerosis (FTD-ALS) can occasionally present with agrammatism and/or apraxia of speech, as well as comprehension deficits on the single word and sentence level (Rusina et al., 2021).

While the first clinical trials for genetic FTD are being rolled out (Boeve et al., 2022), there is an unmet clinical need for reliable non-invasive markers to monitor disease progression and therapeutic effects. Quantitative analysis of speech and language in FTD could potentially provide objective, low-cost and sensitive markers suitable for this purpose. Specifically, psychoacoustic markers can be used to quantify motor speech disorders such as apraxia of speech and dysarthria, while linguistic markers may quantify single word use or detect sentence construction abnormalities.

One of the important challenges regarding the clinical implementation of psychoacoustic and linguistic markers is to identify which, if any, markers are applicable across different languages. There is a paucity of published research on the speech and language changes that occur in FTD spectrum disorders in non-English speaking patients (García et al., 2023). Therefore, it would be beneficial to determine which changes in speech and language are generalizable across languages and which are language-specific.

Research has shown significant interlinguistic differences between patients across the FTD spectrum (García et al., 2023). For instance, significant differences have been found between English and Italian patients with non-fluent variant PPA (nfvPPA) in motor speech and syntactic complexity (Canu et al., 2020).

There are numerous approaches to investigating the changes that occur in speech and language. Connected speech (comprised of consecutive words forming utterances) offers a wealth of information about the cognitive state of a patient, and countless variables can be extracted from a relatively small sample of connected speech. The cookie theft picture description task for instance, one of the most commonly used tasks to generate connected speech (Goodglass & Kaplan, 1972), takes less than two minutes to administer and can be carried out by experts and non-experts alike. There are also numerous alternatives to picture description tasks, for instance, semi-structured interviews (Knibb et al., 2009), narrative tasks (Ash et al., 2006), reading tasks (Baque et al., 2022), and repetition tasks (Bouvier et al., 2021). An advantage of picture description tasks such as the cookie theft picture description task is that large existing databases of speech samples from patients with FTD as well as from controls can be used as comparisons for newly collected data. These large databases will be beneficial in creating machine learning models to diagnose FTD using (semi) automated analysis of speech.

In this paper, we performed a systematic review of the known quantitative psychoacoustic and linguistic markers in connected speech across the FTD spectrum to inform future cross-linguistic research and clinical implementation.

2. METHODS

A systematic review of the literature on the quantitative psychoacoustic and linguistic markers of FTD was carried out to determine the most relevant features of speech and language to analyze in discursive speech samples and to determine which features were the most generalizable across different languages. Using the databases SCOPUS and Web of Science the relevant literature was identified and screened on the 1st

of March 2023. The search terms used were “FTLD”, “primary progressive aphasia”, “frontotemporal dementia”, “semantic dementia”, “non-fluent primary progressive aphasia”, “progressive supranuclear palsy”, “corticobasal degeneration”, “ALSFTD”, “speech”, and “language”. The disorders were grouped by an ‘OR’ operator and combined with the speech and language search terms with the ‘AND’ operator, which were also grouped with the ‘OR’ operator. All words are MeSH terms.

This search yielded 5272 results in total including duplicates, which were manually removed, leaving 3771 peer-reviewed papers (see Figure 1). Using Rayyan, a literature search tool (Ouzzani et al., 2016), the titles and abstracts were triaged to filter for the relevant papers. Papers were included if they studied a population of patients with frontotemporal lobar degeneration and obtained results relating to the psychoacoustic or linguistic properties of elicited connected speech or discourse of the patients. Patients with nfvPPA, primary progressive apraxia of speech (PPAOS), logopenic variant PPA (lvPPA), semantic variant PPA (svPPA), semantic dementia (SD), mixed PPA (mxPPA), bvFTD, CBS, PSP, and ALS-FTD were included. Only patient groups that were diagnosed according to international consensus criteria were included. Papers were excluded if there was no control group, or if they were case studies or review papers. Only peer-reviewed papers were included.

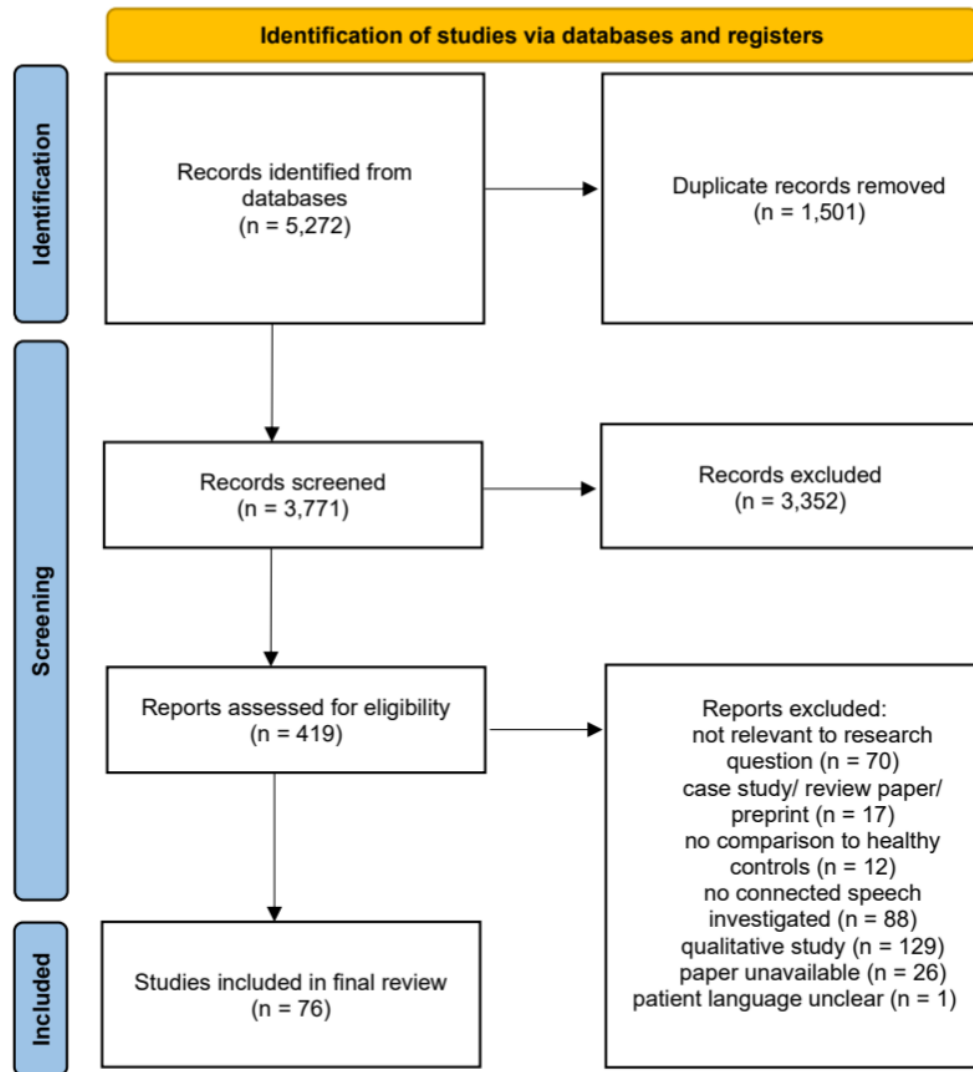


Figure 1

PRISMA flowchart of methods of systematic literature review

With the inclusion and exclusion criteria stated in Figure 1, a total of 419 papers were selected for further reading. The following data was extracted from these 419 papers: (i) the sample size, (ii) the language of the patients, (iii) the methods used to obtain the speech and language features, (iv) the psychoacoustic and linguistic features investigated, and (v) the relevant findings.

Papers published in all languages were considered. Five of the 419 papers were only available in Spanish, one only available in German and the rest were written in English (though not all about English-speaking

patients).

Upon further reading and data extraction, 76 papers were selected for inclusion in the final paper. The date range of these papers was from May 1997 to October 2022.

Based on the 76 papers, there were a total of 342 features of speech compared in the patient groups and healthy controls in discourse. 44 of these features were studied in more than one language.

In four papers the PPA patients consisted of a mixed group of several subtypes, or the subtype was not specified. The results that were relevant to this review were considered separately from the other PPA variants.

76 papers studying discourse in patients with FTD were included in the final review. 57 of these papers (75% of all papers) studied English-speaking patients and the remaining 19 papers studied patients speaking Spanish (Baque et al., 2022; Matias-Guiu et al., 2020, 2022), Czech (Daoudi et al., 2022; Rusz et al., 2015; Skrabal et al., 2020), Italian (Catricala et al., 2019; Silveri et al., 2014), French (Bouvier et al., 2021; Macoir et al., 2021), German (Hohlbaum et al., 2018; Staiger et al., 2017), Dutch (Bruffaerts et al., 2022), Greek (Karpathiou & Kambanaros, 2022; Koukoulioti et al., 2018, 2020; Potagas et al., 2022), Hindi (Sachin et al., 2008), and Korean (Suh et al., 2010) (Table 1). Figure 2 shows the geographical representation of the published papers, with a paucity of languages from South America, Asia, and Africa. As Figure 2B shows, the language distribution of the literature is in no way representative of the total population of each language, with English being drastically overrepresented relative its total population of native speakers. The vast majority of these papers describe patients with sporadic FTD (99%).

