Linguistic biomarkers of dementia in Italian patients living in Lombardy: insights from NLP analysis*

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Abstract

Nowadays, dementia poses a major challenge for healthcare services, with consequences on both the economic and the organizational front. The number of people affected by this disease is steadily increasing, and existing pharmacological and psycho-social therapies only aim to slow its progression. Therefore, a timely diagnosis is crucial for early intervention. For this reason, researchers from different disciplines are trying to find the "biomarkers" of dementia to obtain a detailed profiling of this disease and its etiology. In particular, great attention has been directed towards language, as it is one of the first cognitive domains affected by the pathology. The new frontier in the analysis of spoken language productions is the employment of Natural Language Processing (NLP) techniques and Artificial Intelligence (AI), as they enable an ecological and non-intrusive detection of dementia.

This study aims at analyzing the speech of elderly individuals diagnosed with dementia and living in Lombardy (Italy) exploiting NLP techniques. A cohort of 8 participants was enrolled, consisting of 4 patients affected by dementia (i. e., Alzheimer's disease or mixed dementia) and 4 healthy controls matched by age, level of education, and sex. Participants' selection was made on four neuropsychological tests (i. e., MMSE – Mini-Mental State Examination, MoCA – Montreal Cognitive Assessment, phonemic and semantic fluences). The speech samples were collected through three elicitation tasks and subsequently manually transcribed using the ELAN software. A multidimensional parameter analysis was performed on the corpus obtained taking into consideration a set of 151 linguistic features. Finally, a statistical analysis was performed by comparing the pathological group and the control group. Results demonstrate the efficacy of computational linguistic analysis in differentiating one group from another. Moreover, given the peculiar sociolinguistic situation in Italy, the study confirms the importance of investigating differences related to diatopic variation in clinical populations.

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1 Introduction

According to the World Health Organization (WHO), "dementia" is a broad term used to indicate an array of symptoms associated with a progressive decrease in cognitive abilities. As outlined by the Diagnostic and Statistical Manual of Mental Disorders (cf. American Psychiatric Association 2013), "dementia", now termed "Major Neurocognitive Disorder", can be diagnosed if present an acquired, progressive, significant decline in one or more cognitive domains (such as perception, reasoning, and language). Importantly, it should not be exclusively present during delirium, and should not be better explained by another mental disorder (such as depression), and daily life activities must be compromised. According to the WHO's *Global Status Report* (2021), over 55 million people worldwide suffer from dementia, and this number is expected to increase due to the major risk factor being age (> 65), coupled with the rise in life expectancy. Projections estimate that around 139 million people will be affected by this condition by the year 2050. The report also highlights that someone develops dementia every three seconds globally, resulting in 10 million new cases annually. This disease represents a significant challenge for health services, with an estimated annual worldwide cost of 1.3 trillion US dollars. This figure is expected to rise to 2.8 trillion by the year 2030. In Italy, the nation with the second-largest elderly population in Europe, the National Institute of Health (Istituto Superiore di Sanità, ISS) reports that there are currently one million people suffering from dementia. Additionally, three million people are directly or indirectly involved in providing assistance, with strong backlash on both the economic and the organizational level.

Unfortunately, there's no cure for this age-related pathology, and existing pharmacological and psycho-social therapies only aim to slow its progression. The situation is further complicated by the fact that dementia has multiple causes, including neurodegenerative diseases. Focusing on the latter, Alzheimer's disease is the primary cause of dementia (60–80 %), followed by mixed dementia (e. g., Alzheimer's disease occurring concurrently with vascular pathology, 50%), cerebrovascular disease alone (i. e., vascular dementia, 5–10%), frontotemporal dementia (5–10%), and Lewy bodies dementia (5%) (Alzheimer's Association 2022: 700–789). Neurodegenerative diseases are conditions that impact the brain, leading to the gradual loss of neurons. It is crucial to emphasize that not all brain cells are affected, but each neurodegenerative disease, or even subcategories of the same pathology, targets different types of neurons or neural networks (cf. Jellinger 2010: 457–487; Dugger/Dickson 2017: 28–35). The reason must be sought in the neurobiological substrate of the disorder: neurodegenerative pathologies are also known as proteinopathies, with protein misfolding considered the primary cause of these diseases (cf. Takalo 2013: 1–14; Bayer 2015: 713–724).

Although a lot of research is being carried out, it is still extremely difficult to differentiate one neurodegenerative disease from the other. This is primarily because many neurodegenerative diseases share similar clinical features, such as progressive cognitive and/or motor impairment (cf. Karantzoulis/Galvin 2011: 1579–1591 for an overview). Furthermore, the genetic hallmarks of different neurodegenerative diseases, such as protein aggregates, can overlap (cf. Ferreira et al. 2020: 3257–3268). Moreover, the molecular and genetic factors underlying neurodegeneration are complex, involving multiple pathways and mechanisms that are not yet fully understood. As neurodegenerative diseases are progressive, diagnosing dementia in advanced stages, from both a clinical and a neuroimaging point of view, makes it difficult to reconstruct the primary cause. As atrophy becomes widespread, the clinical presentation becomes so severe on all levels that even cognitive tests lose their sensitivity (cf. Davenport et al. 2023). Lastly, the current fine-grained examination used for diagnosing dementia involves a variety of clinical instruments, including the patient's medical history, physical examination, laboratory tests (e. g., genetic and blood tests), psychiatric evaluation, brain scans, and neuropsychological tests (cf. Duong/Patel/Chang 2017: 118–129) that are time-consuming, invasive and expensive.