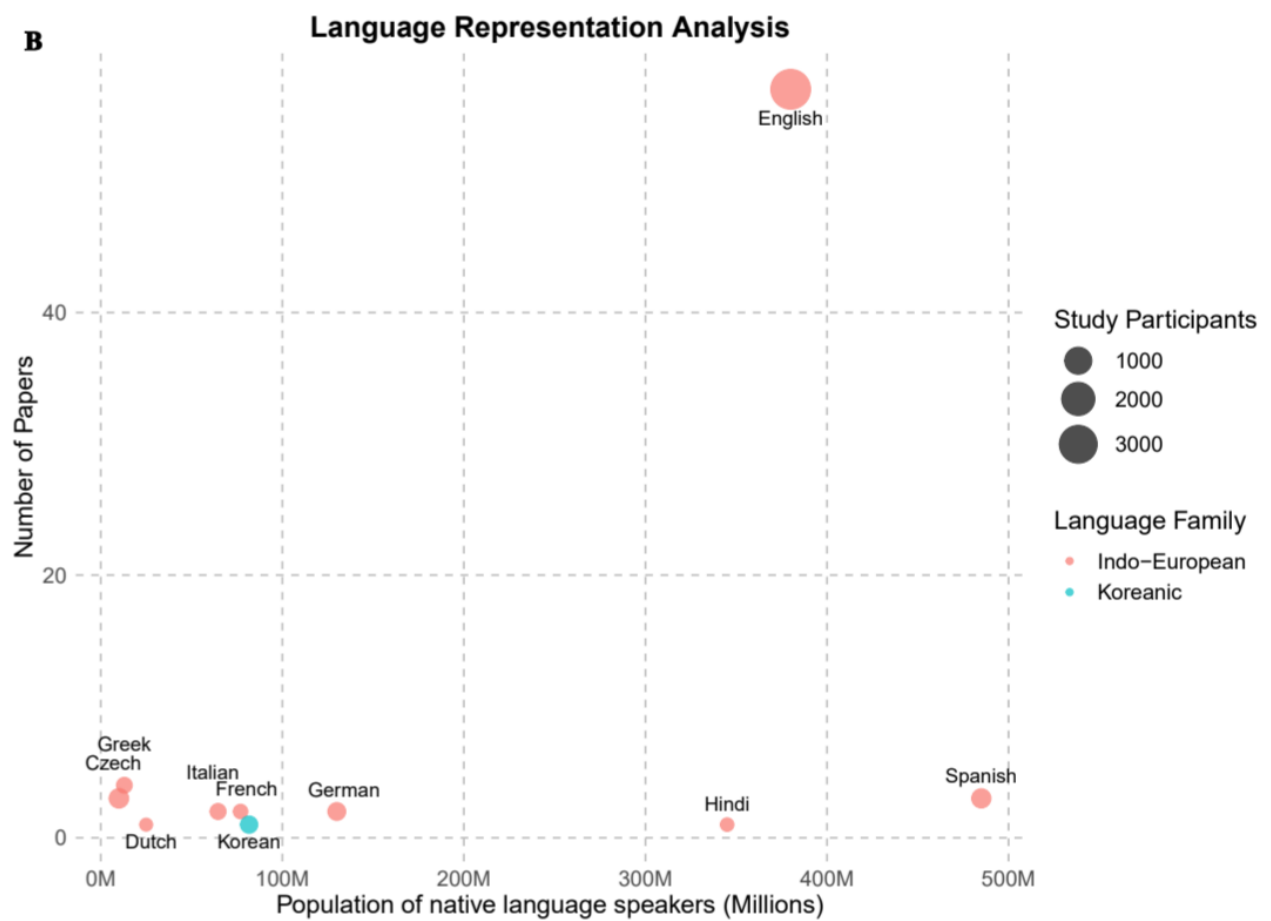
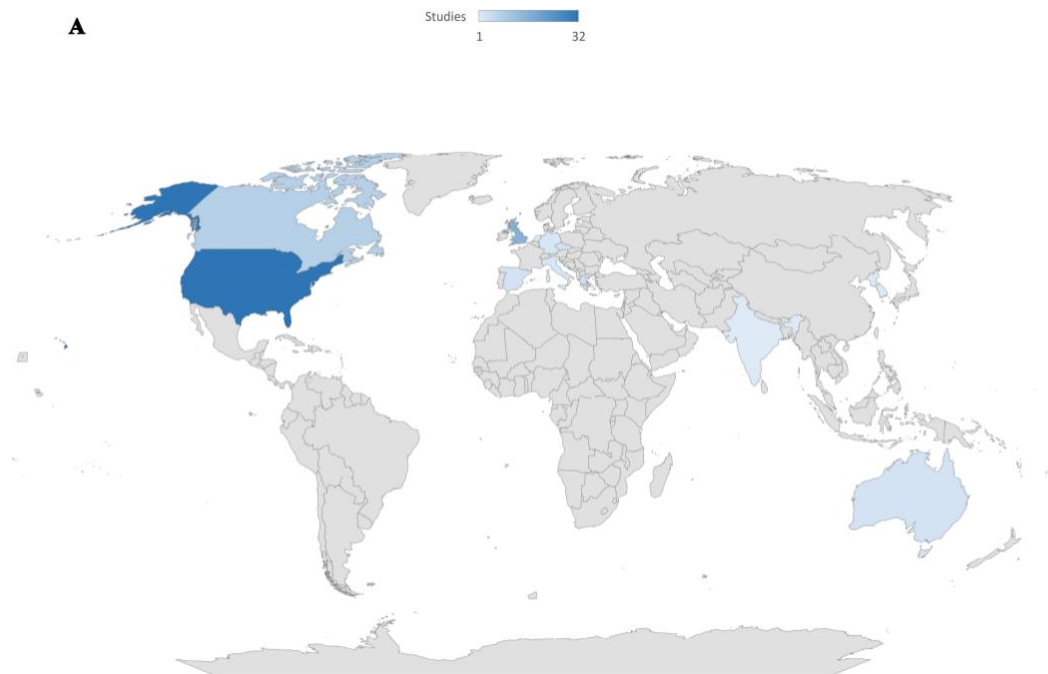


Figure 2

The (A) geographical locations and (B) language representation analysis of the 76 included papers.

As previously stated, only papers using tasks which elicited connected speech were included. The tasks chosen were varied, but the most commonly used were picture description, interviews, narrative, and reading tasks. The cookie theft picture description task was the most widely used task, in a total of 23 papers with patients speaking English, Spanish, Dutch, Italian, and Greek. Sentence repetition tasks were only used in papers studying non-English-speaking patients. Conversely, conversation as a task was not used by any papers studying non-English-speaking patients, and was only used by two papers studying English-speaking patients (Figure 3).

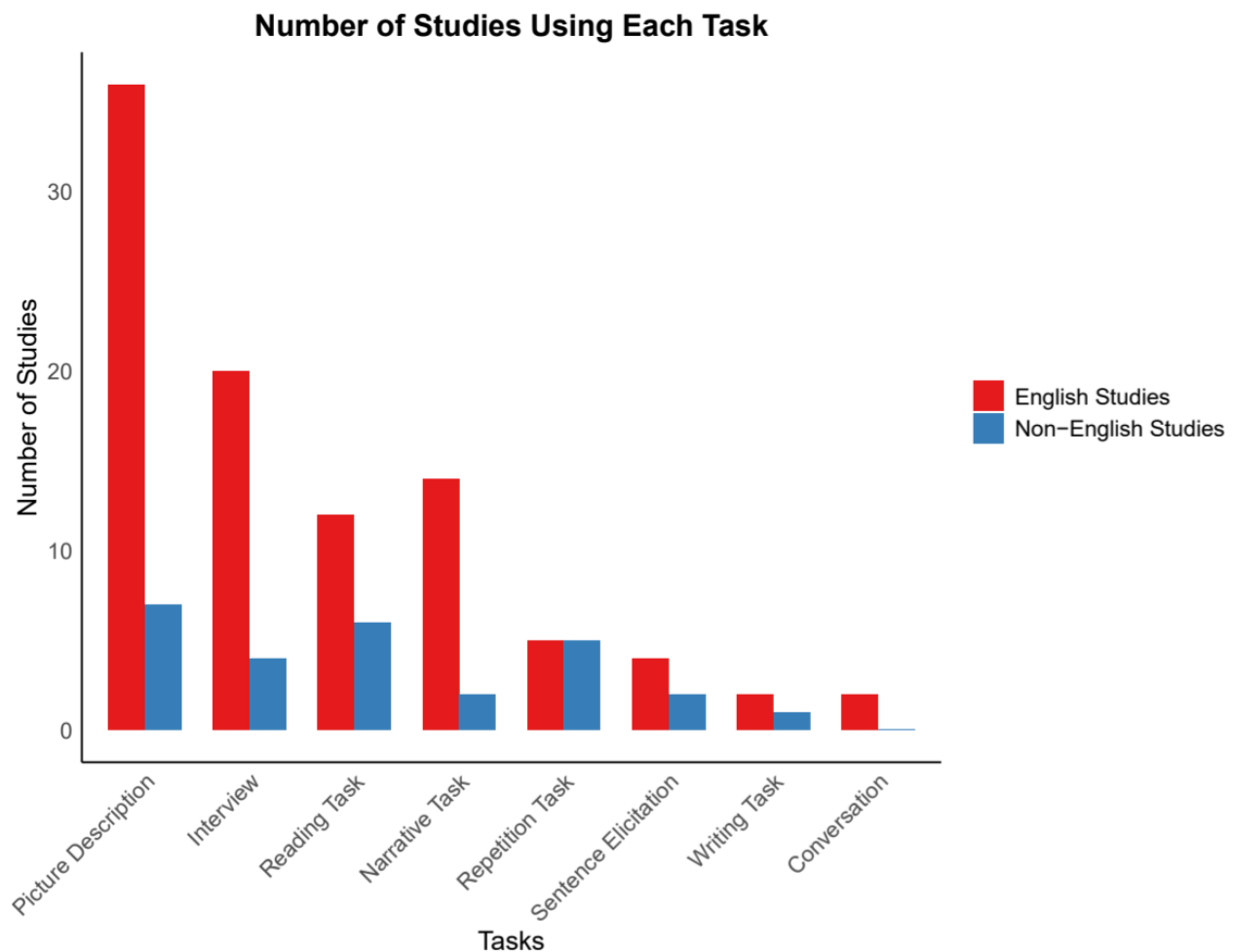


Figure 3

The tasks used by the papers in the review in English and non-English speakers.

shows which language was significantly different for which group.

The psychoacoustic and linguistic features of speech across the FTD spectrum were extracted, resulting in 342 features. The features were grouped based on the categorisation method of Boschi et. al. (2017) for connected speech in neurodegenerative disorders (2017), comprised of the following five categories: phonetic-phonological, lexico-semantic, morpho-syntactic, syntactic, and discourse-pragmatic. The phonetic and phonological category includes features at the level of the speech sound such as pausing behaviour, and the time taken to produce components of speech including words, phonemes, and syllables. Lexico-semantic features include features at the word and content level, such as number of nouns, verbs, adjectives, and pronouns, obtained through techniques like part-of-speech tagging (Jarrold et al., 2020). The morphosyntactic-syntactic category includes features relating to inflectional morphology, while the syntactic category includes features purely related to syntax, such as the number of words per clause, utterance, and sentence. Finally the discourse and pragmatic category was comprised of features that contribute to the continuation of conversation, such as cohesion, coherence, and correct use of conjunctions. (Boschi et al., 2017). An additional category for error typing was added, as recent research has demonstrated the importance of these features in FTD (Bruffaerts et al., 2020; Catricalà et al., 2015). This additional category involved features relating to the number or rate of any type of any errors (e.g. phonological errors, semantic errors etc.).

44 of these features of speech and language were studied in more than one language and we focused on these features (see Table 1 for definitions). Within these, the most widely studied features were speech rate and articulation rate. The 18 features with the same main finding in more than one language are shown in Table 2. Six of the features were found to have the same main finding in both *more than one language* and in *more than one clinical variant of FTD*. For these features, the quantitative values of the papers were

extracted where possible and plotted for interlinguistic comparison in Figure 4. Quantitative value comparisons aim to identify potential variances in baseline measures among healthy controls across distinct languages, which may be important for determining differences in cut-off points for what should be considered normal values of different features within each language.

3. RESULTS

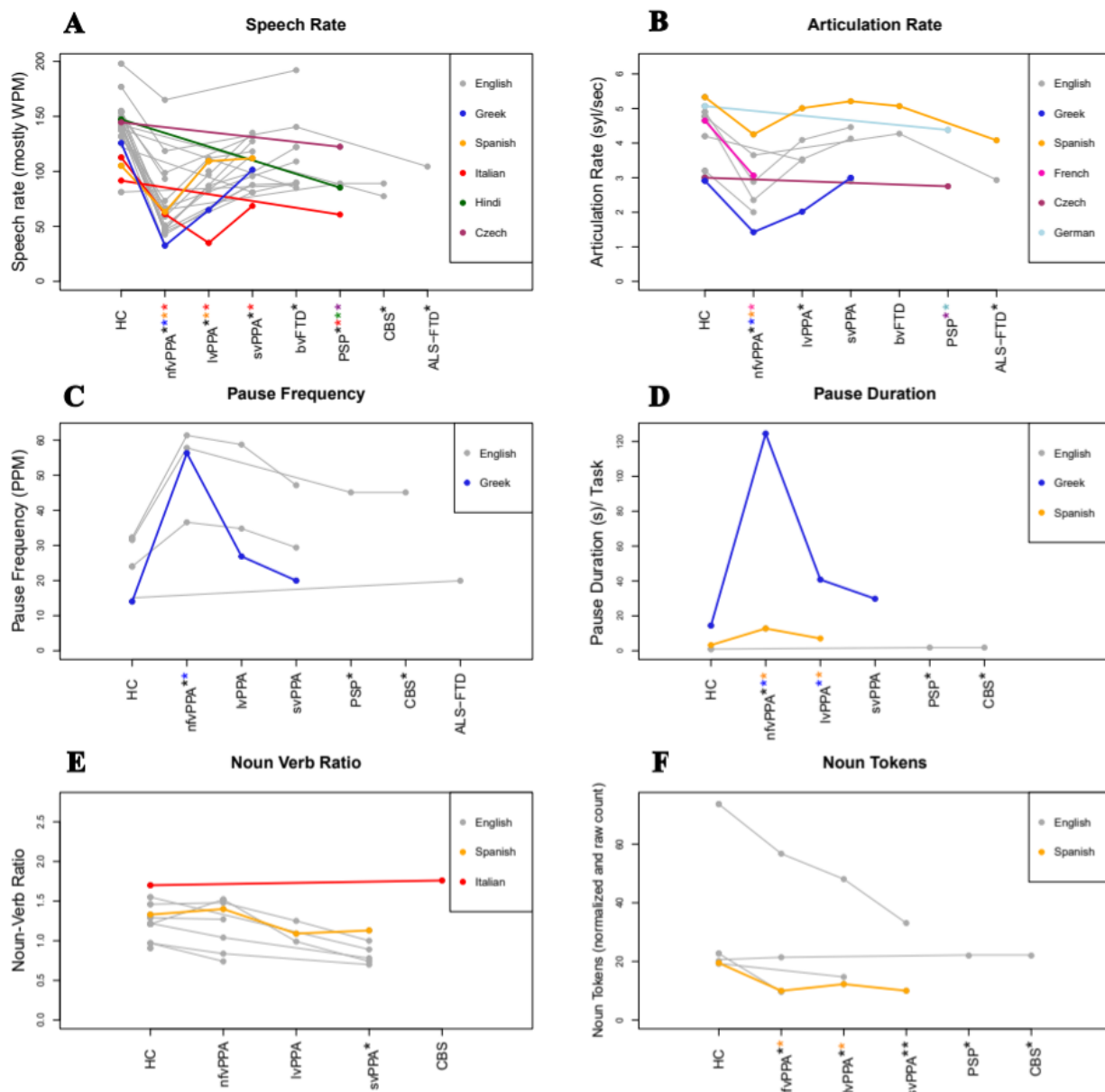


Figure 4

The quantitative values of each paper studying the 6 most generalizable features. Lines in the plot connect groups from the same study. A) Speech rate: the papers investigating syllables per second were combined with papers investigating words per minute (after being multiplied by 60). This does not appear to have affected the results, as the highest values for speech rate do not measure syllables per second, but words per minute. B) Articulation rate: for the papers using syllables per minute or words per minute, the values were divided by 60 to compare to the values of the papers using syllables per second. C) Pause frequency: certain papers used different units of measurement, for instance, some papers used pauses per second (PPS) while others used pauses per minute (PPM). In these instances, the PPS values were multiplied by 60 to compare them to the PPM values. D) Pause duration per minute (s) E) Noun-verb ratio. F) Number of nouns shows the number of noun tokens per total words (Catricala et al., 2019; Fraser et al., 2014; Graham et al., 2004; Matias-Guiu et al., 2022; Thompson et al., 1997), per 100 words (Ash et al., 2013, 2016; Cho et al., 2022; Parjane et al., 2021), and the total count (Mack et al., 2015). Despite the variation in the units used, the values were found to be comparable on the same scale, ranging from 0 to 70 and were therefore plotted and displayed within the same graph to allow a rough comparison across studies in English and Spanish. Studies based on nouns per utterance were excluded (Ash, 2009) because it was not possible to compare these results with the other three metrics. See Supplemental Table 2 for full list of studies included in Figure 4.

*WPM = words per minute, PPM = pauses per minute. Different languages are represented by different colors. * Shows which groups were significantly different to controls (in at least half of papers). Colour of*

As is shown in Figure 4A, the **speech rate** of patients was reduced compared to controls in more than half the papers for all patient groups. Lines in Figure 4 connect groups reported in the same study. However, a Greek patient population showed a reduced speech rate in nvPPA while lvPPA and svPPA had no significant reduction in speech rate (Potagas et al., 2022). A second paper investigating Greek patients with PPA also found no significant reduction in speech rate, though they did not differentiate between the

variants (Karpathiou & Kambanaros, 2022). The majority of English patient populations with lvPPA, svPPA, and bvFTD showed significant reductions in speech rate. Aside from Greek, all other non-English languages (Spanish, Italian, Hindi, and Czech) studying the FTD spectrum had a significant reduction in speech rate although not every patient group has been studied (Catricala et al., 2019; Daoudi et al., 2022; Matias-Guiu et al., 2022; Sachin et al., 2008; Silveri et al., 2012; Potagas et al., 2022). The values of healthy controls did not visibly differ based on language. However, considerable variability within the English-speaking controls was observed.

Figure 4B shows that the **articulation rate** was reduced compared to controls in more than half of papers investigating nvPPA, lvPPA, and PSP. As is visible in Figure 4B, there was an overall trend of Spanish patients and controls to exhibit the highest values for articulation rate and Greek patient and control samples to exhibit the lowest values (Baque et al., 2022; Potagas et al., 2022). A study investigating Greek PPA patients also found a significant reduction in articulation rate, though again they did not differentiate between the variants (Karpathiou & Kambanaros, 2022). On the other hand, the lvPPA Spanish and Greek patient samples did not exhibit a significant difference compared to healthy controls from the same language group, while the English patient samples had a significantly reduced articulation rate (Cho et al., 2022; Cordella et al., 2019; Cordella et al., 2017). PSP patients had a significantly reduced articulation rate in both Czech and German patient samples (Rusz et al., 2015; Skrabal et al., 2020; Staiger et al., 2017). ALS-FTD also had a significantly reduced articulation rate in English patients (Yunusova et al., 2016), however there was no significant difference in the Spanish patient sample (Baque et al., 2022). Finally, the bvFTD patient samples did not have a significant difference in articulation rate compared to controls for both the English and Spanish patient groups (Baque et al., 2022; Yunusova et al., 2016). The values of healthy controls do not noticeably differ based on language.

As can be seen in Figure 4C, the **pause frequency** was increased in nvPPA in English-speaking patient samples as well as Greek (Cordella et al., 2017; Nevler et al., 2019; Parjane et al., 2021; Potagas et al., 2022). For lvPPA, svPPA, and ALS-FTD patient groups, the difference was not significant in most papers

in both Greek and English-speaking patient samples (Cordella et al., 2017; Potagas et al., 2022; Yunusova et al., 2016). For PSP and CBS, the pause frequency was also increased in one English patient sample (Parjane et al., 2021). As shown in Figure 4D, the **total pause duration** was significantly increased in nvPPA, lvPPA, bvFTD, PSP, CBS, and ALS-FTD in all English, Spanish, and Greek-speaking patient samples (Matias-Guiu et al., 2020; Parjane et al., 2021, 2021; Potagas et al., 2022; Yunusova et al., 2016). In one relatively small Greek svPPA sample there was an increase in pause duration (visible in Figure 4D). However this difference was not found to be significant (Potagas et al., 2022). The values of healthy controls do not appear to differ based on language for total pause duration.

As is shown in Figure 4E, the **noun-verb ratio** was significantly reduced in the majority of the English patient groups with svPPA (Fraser et al., 2014; Garrard & Forsyth, 2010; Mack et al., 2015; Thompson et al., 2012). However, in one Spanish patient sample there was no significant difference in this ratio (Matias-Guiu et al., 2022). For the English, Spanish, and Italian patients with nvPPA, lvPPA, and PSP there were no significant differences in the noun-verb ratio (Catricala et al., 2019; Fraser et al., 2014; Graham et al., 2004; Knibb et al., 2009; Mack et al., 2015; Marcotte et al., 2017; Matias-Guiu et al., 2022; Thompson et al., 1997; Thompson et al., 2012). Some variability was observed for noun-verb ratio in the English-speaking control group (the highest having a ratio of 1.55 (Fraser et al., 2014) and the lowest a ratio of 0.9 (Garrard & Forsyth, 2010)). The Italian-speaking control group had the highest noun-verb ratio. Figure 4F reports the values for noun tokens and combines the quantitative number of noun tokens per total words, per 100 words, and the total count. As is shown in Figure 4F, the **number of noun tokens** was significantly decreased in nvPPA, lvPPA, and svPPA, in both Spanish (for total number of tokens) (Matias-Guiu et al., 2022) and English-speaking patients (for nouns per 100 words, per total words, total noun count, and for nouns per utterance – which is not plotted because of the difference in units) (Ash et al., 2009; Cho et al., 2022; Cupit et al., 2017; Fraser et al., 2014; Graham et al., 2004; Mack et al., 2015). In contrast, the number of noun tokens per 100 words was significantly increased in PSP and CBS in one English patient sample (Parjane et al., 2021). There was no significant difference in the number of noun tokens per utterance in

bvFTD in one English-speaking patient sample (Ash et al., 2009), which is not plotted because of the difference in measured units. The values of healthy controls do not appear to differ based on language for the number of noun tokens.

Further information about the speech and language alterations found in FTD can be found in supplementary Table 1, which includes the sample sizes, languages, speech and language features studied, and relevant findings of all included papers.

Exploratory Meta-Analysis

An exploratory meta-analysis was attempted on the six features which were found to be the most generalizable based on the systematic literature review. For the meta-analysis, the following variables were extracted from 45 papers studying the relevant features: mean values, standard deviation, sample size, language, and task. Hedge's g and variance were calculated for each study. A random effects model with a restricted maximum likelihood (REML) was selected due to the range of tasks, languages, and patient groups that were studied. The analyses were performed using the "rma" function from the metafor package in R (Viechtbauer, 2010). An insufficient number of studies investigated individual variants of FTD and different tasks or languages (other than English). For this reason, a moderator analysis was not included for variant, task, or language.

For all 6 features, we observed very high heterogeneity (I^2 : between 79.31 and 97.16%) and significant p -values for Cochran's Q Test ($P < 0.001$). Given the very high heterogeneity, we concluded that insufficient data was available to pursue a further meta-analysis.

4. DISCUSSION

This review shows that the most generalizable speech and language features of FTD across languages are speech rate, articulation rate, pause frequency, total pause duration, noun-verb ratio, and number of noun tokens. Four out of the six features are in the phonetic and phonological category and the remaining two

are in the lexico-semantic category. Phonetic and phonological features were useful in the detection of nfvPPA and PSP. In contrast, lexico-semantic features were more able to detect svPPA. Our results suggest that connected speech analyses on relatively short samples can be used across multiple diverse languages to detect emerging neurodegenerative diseases in the FTD-spectrum. Our findings also promote the use of not just one single feature but advocate for the creation of an individualized speech and language profile for each phenotype combining both phonological and lexico-semantic features.

With regard to the phonetic and phonological features, one aspect that should be considered is the fact that nfvPPA is the most widely studied of the variants, both in number of papers and number of languages. NfvPPA tends to have more alterations at the speech sound level, in the phonetic and phonological category, which is reflected in the fact that such features were found to be generalizable. While phonetic and phonological features offer the most potential as interlinguistic markers of nfvPPA, inter-linguistic differences have been described in patients with nfvPPA. For instance, when comparing Italian nfvPPA patients to English nfvPPA patients, Canu et al., 2020 found significant differences in the number of motor speech errors. In addition, work in Chinese patients with nfvPPA shows an increase in compound word production and in radical dysgraphia (substitution, transposition, omission, or addition of graphical units) relative to English patients (Tee et al., 2022). Despite differences, the findings of this review show generalizable results across language groups for phonetic and phonological features. The literature suggests that phonetic and phonological features may be broadly applicable in the Indo-European languages, in PSP as well as nfvPPA, with Hindi as an Indo-Iranian language (Potagas et al., 2022; Sachin et al., 2008), Greek as a Hellenic language (Potagas et al., 2022), Czech as a Slavic language (Daoudi et al., 2022; Rusz et al., 2015; Skrabal et al., 2020), Italian, French, and Spanish as Romance languages (Baque et al., 2022; Bouvier et al., 2021; Silveri et al., 2014), and English and German as Germanic languages (Hohlbaum et al., 2018; Parjane et al., 2021).

The lexicosemantic features of speech and language were, as expected, the most studied and generalizable features for svPPA, though they were only studied in Indo-European languages. However, lexicosemantic

features also offer the potential to diagnose lvPPA. Due to its underlying pathology, lvPPA is often considered an atypical variant of Alzheimer's Disease (AD), rather than a variant of FTD. This could have constituted a reason to exclude such cases in the present review. However, as lvPPA patients are an integral clinical phenotype within the primary progressive aphasia, and as it is often a necessary challenge to differentiate nvPPA and lvPPA at an early stage, we chose to include these cases. Moreover, findings of speech and language differences in lvPPA may inform the study of typical AD patients. For instance, the number of nouns is reduced in connected speech in both AD and lvPPA (Fraser et al., 2016; Matias-Guiu et al., 2020). Pronoun use is also increased in both lvPPA and AD (Boschi et al., 2017; Lavoie et al., 2021; Slegers et al., 2018; Wilson et al., 2010). In addition, impaired naming abilities are typically found in both disorders (Brandt et al., 2010; Evrard, 2002; Jebahi et al., 2023).