For this reason, researchers are striving to find new hallmarks that may better differentiate various neurodegenerative processes. To be more specific, researchers are trying to find new "biomarkers", i. e., objectively measurable and evaluable biological characteristics, for the detection and classification of dementia (cf. Sanjay et al. 2015: 7062–7081). Among the emerging domains, lot of research has been conducted in the area of language.

1.2 Language impairment in neurodegenerative diseases

Several neurodegenerative pathologies manifest evident language impairments (cf. Boschi et al. 2017). In the case of Alzheimer's disease (AD), a progressive language disorder is typically observed across all stages and levels of the language capacity (cf. Ahmed et al. 2013: 3727–3737; Szatloczki et al. 2015). AD is particularly recognized for inducing word-finding difficulties in the early stages. As a consequence, patients often fill their discourses with circumlocutions. As the pathology advances, there is a decline in verbal fluency, and patients, while experiencing misidentification of objects, produce semantic paraphasias (i. e., substitution of the intended word with one of similar meaning, for instance "son" instead of "daughter"). At a certain stage, passe-partout words (i. e., "the thing") prevail, indicating an overwhelming breakdown in semantic memory (cf. Hoffmann et al. 2010: 29–34; Chen/Gordon 2019; Martines-Nicolás et al. 2019). This loss is also reflected in the progressive impairment of both oral and written comprehension (cf. Harnish/Neils-Strunjas 2008: 44–59). As for the phonetic level, alterations in temporal speech parameters, such as a gradual drop in speech rate and a significant increase in hesitations, becomes significant as the pathology develops (cf. Sajjadi et al. 2012: 847–866; Martínez-Sánchez et al. 2013: 325–331). Moreover, several studies suggest the presence of phonemic paraphasias from the earliest stages of the disease (cf. Wutzler et al. 2013: 300–309; Satt et al. 2014: 2538 2542). As for morphosyntax, although comprehension and production have been claimed to be sources of difficulty at mild-to-moderate stages of the disease, both at the word and sentence levels (cf. Waters/Caplan/Rochon 1995: 1–30; Colombo et al. 2009: 1069–1078; Marková et al. 2017: 456–468; Manouilidou et al. 2020; Chapin et al. 2022), there are still open theoretical issues. Firstly, there is debate on whether and why morphosyntax seems to be better maintained than other language domains, such as lexical semantics. As a matter of fact, patients have been reported to produce correct but shorter sentences, with a simplified syntax (cf. Ferris/Farlow 2013: 1007–1014; Szatloczki et al. 2015; Varlokosta et al. 2023). Moreover, researchers do not agree on the source of impairment in this domain. Some are in favor of a genuine language deficit (cf. Emery 1985: 3–60; Grober/Bang 1995: 95–107), while others believe that it is all a matter of performance difficulties related to extra-processing demands and the typical working memory limitations presented by individuals with this pathology (cf. Waters/Caplan/Hildebrant 1991: 81–126; Rochon/Waters/Caplan 1994: 329–349; W Waters/Caplan/Rochon 1995: 1–30). At the pragmatic level, difficulties have been noted in the domain of referential/temporal cohesion, discourse planning and coherence. Therefore, the texts produced by AD patients are typically shorter and contain a lower amount of relevant information (cf. Ripich/Carpenter/Ziol 2000: 49–64; Drummond et al. 2015; Toledo et al. 2017: 31–40).

Frontotemporal dementia (FTD) is commonly subdivided into behavioral variant (bvFTD) and language variant (lvFTD). The language impairments of individuals affected by bvFTD mainly involve lexico-semantic, orthographic and prosodic domains. Lexico-semantic deficits include difficulties in word-retrieval (especially action naming), word comprehension, and semantic knowledge. Orthographic deficits result in a slower articulation rate and an increased number and duration of pauses. Prosodic deficits consist of reduced prosodic pitch inflection (i. e., hypoprosodia) and difficulties in prosodic emotion recognition. Apparently, there are no phonological impairments, and even grammar seems to be predominantly spared (cf. Nevler et al. 2017: 650–656; Pressman et al. 2019: 1352–1357; Geraudie et al. 2021: 1076–1095). The language variant of FTD is also known as Primary Progressive Aphasia (PPA), further subdivided into three variants: semantic, logopenic, and non-fluent/agrammatic. The semantic variant (svPPA) is characterized by difficulties in single-word comprehension and in object naming, the presence of semantic paraphasias, and surface dyslexia, while repetition and speech production are spared. Patients with the logopenic variant (lvPPA) exhibit word retrieval impairments, phonological errors in spontaneous speech, and difficulties in sentence repetition, while their grammar and motor speech are spared. Lastly, the nonfluent/agrammatic variant (nfvPPA) is characterized by typical agrammatical deficits in language production, apraxia of speech, and impaired comprehension of sentences with complex syntax, while object knowledge and single-word comprehension are spared (cf. Bonner/Ash/Grossman 2011: 484–490; Grossman 2012: 545–555; Europa et al. 2020: 1833–1849).