Morphosyntactic and syntactic features tend to differ across languages so it was expected that these features would be less generalizable, though they are associated with nvPPA, which was most frequently studied. Discourse and pragmatic features were not widely studied in the reviewed papers, and definitions of cohesiveness and coherence varied greatly. However, with consistent measures, this category may still contain generalizable features of the FTD spectrum.

Defining the variants of PPA poses a challenge in the clinic, as the optimal diagnostic tools and definitions of certain speech and language abnormalities are still subject to debate. It is also likely that the criteria for PPA derived in English-speaking patients do not perfectly map onto those of non-English-speaking PPA patients (Tee et al., 2022). For instance, word repetition tasks with polysyllabic words with consonant clusters, often used in English to detect PPAOS, are not applicable for Chinese patients, as Cantonese is generally monosyllabic (Tee et al., 2022). Even within English, there is some contention regarding aspects such as motor speech, which has variable definitions depending on the authors and clinicians (Duffy et al., 2014; Grossman, 2018).

While the Indo-European languages are relatively well represented in the papers included in this review, data is lacking entirely for some major language groups. At the time of writing there are no known papers

studying connected speech in FTD for the Uralic, Altaic, Caucasian, Sino-Tibetan, Tai, Austronesian, Niger-Congo, or Afro-Asiatic language families. The absence of diverse language representation in FTD research hinders tailored characterization and sensitive assessment methods for non-English speaking patients. This gap could result in delayed or misdiagnosis, and ultimately perpetuate healthcare disparities. However, some research is being carried out investigating language in FTD for these language groups. For instance, the Genetic FTD Initiative (GENFI) consortium is starting to investigate Finnish (a Uralic language). Further research is necessary to determine whether the results from Indo-European languages apply to these other major language groups.

Another consideration when investigating speech and language markers is the difference in quantitative values across different languages, as well as the variation seen within languages. It is difficult to discern which differences are due to linguistic differences and which are due to differences in methods and metrics. Differences in task use likely contribute to the observed variation within English controls. Differences in units of measurement presented significant challenges when comparing the quantitative values of features across different studies in Figure 4. This issue was especially pronounced for “non-normalized” features such as total pause duration (Figure 4D) and the number of noun tokens (Figure 4F).

Additionally, FTD is a very heterogenous group, and disease stage plays a great role. Different studies often include patients with different disease severities, which may also contribute to the observed variation within English patients. Standardization using z-scores based on norms for each language would make comparisons across languages feasible and allow us to apply findings to less-studied language groups. On the other hand, simply translating speech and language tests into another language is not always possible; for every language, linguistically and culturally equivalent tasks are necessary and should be developed to elicit valid responses (Fyndanis et al., 2017).

In alignment with the findings of García et al., 2023 on speech and language research in neurodegenerative diseases, we reiterate the need for cross-linguistic behavioural research in the FTD spectrum. Collection of data in a standardized and transparent way is vital for future comparisons across languages and disorders,

in order to determine accurate baseline values to detect different disorders. This requires the adaptation of tasks for the study of connected speech to other languages. We show a clear need for further investigation of speech and language markers of the FTD spectrum in more non-English languages, especially non-Indo-European languages.

5. LIMITATIONS

Certain limitations should be taken into consideration when interpreting the findings of this systematic literature review. Firstly, the different tasks and methods used to elicit connected speech in the studies varied widely (see Figure 2). These variations likely influenced the observed differences, highlighting the need for further research to determine potential interactions between task type, patient language, disease severity, and diagnosis. Related to this, the reviewed papers use variable units of measurement for speech and language features; without standard units of measurement, comparison between values across different papers is limited. Secondly, the sample sizes in many of the included studies were limited. This, combined with the fact that very few studies investigated connected speech in FTD patients in non-English languages, makes extrapolating findings from English-speaking to non-English-speaking populations challenging. Future research should aim to include a more diverse range of languages to improve the generalizability of the results. The high heterogeneity between studies and lack of inclusion of non-English languages also prevented a robust meta-analysis to determine the linguistic effects on effect size.

6. CONCLUSION

The findings of this systematic review show that while interlinguistic differences in FTD patients exist, there may indeed be features of speech and language that are generalizable across several languages. Certain phonological and lexico-semantic features offer the potential for future implementation as interlinguistic markers of FTD. Further study of these variables in different languages and across the FTD spectrum will determine the applicability of these markers in the clinic.

7. COMPETING INTERESTS

The authors declare the following competing interests:

Jonathan D. Rohrer: received a grant from Bluefield Project Alzheimer's Association and receives consulting fees from Novartis, Wave Life Sciences, Prevail, Alector, Aviado Bio, Takeda, Arkuda therapeutics, and Denali Therapeutics.

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FIGURE CAPTIONS

Figure 1

PRISMA flowchart of methods of systematic literature review

Figure 2

The (A) geographical locations and (B) language representation analysis of the 76 included papers.

Figure 3

The tasks used by the papers in the review in English and non-English speakers.

Figure 4

The quantitative values of each paper studying the 6 most generalizable features. Lines in the plot connect groups from the same study. A) Speech rate: the papers investigating syllables per second were combined with papers investigating words per minute (after being multiplied by 60). This does not appear to have affected the results, as the highest values for speech rate do not measure syllables per second, but words per minute. B) Articulation rate: for the papers using syllables per minute or words per minute, the values were divided by 60 to compare to the values of the papers using syllables per second. C) Pause frequency: certain papers used different units of measurement, for instance, some papers used pauses per second (PPS) while others used pauses per minute (PPM). In these instances, the PPS values were multiplied by 60 to compare them to the PPM values. D) Pause duration per minute (s) E) Noun-verb ratio. F) Number of nouns shows the number of noun tokens per total words (Catricala et al., 2019; Fraser et al., 2014; Graham et al., 2004; Matias-Guiu et al., 2022; Thompson et al., 1997), per 100 words (Ash et al., 2013, 2016; Cho et al., 2022; Parjane et al., 2021), and the total count (Mack et al., 2015). Despite the variation in the units used, the values were found to be comparable on the same scale, ranging from 0 to 70 and were therefore plotted and displayed within the same graph to allow a rough comparison across studies in English and

Spanish. Studies based on nouns per utterance were excluded (Ash, 2009) because it was not possible to compare these results with the other three metrics. See Supplemental Table 2 for full list of studies included in Figure 4.

*WPM = words per minute, PPM = pauses per minute. Different languages are represented by different colors. * Shows which groups were significantly different to controls (in at least half of papers). Colour of * shows which language was significantly different for which group.*

TABLES

Table 1

The number of studies investigating connected speech in FTD in different languages.

Language	Number of Studies
English	57
Greek	4
Spanish	3
Czech	3
Italian	2
French	2
German	2
Korean	1
Hindi	1
Dutch	1
Total	76

Table 2

The definitions of the 44 linguistic and psychoacoustic features studied in more than one language in the FTD spectrum. References to the papers can be found in the supplementary materials.

Linguistic Feature	Definition of Feature	Languages studying Feature
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Phonetic and Phonological		
false starts	the number of partial words spoken	English, Spanish
F0 standard deviation	the degree of variability of the fundamental frequency of speech	English, Czech
PVI strong-weak	the pairwise variability index of length of syllables words	English, Dutch
PVI weak-strong	the pairwise variability index of length of syllables words with a weak-strong timing, includes median and mean	English, Dutch
intensity level	the intensity level of speech	English, Czech
pause frequency	the frequency that filled pauses occur	English, Greek
mean pause duration	the average of the pause durations in speech	English, Greek
total pause duration	the total pausing time throughout speech	English, Spanish, Greek
number of pauses	the total number of pauses that occur in speech	English, Spanish, Greek, Italian
pause duration variability	the standard deviation of pausing during speech	English, Spanish
speech rate	the number of speech units per time. Included in this feature are - words per minute, syllables per second and content units per second	English, Spanish, Greek, Italian, Czech
articulation rate	the number of syllables per total speech time. Included in this feature are - words per second and syllables per second	English, Spanish, Greek, German, Czech
total speaking time	the total response time taken to speak on a topic	English, Spanish, Italian
median silence length	the median length of silent pauses with no filler words.	English, Spanish
percentage of speech	the percentage of speech in the total response	English, Spanish
Lexico Semantic		
pronoun ratio	the total pronouns divided by the total words	English, Italian
#nouns/#words	the total number of nouns divided by the total number of words	English, Italian
nouns (token)	the total number of nouns spoken	English, Spanish
verbs (token)	the total number of verbs spoken	English, Spanish
#verbs/#words	the total number of verbs divided by the total number of words	English, Italian
No. closed-class words	the total number of closed-class words	English, Spanish
noun-verb ratio	the total number of nouns divided by the total number of verbs	English, Spanish
verb frequency	the frequency of the verbs spoken based on occurrence in speech corpus	English, Spanish
noun frequency	the frequency of the nouns spoken based on occurrence in speech corpus	English, Spanish
nouns per 100 words	the total number of nouns divided by the number of hundred words spoken	English, Spanish
inaccurate/irrelevant information	the total number utterances that are unrelated to the question or task at hand	English, Italian
conduites d'approche	the repetition of a response several times in succession with or without improvement	Spanish, Italian
content units	the number of speech units that contain information	English, Italian
Morphosyntactic Syntactic		

total dependent clauses	the total number of dependent clauses	English, Italian
total words/total time	the total number of words divided by the total time spent speaking	English, Spanish, Italian
syllable duration	the average duration of syllables	English, German
total words	the total number of words spoken	English, Spanish, Greek, Italian
MLU	the mean length utterance in speech	English, Spanish, Italian
number of sentences	the total number of sentences spoken	English, Italian
total utterances	the total number of utterances spoken	English, Italian
mean length of sentence	the mean length of sentences in speech	English, Greek
Errors		
number of errors	the total number of errors in speech	English, Spanish
number of errors/number of words	the total number of errors divided by the total number of words	English, Spanish
word omissions	the total number of word omissions	English, French
word repetitions	the total number of word repetitions	English, French
phonological	the total number of phonological errors	English, Spanish
Semantic	the total number of semantic errors	English, Italian
phonetic errors	the total number of phonetic errors	English, Italian
Phonemic	the total number of phonemic errors	English, Italian

Table 3 a) *features with the same finding in more than one language in PPA*

Linguistic Feature	PPA/mxPPA	Languages	nfvPPA	Languages	lvPPA	Languages	svPPA/SD
Phonetic and Phonological							
PVI strong-weak			nfvPPA<HC**	G EN, DU	-		-
Pause frequency			nfvPPA>HC**	G EN, GR	-	g EN, GR	- n EN, GR
Total pause duration	PPA>HC*		nfvPPA>HC**	G EN, GR, SP	lvPPA>HC**	G GR, SP	- g GR, SP
Number of pauses	PPA>HC*	GR	nfvPPA>HC**	G EN, SP	lvPPA>HC*		-
Speech rate	PPA<HC**	n EN, GR, SP	nfvPPA<HC**	G EN, GR, SP, IT	lvPPA<HC**	n EN, GR, SP, IT	svPPA<HC* n EN, SP, GR, IT
Articulation rate	-	GR	nfvPPA<HC**	G EN, GR, SP, FR	lvPPA<HC**	n EN, GR, SP	- n EN, SP, GR
Total speaking time			nfvPPA<HC**	G EN, SP	lvPPA<HC*		-
Lexico Semantic							
Nouns (token)			nfvPPA<HC**	n EN, SP	lvPPA<HC**	G EN, SP	svPPA<HC** G EN, SP
Verbs (token)			nfvPPA<HC**	n EN, SP	-	g EN, SP	- g EN, SP
Noun-verb ratio			-	g EN, SP	-	g EN, SP	svPPA<HC** G EN, SP
Noun frequency			-	g EN, SP	-		svPPA>HC** n EN, SP
Nouns per 100 words			-	g EN, SP	lvPPA<HC*	n EN, SP	svPPA<HC** n EN, SP
Morphosyntactic Syntactic							
Total words	PPA>HC*		nfvPPA<HC**	G EN, SP	-		-
MLU	PPA>HC*		nfvPPA<HC**	G EN, SP, IT	lvPPA<HC**	n EN, SP, IT	- n EN, IT
Errors							
Number of errors/number of words			nfvPPA>HC**	G EN, SP	lvPPA>HC*	n EN, SP	svPPA>HC* n EN, SP
Word repetitions					lvPPA>HC*	G EN, FR	
Incomplete sentences			-	-		-	
Syntactic errors			-	lvPPA>HC*		-	

b) features with the same finding in more than one language in bvFTD, PSP, and ALS-FTD

Linguistic Feature	bvFTD	Languages	PSP	Languages	ALS-FTD
Phonetic and Phonological					
PVI strong-weak					
Pause frequency					-
Total pause duration	bvFTD>HC*				ALS-FTD>HC*
Number of pauses	bvFTD>HC*				
Speech rate	bvFTD<HC**		PSP<HC**	G EN, CZ, IT, HI	ALS-FTD<HC*
Articulation rate	-	g EN, SP	PSP<HC**	G CZ, GE	ALS-FTD<HC* n EN, SP
Total speaking time	-		-		
Lexico Semantic					
Nouns (token)	-		PSP>HC*		
Verbs (token)	-		-		
Number of closed-class words					
Noun:verb ratio			-		
Noun frequency					
Nouns per 100 words	bvFTD<HC*				
Morphosyntactic Syntactic					
Total words	bvFTD<HC**		PSP<HC*		
MLU	-		-		
Errors					
Number of errors/number of words	-				
Word repetitions					
Incomplete sentences	-		-		
Syntactic errors	-		PSP>HC*		

Note: - attested in at least one paper and insignificant in more than half of papers; *attested and significant in one paper and significant in half or more of papers; **attested and significant in two or more papers and significant in half or more of the papers, g: same insignificant result in more than one language, G: same significant result in more than one language, n: different result in more than one language. The features in **bold** are generalisable in more than one variant.

Supplemental Table 1

Supplementary materials Table 1. HC : Healthy controls, PPA : Primary progressive aphasia, nfvPPA: non-fluent variant PPA, svPPA : semantic variant PPA, lvPPA : logopenic variant PPA, FTD : Frontotemporal dementia, bvFTD : Behavioural variant FTD, PSP : Progressive supranuclear palsy, CBS : Corticobasal degeneration, ALS-FTD : Amyotrophic lateral sclerosis with FTD. Papers are ordered by year, followed by first author name.

Year	First Author	Language	Participants	Methods	Speech and Language features	Results (significant only)
2022	Baque	Spanish	4 HC, 4 nfvPPA, 2 svPPA, 4 lvPPA, 5 bvFTD 4 ALS-FTD	reading task	total silence duration, median/mean silence length, variability of silence duration, silent pause: filled pause + speech, silent pause: total speech duration, articulation rate, total reading time, percentage of speech, total words/total time, speech segments between pauses, sum of speech segments between pauses, duration of longest phonic group, mean duration of phonic groups between silent pauses, median duration of phonic groups, standard deviation of the duration of the phonic groups, total number of syllabic nuclei of the longest phonic group obtained manually, mean duration of the syllables of the phonic group of maximum duration	articulation rate - decreased for nfvPPA, total reading time - decreased for lvPPA, speech segments between pauses - increased for nfvPPA, lvPPA, mean duration of the syllables of the phonic group of maximum duration - increased for lvPPA
2022	Bruffaerts	Dutch	24 HC, 12 nfvPPA, 11 svPPA	picture description – cookie theft, repetition task – Akense Afasie task	PVI of vowel nucleus duration, vowel duration	PVI (weak-strong words) – reduced in nfvPPA, vowel duration (strong-weak words first vowel) – increased in nfvPPA, vowel duration (strong-weak words second vowel) – increased in nfvPPA, vowel duration (weak-strong words first vowel) – increased in nfvPPA
2022	Cho	English	28 HC, 21 lvPPA	picture description - cookie theft	Tense-inflected verbs, dysfluency markers, and for each word: the concreteness, semantic ambiguity, frequency, age at acquisition, and familiarity, word length by the number of phonemes, moving-average type-token ratio (measure of lexical diversity), mean speech segment duration, mean pause segment duration, percent of speech, and pause rate per minute, articulation rate (syl/sec), pitch range	tense-inflected verbs - reduced in lvPPA, lexical diversity- reduced in lvPPA, adjectives- reduced in lvPPA, fillers - increased in lvPPA, pause rate - increased in lvPPA, partial words - increased in lvPPA, prepositions - reduced in lvPPA, nouns - reduced in lvPPA, speech segment length - reduced in lvPPA, % speech time - reduced in lvPPA, content word length - reduced in lvPPA, content word frequency - increased in lvPPA, content word acquisition age - increased in lvPPA, concreteness - increased in lvPPA, adverbs and repetitions - increased in lvPPA, speech rate - reduced in lvPPA, total words - reduced in lvPPA
2022	Daoudi	Czech	150 HC, 20 PSP	reading task, 90s monologue on chosen theme	fundamental frequency variability (F0 SD), relative loudness of respiration (RLR), rate of speech respiration (RSR), pause intervals per respiration (PIR), gaping in-between voiced intervals (GVI), duration of stop consonants (DUS), resonance frequency attenuation (RFA), entropy of speech timing (EST), rate of speech timing (RST)	RLRm - increased in PSP, RSRm/t - increased in PSP, PIRm - decreased in PSP, PIRt - decreased in PSP, GVIm/t - decreased in PSP, DUSm - increased in PSP, DUS (increased in PSP), ESTm - decreased in PSP, ESTt - decreased in PSP, RSTm - decreased in PSP, RSTt - decreased in PSP, ASTt - decreased in PSP, stdF0t - increased in PSP, NSRt - decreased in PSP. (t: text, m: monologue).
2022	Garcia	English	10 HC, 22 nfvPPA, 15 svPPA	reading task - grandfather passage	Articulation rate, syllable duration, pause duration, syllable duration variability, pause duration variability	articulation rate – decreased in nfvPPA and svPPA, syllable duration – increased in nfvPPA and svPPA, pause duration – increased in nfvPPA and svPPA, syllable duration variability – increased in nfvPPA and svPPA, pause duration variability - increased in nfvPPA and svPPA
2022	Karpathiou	Greek	15 HC, 10 PPA	cookie theft and a story retell task	Articulation rate, speech rate, mean pause duration, number of pauses, total words, mean length sentences, sentence elaboration index, type token ratio, embedding index, narrative words/total words, mean log frequency of narrative words, dysfluencies per total words	Articulation rate - decreased in mxPPA, mean pause duration - increased in mxPPA, number of pauses - increased in mxPPA, total words - decreased in mxPPA, mean length sentences - decreased in mxPPA, sentence elaboration index - decreased in mxPPA, type token ratio - decreased in mxPPA, embedding index - decreased in mxPPA, narrative words/total words - decreased in mxPPA, mean log frequency of narrative words - increased in mxPPA, dysfluencies per total words - increased in mxPPA

Year	First Author	Language	Participants	Methods	Speech and Language features	Results (significant only)
2022	Matias-Guiu	Spanish	31 HC, 31 nfvPPA, 45 lvPPA, 11 svPPA	picture description – cookie theft	speech rate (WPM), total words, nouns (token), verbs (token), percentage of verbs, number of open-class words, number of closed-class words, noun-verb ratio, nouns frequency, verb frequency, nouns per 100 words, percentage of mazes, number of different words, different words per time, number of errors, number of errors/number of words	speech rate – decreased in nfvPPA, lvPPA, total words – decreased in nfvPPA, insignificant in lvPPA, svPPA, nouns (token) – decreased in nfvPPA, lvPPA, svPPA, verbs (token) – decreased in nfvPPA, number of open-class words – increased in nfvPPA, lvPPA, svPPA, number of closed-class words – decreased in nfvPPA, lvPPA, nouns per 100 words – decreased for lvPPA, svPPA, percentage of mazes – increased in nfvPPA, lvPPA, svPPA, number of different words – decreased in nfvPPA, lvPPA, svPPA, different words per time – decreased in nfvPPA, lvPPA, svPPA, number of errors/number of words – increased in nfvPPA.
2022	Potagas	Greek	17 HC, 6 nfvPPA, 6 svPPA, 8 lvPPA	Picture description - cookie theft, personal narration - description of course of disease	Pause frequency, pause total duration, speech rate, articulation rate	pause frequency (picture description) - increased in nfvPPA, lvPPA, and svPPA, pause frequency (personal narration) - increased in nfvPPA, lvPPA, pause total duration (picture description) - increased in nfvPPA, lvPPA, pause total duration (personal narration) - increased in nfvPPA, speech rate (picture description) - decreased in nfvPPA, lvPPA, speech rate (personal narration) - decreased in nfvPPA, lvPPA, articulation rate (picture description) - decreased in nfvPPA, lvPPA, articulation rate (picture description) - decreased in nfvPPA
2022	Rezaii	English	53 HC, 29 nfvPPA, 26 lvPPA, 24 svPPA	picture description - picnic scene, topic-directed interview	content word frequency, frequency of syntactic constructions	content word frequency - decreased in nfvPPA, increased in lvPPA, svPPA, frequency of syntactic constructions - increased in nfvPPA, decreased in lvPPA, svPPA
2021	Bouvier	Quebec French	30 HC, 9 PPAOS, 4 DAOS	repetition task - TEst Français de Répétition de Phrases (TEFREP)	Length of speech runs (number of syllables), Articulation rate (syllables/s), normalized pairwise variability index (nPVI)	Length of speech runs (number of syllables) - reduced in PPAOS, articulation rate (syllables/s) - reduced in PPAOS, normalized pairwise variability index (nPVI) - reduced in PPAOS
2021	Gallee	English	31 nfvPPA, 25 HC, 26 lvPPA, 15 svPPA	Picture description - picnic	content units (raw and normalized), self-referential utterances, inability to express, tangential utterances, empty utterances, false starts	content units - decreased in nfvPPA, lvPPA, and svPPA, content units/total utterances - decreased in lvPPA, and svPPA, self-referential utterances - increased in svPPA, inability to express - increased in svPPA and lvPPA, empty utterances - increased in lvPPA, false starts - increased in lvPPA
2021	Lavoie	English	13 HC, 13 lvPPA	picture description - cookie theft, narrative task - Cinderella, semi-structured interview	mean length of sample, proportion open-class words, proportion nouns, proportion pronouns, proportion verbs, proportion well-formed sentences	mean length of samples - insignificant for lvPPA, proportion of open-class words - reduced in lvPPA, proportion of verbs - increased in lvPPA, proportion of pronouns - increased in lvPPA, well-formed sentences - reduced in lvPPA
2021	Mack	English	40 HC, 34 nfvPPA, 16 lvPPA, 15 svPPA, 12 mxPPA	Narrative task - Cinderella story, Sentence Production Priming Test (SPPT) and the Northwestern Anagram Test (NAT)	clause diversity, narrative accuracy	clause diversity - reduced for mxPPA, nfvPPA, lvPPA, svPPA, narrative accuracy - reduced for mxPPA, nfvPPA, lvPPA, svPPA
2021	Macoir	Quebec French	12 HC, 4 lvPPA	repetition subtests of the batterie d'évaluation cognitive du langage (battery of cognitive assessment of language), test français de répétition de phrases (French sentence repetition test)	repetition accuracy (error typing)	word omissions - increased in lvPPA, word additions - increased in lvPPA, and word repetitions - increased in lvPPA
2021	Parjane	English	41 HC, 25 nfvPPA, 87 PSP-CBS	Picture description - cookie theft	mean speech segment duration, mean pause segment duration, and pause rate, fundamental frequency (f0), Speech rate, dependent clauses per 100 utterances (DC), noun and verb production and percentage of utterances that are well-formed sentences (WFS).	nfvPPA and PSPS-CBS speech produced shorter speech segments, longer pauses segment durations, higher pause rates, reduced fundamental frequency (f0) pitch ranges, and slower speech rate compared to HC. WPM was lower in both patient groups, verb production was lower in nfvPPA and insignificant in PSP-CBS, noun tokens per 100 words higher in PSP-CBS and insignificant in nfvPPA.

Year	First Author	Language	Participants	Methods	Speech and Language features	Results (significant only)
2020	Faroqi-Shah	English	25 HC, 10 nfvPPA, 9 lvPPA, 7 svPPA	picture description - cookie theft	WPM, total number of dysfluencies, moving average type token ratio, idea density (# of propositions (non-noun entities)/ 10 words), CUs (Total # correct information units/ Total # words in sample), total semantic errors, total phonological errors, total word retrieval errors, MLU, proportion of grammatical utterances, verbs per utterance, sentence complexity, total morphological errors, total errors	speech rate (WPM) - reduced in PPA, total number of dysfluencies - increased in PPA, CUs (Total # correct information units/ Total # words in sample) - reduced in PPA, total phonological errors - increased in PPA, total word retrieval errors - increased in PPA, proportion of grammatical utterances - reduced in PPA, total errors - increased in PPA.
2020	Jarrod	English	10 HC, 14 nfvPPA, 25 svPPA, 11 lvPPA, bvFTD	Picture description - picnic	ratio of pronouns to verbs	pronoun to verb ratio - increased for svPPA
2020	Koukouloti	Greek	5 HC, 5 SD	sentence completion task	inflection past perfect/ present, inflection present, inflection past perfect/ imperfect, inflection past imperfect	inflection past perfect/ present - increased in SD, inflection present - increased in SD, inflection past perfect/ imperfect - increased in SD, inflection past imperfect - increased in SD
2020	Matias-Guiu	Spanish	31 HC, 23 nfvPPA, 41 lvPPA,	Narrative task - “Historia de un Pajarito” (A little bird story)	false starts, proportion pause, total pause duration, number of pauses, total reading time, total speaking time, percentage of speech, mean length utterances (MLU), mean duration utterances, time after full stops, sentence duration, pause number, pause duration, final rise, conduites d'approche, number of errors, phonological errors, number of errors short declarative, number of errors, function word changes	false starts - increased for nfvPPA, proportion pause - increased for nfvPPA, lvPPA, total pause duration - increased for nfvPPA, lvPPA, number of pauses - increased for nfvPPA, lvPPA, total reading time - decreased for nfvPPA, lvPPA, total speaking time - decreased for nfvPPA, lvPPA, percentage of speech - decreased for nfvPPA, lvPPA, mean length utterances (MLU) - decreased for nfvPPA, lvPPA, mean duration utterances - decreased for nfvPPA, lvPPA, time after full stops - increased for nfvPPA, sentence duration - increased for nfvPPA, lvPPA, pause number - increased for nfvPPA, lvPPA, pause duration - increased for nfvPPA, lvPPA, final rise - decreased for nfvPPA, conduites d'approche - increased for nfvPPA, lvPPA, phonological errors - increased for nfvPPA, lvPPA, number of errors short declarative - increased for nfvPPA, number of errors long declarative - increased for lvPPA, number of errors short exclamatory - increased for lvPPA, number of errors long exclamatory - increased for nfvPPA, lvPPA, number of errors short interrogative - increased for nfvPPA, number of errors long declarative - increased for nfvPPA, function word changes - increased for nfvPPA
2020	Skrabal	Czech	17 HC, 17 PSP	reading task - normally and in clear speech condition	intensity level, intensity variability, fundamental frequency variability (F0 SD), vowel space area (VSA), and articulation rate	F0 SD, VSA, and articulation rate - reduced in PSP.
2020	Zimmerer	English	20 HC, 34 nfvPPA, 25 lvPPA, 29 svPPA	holiday narrative	total words, combination ratio (how often longer combinations are produced), content word count, content word frequency, collocation strength	total words - reduced in nfvPPA, bvFTD, content word frequency - increased for lvPPA, svPPA, bvFTD, connectedness - reduced for nfvPPA, lvPPA, bvFTD, collocations - increased for svPPA.
2019	Ash	English	36 HC, 9 nfvPPA, 14 lvPPA, 11 svPPA	picture description - cookie theft	words per minute, speech errors/100 words, dependent clauses per 100 utterances, percentage of utterances that are well formed sentences	speech rate (WPM) - reduced for bvFTD, lvPPA, svPPA, and nfvPPA, speech errors per 100 words - reduced for lvPPA, svPPA, and nfvPPA, dependent clauses per 100 utterances - reduced for bvFTD, svPPA, and nfvPPA, percentage of utterances that are well formed sentences - reduced for bvFTD, lvPPA, svPPA, and nfvPPA
2019	Berube	English	50 HC, 44 PPA	Picture description task - updated cookie theft	number of syllables, content units (CUs), syllables per CU, and the ratio of left-right CUs (information from left and right sides of image)	number of syllables - reduced in mxPPA, content units (CUs) - reduced in mxPPA, syllables per CU - reduced in mxPPA, ratio of left-right CUs - increased in mxPPA

Year	First Author	Language	Participants	Methods	Speech and Language features	Results (significant only)
2019	Catricala	Italian	27 HC, 17 PSP	Picture description task - seaside scene	speech rate (total words/total time), total locution time, number of pauses (number/total locution time), between-utterance pause duration, phonemic errors (Well-articulated phoneme substitutions, additions, transpositions, and deletions/total words), noun rate, verb rate, pronoun rate, noun-verb ratio, quantifiers, repaired sentences, semantic errors, mean length sentences, total sentences, incomplete sentences, dependent clauses, morpho-syntactic errors, total words, information units, micro proposition, implausible or irrelevant details, index of discourse effectiveness (The ratio of the total number of recalled words divided by the number of information units. Index of discourse effectiveness/total sentences), errors in content elements, referential cohesion errors (Total number of referential cohesive ties (pronouns), used in an ambiguous or erroneous way. Referential cohesion errors/total pronouns), efficiency	percentage of speech - decreased for PSP, syllable duration variability - decreased for PSP, number of sentences - decreased for PSP, mean length of sentence - decreased for PSP, proportion pronouns - increased for PSP, maintenance of search theme - decreased for PSP, incomplete sentences - increased for PSP
2019	Cordella	English	20 HC, 22 nvfPPA, 23 lvPPA, 19 svPPA	Picture description - picnic	Articulation rate (syllables per second)	articulation rate - reduced for nvfPPA, lvPPA, and svPPA
2019	Nevler	English	31 HC, 15 nvfPPA, 21 svPPA, 23 lvPPA	picture description - cookie theft	fundamental frequency, speech and pause durations.	fundamental frequency - reduced in nvfPPA, pause rate - reduced in nvfPPA, svPPA, and lvPPA, mean speech duration - reduced in nvfPPA, svPPA, and lvPPA
2019	Pressman	English	170 HC, 29 bvFTD, 14 rtFTD, 14 nvfPPA, 19 svPPA	conversation	speech rate (syllables/second), variation of fundamental frequency, and standard deviation of intensity	speech rate (syllables/second) - reduced in bvFTD, nvfPPA.
2018	Hohlbaum	German	7 HC, 8 lvPPA	repetition task with: (a) simple S-V-O sentences, (b) sentences with a temporal adverb, (c) questions	sentence repetition errors	repetition errors - increased in lvPPA
2018	Koukouloti	Greek	7 HC, 7 SD	elicited speech production task	verb retrieval	verb production - decreased in SD
2017	Cordella	English	8 HC, 11 nvfPPA, 14 lvPPA, 13 svPPA	Picture description - picnic	total syllables/total response, articulation rate, pause frequency, proportion pause, mean pause duration	total syllables/total response - reduced in nvfPPA, lvPPA, and svPPA, articulation rate - reduced in nvfPPA, lvPPA, and svPPA, pause frequency - increased in nvfPPA, proportion pause - increased in and lvPPA, mean pause duration - increased in nvfPPA.
2017	Cousins	English	31 HC, 20 svPPA, 42 bvFTD	picture description - cookie theft	noun concreteness, number of words produced, number of nouns per 100 words	number of words produced - reduced in svPPA and bvFTD, number of nouns per 100 words - reduced in svPPA and bvFTD, noun concreteness - reduced in svPPA and bvFTD
2017	Cupit	English	23 HC, 18 nvfPPA, 13 svPPA	constrained picture description task, eliciting active, passive, dative, and dative-passive sentences	sentence production - noun, verb and grammar production	noun accuracy - reduced in nvfPPA and svPPA, difficulty with the passive and dative passive structures vs active and dative sentence structures - increased in nvfPPA and svPPA
2017	Marcotte	English	18 HC, 13 nvfPPA, 12 svPPA	topic-directed interviews - about (1) family, (2) health, (3) daily activities, (4) where they were born and raised, and (5) jobs or work	speech rate, number of sentences, mean length of sentence, mean word length, pronoun ratio, #nouns/#words, #verbs/#words, proportion verbs, noun-verb ratio, noun and verb frequency, imageability, adverbs, brunets index, words used once, type token ratio, mean length of clause, clauses, complex nominals per clause, T-units, mean length of T-unit, insignificant in svPPA, complex nominals per T-unit, total Yngve depth, max and mean Yngve depth	speech rate - reduced in nvfPPA, number of sentences - increased in nvfPPA, mean length of sentence - reduced in nvfPPA, mean word length - reduced in nvfPPA, pronoun ratio - increased in svPPA, #nouns/#words - reduced in svPPA, #verbs/#words - reduced in nvfPPA, proportion verbs - reduced in svPPA, word frequency - increased in svPPA, adverbs - increased in svPPA, brunets index - reduced in svPPA, words used once - reduced in svPPA, type token ratio - reduced in svPPA, mean length of clause - reduced in nvfPPA, clauses - reduced in nvfPPA, complex nominals per clause - reduced in nvfPPA and svPPA, T-units - increased in nvfPPA, mean length of T-unit - reduced in nvfPPA, complex nominals per T-unit - reduced in nvfPPA and svPPA, total Yngve depth - reduced in nvfPPA, max and mean Yngve depth - reduced in nvfPPA and svPPA

Year	First Author	Language	Participants	Methods	Speech and Language features	Results (significant only)
2017	Nevler	English	17 HC, 32 bvFTD	picture description - cookie theft	fundamental frequency - extracted pitch range, mean speech duration, mean pause duration, speech rate (WPM)	f0 range - decreased in bvFTD, speech duration - reduced in bvFTD, pause duration - increased in bvFTD, speech rate - reduced in bvFTD
2017	Staiger	German	130 HC, 17 PSP	reading task	articulation rate	articulation rate - reduced in PSP
2017	Vogel	English	24 HC, 24 bvFTD	40s monologue, reading task - grandfather passage, days of the week	Mean silence length, variability of silence length, proportion of silence time, speech rate (syl/s)	Mean silence length - increased for bvFTD for "days of the week", unprepared monologue, variability of silence length - increased for bvFTD for unprepared monologue, proportion of silence time - increased for bvFTD for reading task and unprepared monologue, speech rate (syl/s) - decreased for reading passage
2016	Ash	English	27 HC, 19 svPPA, 54 bvFTD, 33 CBS	picture description - cookie theft	quantifiers per 100 words, nouns per 100 words, WPM	quantifiers - reduced for bvFTD and CBS, insignificant for svPPA, nouns - reduced for svPPA, WPM - reduced for bvFTD. svPPA and CBS
2016	Hardy	English	24 HC, 18 nvfPPA, 14 svPPA, 24 bvFTD	holiday narrative	total words, mean words/prompt, words frequency	Total words - reduced in nvfPPA, mean words per prompt - reduced for bvFTD, nvfPPA, svPPA, word frequency - increased for nvfPPA and svPPA
2016	Irish	English	10 HC, 10 svPPA	Semi-structured interview	use of past tense	use of past tense - reduced in svPPA
2016	Rogalski	English	35 HC, 6 nvfPPA, 13 lvPPA	Narrative task	speech rate (WPM)	speech rate (WPM) - decreased in nvfPPA and lvPPA
2016	Santos-Santos	English	10 HC, 5 PSP, 9 CBS	Picture description - picnic	total narrative words, speech rate (WPM), proportion of syntactic errors, proportion of words in sentences, proportion of distortions (per 100 words)	speech rate (WPM) - decreased in nvfPPA, total words - decreased in nvfPPA, proportion words in sentences - decreased in nvfPPA, syntactic errors - increased in nvfPPA, distortions/100 words - increased in nvfPPA
2016	Yunusova	English	33 HC, 9 nvfPPA, 9 bvFTD	reading task - bamboo passage	proportion pause, mean pause duration, total pause duration, number of pauses, pause duration variability, speech rate, articulation rate, mean phrase duration, coefficient of variation phrase	proportion pause - increased for nvfPPA, bvFTD, total pause duration - increased for nvfPPA, bvFTD, ALS-FTD, number of pauses - increased for nvfPPA, bvFTD, ALS-FTD, pause duration variability - increased for bvFTD, ALS-FTD, insignificant for nvfPPA, speech rate - decreased for nvfPPA, bvFTD, ALS-FTD, articulation rate - decreased for nvfPPA, ALS-FTD, insignificant for bvFTD, mean phrase duration - decreased for nvfPPA, ALS-FTD, coefficient of variation phrase - increased for nvfPPA, ALS-FTD
2015	Mack	English	12 HC, 12 nvfPPA, 11 lvPPA, 12 svPPA	Narrative task - Cinderella story	speech rate (WPM), mean length utterance (MLU), mean length phonemes, mean length phoneme nouns, nouns (token), verbs (token), open: closed class ratio, noun-verb ratio, verb frequency, noun frequency, %grammatical sentences	speech rate (WPM) - reduced for nvfPPA, mean length utterance (MLU) - reduced for nvfPPA, mean length phoneme nouns - reduced for nvfPPA, nouns (token) - reduced for nvfPPA, lvPPA, svPPA, verbs (token) - reduced for nvfPPA, open: closed class ratio - reduced for svPPA, noun-verb ratio insignificant for nvfPPA, lvPPA, svPPA, %grammatical sentences - reduced for nvfPPA, svPPA.
2015	Rusz	Czech	37 HC, 12 PSP	90s monologue	% Pause time, no. pauses, mean speech intensity, pitch variability, vowel articulation index, percentage dysfluent words, articulation rate, intensity variations.	intensity - decreased in PSP, intensity variability - increased in PSP, percentage pause - increased in PSP, articulation rate - decreased in PSP, vowel articulation index, % dysfluent words - increased in PSP
2014	Ballard	English	17 HC, 20 nvfPPA, 21 lvPPA	reading task - grandfather passage	syllable segregation, PVI, silence duration, variability of silence duration	median PVI strong-weak - reduced in nvfPPA, median PVI weak-strong - reduced in nvfPPA, proportion silence time - increased in nvfPPA, lvPPA, variability of silence duration - increased in nvfPPA, lvPPA

Year	First Author	Language	Participants	Methods	Speech and Language features	Results (significant only)
2014	Fraser	English	16 HC, 14 nvfPPA, 10 SD	Narrative task - Cinderella story	total words/total time, total words, mean length sentences, mean length clause, mean length clause, word frequency, number of sentences, mean word length, pronoun ratio, #nouns/#nouns + #verbs, nouns (token), verbs (token), noun-verb ratio, word frequency, verb frequency, noun frequency, imageability, noun imageability, verb imageability, light verbs, demonstratives, adverbs, adjectives, determiners, prepositions, type-token ratio, real word inflection, clauses, clauses per sentence, clauses per t-unit, complex t-units per t-unit, coordinate phrases per t-unit, complex nominals per t-unit, t-units per sentence, coordinate phrases per clauses, tree height, t-units, complex t-units, complex nominals, complex nominals per t-unit, total Yngve depth, max Yngve depth, mean Yngve depth, verb phrases, verb phrases per t-unit, dependent clauses per clauses, total dependent clauses, dependent clauses per t-unit, function words, fillers, age of acquisition (AOA), noun AOA, verb AOA, familiarity, noun familiarity, verb familiarity, coordinate phrases, number of um/uh's	total words/total time - reduced in nvfPPA and SD, total words - reduced in nvfPPA, mean length sentences - reduced in SD, mean length clause - reduced in SD, word frequency - increased for SD and nvfPPA, mean word length - reduced in nvfPPA and SD, pronoun ratio - increased for SD, #nouns/#nouns + #verbs - reduced in SD, nouns (token) - reduced in SD, noun-verb ratio - reduced in SD, word frequency - increased for SD and nvfPPA, verb frequency - increased for SD and nvfPPA, noun frequency - increased in SD, verb imageability - increased for SD, demonstratives - increased in nvfPPA and SD, adverbs - increased in SD, type-token ratio - decreased in SD, clauses - increased in SD, t-units per sentence - reduced in in nvfPPA and SD, complex nominals per t-unit - reduced for nvfPPA, mean Yngve depth - reduced in SD, age of acquisition (AOA) - reduced in nvfPPA noun AOA - reduced in nvfPPA, familiarity - increased in SD, noun familiarity - increased in SD, verb familiarity - decreased in SD
2014	Hoffman	English	8 HC, 7 SD	Semi-structured interview - Autobiographical Memory Interview	noun frequency, imageability	noun frequency - increased in SD, imageability - decreased in SD
2014	Marcotte	English	15 HC, 12 nvfPPA, 11 svPPA	story completion task	verb retrieval, errors in heavy/light verbs, grammaticality	grammatically correct responses - decreased in nvfPPA, errors in general verbs - increased in nvfPPA, errors in specific verbs - increased in nvfPPA, svPPA, errors in heavy verbs - increased in nvfPPA, errors in light verbs - increased in nvfPPA
2014	Maruta	English	17 HC, 15 nvfPPA	reading task with DAF paradigm - grandfather passage	mean number of words/second, mean number of errors (speech sound errors/grammatical errors)	mean words/minute - reduced in nvfPPA.
2014	Meteyard	English	8 HC, 8 SD	Semi-structured interview - Autobiographical Memory Interview	open class items, closed class items, noun and verb tokens, light verbs, light nouns, demonstrative pronouns, interrogative pronouns and indeterminate locative terms, open: closed class, light nouns: all nouns, light verbs: all verbs, word-form frequency analysis, Frequency of complex verb morphology, frequency of syntactic constructions	frequency - increased for SD, noun frequency - increased for SD, demonstrative pronouns - increased for SD, interrogative pronouns - increased for SD
2014	Silveri	Italian	10 HC, 21 nvfPPA, 3 lvPPA, 11 svPPA, 3 mxPPA	picture description - cookie theft and picnic description	mean length of utterance (MLU), speech rate (WPM) and percentage of fragments	speech rate - reduced in nvfPPA, lvPPA, svPPA, mean length utterance (MLU) - reduced in nvfPPA, lvPPA, svPPA
2014	Wilson	English	13 HC, 12 nvfPPA, 23 svPPA, 13 lvPPA	elicited speech production task	inflectional morphology	Real word inflection - reduced for nvfPPA, lvPPA, and svPPA, non-word inflection - reduced for nvfPPA, lvPPA.
2013	Ash	English	12 HC, 15 nvfPPA, 29 lvPPA, 18 svPPA, 17 bvFTD	picture description - cookie theft	speech rate (WPM), total words, MLU, percentage open-class words, nouns per 100 words, well-formed sentences, dependent clauses per 100 utterances, phonetic errors, phonemic errors, fluency disruptions per 100 words	speech rate (WPM) - decreased in nvfPPA, lvPPA, svPPA, total words - decreased in nvfPPA, lvPPA, svPPA, bvFTD, MLU - decreased in nvfPPA, percentage open-class words - decreased in lvPPA, svPPA, nouns per 100 words - decreased in svPPA, well-formed sentences - decreased in lvPPA, svPPA, dependent clauses per 100 utterances - decreased in nvfPPA, phonemic errors - increased in nvfPPA, fluency disruptions per 100 words - increased in lvPPA
2012	DeLeon	English	12 HC, 16 nvfPPA, 7 svPPA, 8 lvPPA, 6 bvFTD	elicited speech production task	targeted structures attempted, attempted structures correct, syntactic errors, semantic errors	targeted structures attempted - decreased for nvfPPA, lvPPA, svPPA, attempted structures correct - decreased for nvfPPA, bvFTD, syntactic errors - increased for lvPPA, semantic errors - increased for svPPA

Year	First Author	Language	Participants	Methods	Speech and Language features	Results (significant only)
2012	Sajjadi	English	30 HC, 16 SD	semi-structured interview, picture description	speech rate, unit length, spontaneity, combined phonological errors, fluency, discourse markers, hesitation markers, editing breaks, open- and closed-class words, Number of verbs per unit, semantic errors, circumlocutions, information content, pictorial theme, complex units, number of arguments, number of clauses, Open- and closed-class word errors, verb agreement errors.	Speech rate - decreased in SD, unit length - decreased in SD, strings of phonemes - increased in SD, hesitation markers - increased in SD, complete units - decreased in SD, elliptical phrases - increased in SD, abandoned utterances - increased in SD, discourse markers - increased in svPPA, editing breaks increased in SD, semantic errors - increased in SD, closed-class words - increased in SD, circumlocutions - increased in SD, redundant words and phrases - increased in SD, pictorial themes - decreased in SD, complex units - decreased in SD, arguments per verb - decreased in SD, verb agreement errors - increased in SD.
2012	Sajjadi	English	30 HC, 12 nvfPPA, 16 mxPPA	semi-structured interview, picture description task - man in armchair	speech rate, unit length, frequency of elliptical phrases, frequency of discourse markers, frequency of hesitation markers, frequency of editing breaks, frequency of relative sentences, closed class insertions, open class omission errors, verb agreement errors, speech rate, number of discrete speech units/100 words, arguments per verb, number of clauses, closed-class errors, frequency of closed-class omissions, verb agreement errors	speech rate - reduced in nvfPPA and mxPPA, unit length - reduced in nvfPPA and mxPPA, number of discrete speech units/100 words - reduced in nvfPPA and mxPPA, speech sound errors - increased in nvfPPA and mxPPA, hesitation markers - increased in nvfPPA and mxPPA, production of complete units - reduced in nvfPPA and mxPPA, elliptical phrases - increased in nvfPPA and mxPPA, abandoned units - increased in mxPPA, editing breaks - increased in nvfPPA and mxPPA, discourse markers - increased in mxPPA, closed class words - increased in mxPPA, semantic errors - increased in mxPPA, open-class words errors - increased in nvfPPA, redundant words and phrases - increased in mxPPA and nvfPPA, mentioned pictorial themes in picture description - decreased in mxPPA and nvfPPA, complex units - reduced in nvfPPA and mxPPA, arguments per verb - reduced in mxPPA, number of clauses - insignificant for nvfPPA and mxPPA, closed-class errors - increased in nvfPPA, verb agreement errors - increased in mxPPA
2012	Thompson	English	13 HC, 11 nvfPPA, 20 lvPPA, 6 svPPA	Narrative task - Cinderella story	speech rate (WPM), mean length of utterance in words (MLU-W), proportion of grammatically correct sentences, open- to-closed-class word ratio, noun-to-verb ratio, correct production of verb inflection, noun morphology, and verb argument structure	speech rate (WPM) - reduced in nvfPPA and lvPPA, mean length utterance (MLU) - reduced in nvfPPA and lvPPA, proportion of grammatically correct sentences - reduced in nvfPPA and lvPPA, open-to-closed-class word ratio - reduced in svPPA, noun-to-verb ratio - reduced in svPPA, production of verb inflection - reduced in nvfPPA, verb argument structure - reduced in nvfPPA
2011	Pakhomov	English	25 HC, 12 nvfPPA, 5 lvPPA, 11 svPPA, 17 bvFTD	picture description - cookie theft	periodicity of speech - g-statistic, average mode of the power spectra, average r-index, principal radial frequency across the power spectra	average r-index - significant difference in the FTLD group, principal radial frequency across the power spectra - significant difference in the FTLD group
2010	Ash	English	10 HC, 16 nvfPPA	Narrative task - Frog where are you	total words, speech rate (WPM), mean length utterance (MLU), editing breaks/hesitation markers per 100 words, open class words per utterance, nouns per utterance, total verbs per utterance, complex structures per utterance, proportion of well-formed utterances	editing breaks - increased in nvfPPA, hesitation markers - increased in nvfPPA, speech rate - decreased in nvfPPA, total words - decreased in nvfPPA, mean length utterance (MLU) - decreased in nvfPPA, verbs per utterance - decreased in nvfPPA, open class words per utterance - decreased in nvfPPA, nouns per utterance - decreased in nvfPPA, complex structures per utterance - decreased in nvfPPA, well-formed sentences - decreased in nvfPPA
2010	Garrard,	English	21 HC, 21 SD	picture description - cookie theft	word count, speech rate (WPM), noun:verb ratio, ratio of content words: function words,	noun-verb - reduced for SD, content to function word ratio - reduced for SD
2010	Gross	English	8 HC, 20 CBS	narrative task – frog where are you	speech rate (WPM), narrative theme (participants' ability to maintain the story theme), global connectedness (whether subjects identified the point of the story), lexical connectedness (conceptual connectedness between consecutive story events)	speech rate (WPM) – reduced in CBS, narrative theme – reduced in CBS, global connectedness – reduced in CBS, lexical connectedness – reduced in CBS
2010	Pakhomov	English	32 HC, 12 nvfPPA, 11 svPPA, 6 lvPPA, 19 bvFTD	picture description - cookie theft	perplexity index (degree of deviation in word patterns used), out of vocabulary rate (proportion of words used by FTLD patients that were not used by HC)	out of vocabulary rate - increased for svPPA
2010	Rohrer	English	18 HC, 24 nvfPPA	picture description - cookie theft	speech rate (WPM), agrammatic errors/min, speech production errors/min, mean pause length, frequency of nouns, frequency of verbs used	speech rate (WPM) - decreased for nvfPPA, agrammatic errors/min - increased for nvfPPA, production errors/min - increased for nvfPPA, mean pause length - decreased for nvfPPA, frequency of nouns - increased for svPPA, frequency of verbs used - increased for nvfPPA

Year	First Author	Language	Participants	Methods	Speech and Language features	Results (significant only)
2010	Suh	Korean	134 HC, 6 SD	Hanja and Hangul reading/writing tasks	Hanja and Hangul reading performance	Hanja reading performance - reduced in SD
2010	Wilson	English	10 HC, 14 nvfPPA, 11 lvPPA, 25 svPPA	elicited speech production task	false starts, repaired sequences, number of pauses, speech rate, maximum speech rate, total speaking time, total words, mean length utterance (MLU), words in sentences, proportion pronouns, verb tokens/word, proportion closed class words, verb frequency, nouns with determiners, embeddings phw, auxiliary complexity, phonological errors, syntactic errors, semantic errors, incomplete sentences, distortions per 100 words	repaired sequences - increased for svPPA, number of pauses - increased for nvfPPA, speech rate - decreased for nvfPPA, lvPPA, svPPA, maximum speech rate - decreased for nvfPPA, lvPPA, total speaking time - decreased for nvfPPA, lvPPA, bvFTD, total words - decreased for nvfPPA, mean length utterance (MLU) - decreased for nvfPPA, lvPPA, svPPA, words in sentences - increased for lvPPA, svPPA, proportion pronouns - decreased for nvfPPA, svPPA, verb tokens/word - increased for lvPPA, verb frequency - increased for svPPA, nouns with determiners - decreased for nvfPPA, syntactic errors - increased for lvPPA, incomplete sentences - increased for svPPA, distortions per 100 words - increased for nvfPPA.
2009	Ash	English	10 HC, 11 nvfPPA, 12 SD, 12 bvFTD	Narrative task - Frog where are you	speech rate, total words, mean segment duration, mean length utterance (MLU), nouns (token), verbs (token), existential subjects, complex structures per utterance, errors/utterance	speech rate - decreased in nvfPPA, SD, bvFTD, total words - decreased in nvfPPA, bvFTD, mean length utterance (MLU) - decreased in nvfPPA, nouns (token) - decreased in nvfPPA, SD, verbs (token) - decreased in nvfPPA, existential subjects - increased in SD, complex structures per utterance - decreased in nvfPPA, errors/utterance - increased in nvfPPA
2009	Knibb	English	15 HC, 15 nvfPPA	semi-structured interview	speech rate (WPM), unit length, noun-verb ratio, elliptical phrases, subordinate syntactic units, grammatical errors, speech sound errors, closed-class errors	speech rate (WPM) - reduced in nvfPPA, unit length - reduced in nvfPPA, elliptical phrases - increased in nvfPPA, subordinate syntactic units - reduced in nvfPPA, closed-class errors - increased in nvfPPA
2009	Mesulam	English	17 HC, 4 nvfPPA, 7 lvPPA, 5 svPPA	Picture description - picnic	phrase length	phrase length - reduced in nvfPPA
2009	Meteyard	English	8 HC, 8 SD	semi-structured interview	total words, mean length utterance, insertions, word omissions, phonological errors, substitution errors, perseveration/anticipation errors, complex morphological errors, simple morphological errors, planning errors, open-class errors, closed-class errors	total words - decreased in SD, mean length utterance (MLU) - decreased in SD, insertions - insignificant in SD, word omissions - increased in SD, phonological errors - insignificant in SD, substitution errors - increased in SD, perseveration/anticipation errors - increased in SD, complex morphological errors - increased in SD, simple morphological errors - insignificant in SD, planning errors - increased in SD, open-class errors - increased in SD, closed-class errors - increased in SD
2008	Sachin	Hindi	37 HC, 12 PSP	semi-structured interview, reading task	maximum phonation time (MPT), semantic fluency and reading speed.	Maximum phonation time (MPT) – reduced in PSP, semantic fluency and reading speed – reduced in PSP
2006	Ash	English	10 HC, 10 nvfPPA, 13 SD, 12 bvFTD (SOC/EXEC)	Narrative task - Frog where are you	duration of narrative sample, number of utterances, number of words, lexical retrieval difficulty (1) occurrence of word-finding difficulty, 2) a general noun in place of a specific one, 3) use of a wrong noun, 4) use of a wrong verb, and 5) a pronoun missing its antecedent), action, global connectedness, search theme, local connectedness,	speech rate (WPM) - reduced for nvfPPA, SD, bvFTD (EXEC/SOC), mean length utterance - reduced for nvfPPA, impaired word finding frequency - reduced for SD, errors - increased for nvfPPA, SD, bvFTD (EXEC/SOC), global connectedness - reduced for bvFTD (EXEC/SOC), maintenance of search theme - reduced for nvfPPA and bvFTD (EXEC/SOC), local connectedness - reduced for nvfPPA and SD
2006	Patterson	English	24 HC, 14 SD	reading task, writing to dictation, inflecting verbs task	reading performance low frequency words, reading performance irregular words	reading performance low frequency words - reduced in SD, reading performance irregular words - reduced in SD
2005	Ash	English	6 HC, 8 nvfPPA, 9 svPPA	Narrative task - Frog where are you	WPM, MLU, #words, well-formed sentences, phrasal adjuncts, dependent clauses, %open class words, semantically deviant utterances, nouns/inflected words, errors on words	speech rate (WPM) - decreased in nvfPPA and svPPA, mean length utterance (MLU) - decreased in nvfPPA, proportion open-class words - decreased svPPA, ratio of nouns to inflected verbs - decreased nvfPPA, phrasal adjuncts - decreased nvfPPA, semantically deviant utterances - increased svPPA, well-formed sentences - decreased nvfPPA, dependent clauses per 100 utterances - decreased nvfPPA, errors on verbs - increased nvfPPA, svPPA
2004	Graham	English	11 HC, 14 nvfPPA	picture description (spoken and written) - cookie theft	speech rate (WPM), word count, information units, inaccurate/irrelevant information, grammatical endings on words, nouns and verbs, content, and function verbs, paraphasia's and neologisms	paraphasia's/words - increased in nvfPPA, paraphasia's - increased in nvfPPA, speech rate (WPM) - decreased in nvfPPA, total speaking time - decreased in nvfPPA, total words - decreased in nvfPPA, nouns (token) - decreased in nvfPPA, verbs (token) - decreased in nvfPPA, nouns (type) - decreased in nvfPPA, verbs (type) - decreased in nvfPPA, #verbs/#words - decreased in nvfPPA, content words as proportion of total words - decreased in nvfPPA, function words as proportion of total words - decreased

Year	First Author	Language	Participants	Methods	Speech and Language features	Results (significant only)
						in nvfPPA, neologisms - increased in nvfPPA, neologisms/word - increased in nvfPPA, content units - decreased in nvfPPA, grammatical errors - increased in nvfPPA
2000	Bird	English	20 HC, 3 SD	picture description - cookie theft	speech rate (WPM), ratio of content and function words, noun verb frequency,	content words: function words ratio - reduced in SD, verb frequency - increased in SD, noun frequency - increased in SD,
1997	Thompson	English	5 HC, 4 nvfPPA	narrative task - Cinderella story, picture description task - cookie theft, interview	mean length utterance (MLU), open: closed-class ratio, noun-verb ratio, % verbs with correct verb arguments, % complex units, proportion grammatical sentences	mean length utterance (MLU) - reduced in nvfPPA, open: closed-class ratio - increased in nvfPPA, noun-verb ratio - insignificant in nvfPPA, % verbs with correct verb arguments - reduced in nvfPPA, % complex units - reduced in nvfPPA, proportion grammatical sentences - reduced in nvfPPA

Supplemental Table 2. list of papers included in Figure 4 for each feature. Papers are listed per language as (first author, year) in order of publication year. Studies could not be included in Figure 4 in case of lack of information of subtypes (Karpithiou, 2022; Faroqi-Shah, 2020), lack of information on patient or control values (Cousins, 2017; Rogalski, 2017; Bird, 2000) difference in measurement units (Ash, 2009), or undefined task duration (Yunusova, 2016).

Speech and Language Feature	Papers included in Figure 4 (first author, year)
Speech Rate	English: (Parjane, 2021) (Ash, 2019) (Pressman, 2019) (Marcotte, 2017) (Nevler, 2017) (Santos-Santos, 2016) (Yunusova, 2016) (Mack, 2015) (Ash, 2013) (Sajjadi, 2012a) (Sajjadi, 2012b) (Thompson, 2012) (Ash, 2010) (Gross, 2010) (Rohrer, 2010) (Wilson, 2010) (Ash, 2009) (Knibb, 2009) (Ash, 2006) (Ash, 2005) (Graham, 2004) Greek: (Potagas, 2022) Spanish: (Matias-Guiu, 2022) Italian: (Catricala, 2019) (Silveri, 2014) Hindi: (Sachin, 2008) Czech: (Daoudi, 2022)
Articulation Rate	English: (Cho, 2022) (Garcia, 2022) (Cordella, 2019) (Cordella, 2017) (Yunusova, 2016) Greek: (Potagas, 2022) Spanish: (Baque, 2022) French: (Bouvier, 2021) Czech: (Skrabal, 2020) German: (Staiger, 2017)
Pause Frequency	English: (Parjane, 2021) (Nevler, 2019) (Cordella, 2017) (Yunusova, 2016). Greek: (Potagas, 2022)
Pause Duration	English: (Parjane, 2021) Greek: (Potagas, 2022) Spanish (Matias-Guiu, 2020)
Number of Noun Tokens	English: (Graham, 2004) (Mack, 2015) (Cho, 2022) Spanish: (Matias-Guiu, 2022)
Noun-Verb Ratio	English: (Marcotte, 2017) (Fraser, 2014) (Mack, 2015) (Garrard, 2010) (Thompson, 2012) (Knibb, 2009) (Graham, 2004) Spanish: (Matias-Guiu, 2022) Italian: (Catricala, 2019)

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