Lewy bodies dementia (LBD) has been reported to cause naming difficulties and verbal fluency alterations (i. e., reduced speech rate and longer pauses), both related to impairments in executive functions. Deficits are also registered in speech articulation, syntax (i. e., reduced syntactic complexity), and pragmatics (i. e., narrative speech organization) (cf. Reilly et al. 2011: 438–452; Ash et al. 2012: 290–302; Grossman et al. 2012: 52–60).

As language disruption can be a useful tool for the detection and classification of disease conditions, there has been a growing interest in “Digital Linguistic Biomarkers” (DLBs). In other words, there is an increasing interest in using NLP techniques to “automatically extract objective indications of the medical state of the patients directly from their verbal productions” (Gagliardi/Tamburini 2022: 5234). This method, compared to classical pen-and-paper neuropsychological tests – such as Mini-Mental State Examination (cf. Magni et al. 1996: 198–202) and Montreal Cognitive Assessment (cf. Conti et al. 2015: 209–214), widely used in healthcare facilities for cognitive frailty screening – is not only low-cost but also time-effective, non-intrusive, and ecological (cf. Gagliardi/Kokkinakis/Andoni Duñabeitia 2021). Therefore, it has been widely tested in recent years for the detection, classification, and monitoring of various types of dementia, even at prodromal stages (cf. Jarrold et al. 2014: 27–37; Fraser/Meltzer/Rudzicz 2016: 407–422; Wang et al. 2019: 3880–3884; Calzà et al. 2021: 101–113; Gagliardi/Tamburini 2021: 3–31).

2 The study

2.1 Rationale

In this study, the speech of elderly people diagnosed with different types of dementia and living in Lombardy was collected and manually transcribed. The aim was to use an NLP pipeline to automatically extract a large set of linguistic features from patients' speech samples and to compare them with the ones extracted from the speech of peer healthy controls balanced for sex, age, geographic origin, and level of education. Statistical testing was conducted to observe which automatically computed linguistic features are the most significant to differentiate pathological participants from healthy ones. The study was approved in March 2023 by the Bioethics Committee of the University of Bologna with protocol number 00940021.

In addition, this study had the aim of helping collecting speech samples from different parts of Italy. This is because, to generalize the results obtained from the analyses using NLP techniques, there is the need of an extremely large collection of linguistic data. For what concerns the Italian language, not only the speech corpora available are limited, but there is also the problem of the presence of high diatopic variation (cf. Berruto 2021). For this reason, it is crucial to help gathering speech samples from all over the Italian Peninsula. Currently, the most relevant corpus was collected at the University of Bologna thanks to the project OPLON – OPportunities for active and healthy LONgevity (funded by the Italian Ministry for University and Research, under the "Smart Cities and Communities" call, SCN_00176), and it includes the linguistic productions of speakers from Emilia Romagna affected by mild cognitive impairment or early dementia (cf. Beltrami et al. 2018: 1–3). Other notable Italian corpora include:

- the CIPP-ma corpus (cf. Dovetto et al. 2021: 165–177), which contains speech samples from Alzheimer's patients living in Campania;
- the CIPP-mci corpus (cf. Dovetto et al. 2021: 165–177), which includes linguistic data from patients with mild cognitive impairment living in Calabria;
- the Anchise corpus 320 (cf. Benvenuti et al. 2020: 51–57; Sigona et al. 2025: 1–27), which is a collection of transcripts of dialogues between healthcare professionals and dementia patients (primarily Alzheimer's) mainly from Lombardy;
- the corpus created by Martinelli/Gagliardi (2023: 711–732), composed of linguistic data from patients living in Basilicata and affected by different types of dementia (including Alzheimer's disease, mixed dementia, unspecified dementia, vascular dementia, and frontotemporal dementia).

2.2 Participants' selection

A cohort of 8 participants, consisting of 4 patients and 4 healthy controls, was enrolled in this project. To be included, participants needed to be at least 65 years old. Secondly, they all had to be Italian monolinguals from the same region (i. e., Lombardy) and the same urban area (i. e., the city of Cremona and its surroundings), where the same dialect is spoken. It was essential to control not only the language participants are exposed to in their daily life, but also their diatopic variety. Participants were all recruited at Istituto Ospedaliero Fondazione Sospiro Onlus (CR). Besides these requirements, participants had to take some neuropsychological tests in order to have a quantification of their cognitive functions. The neuropsychological tests exploited were the Mini-Mental State Examination (MMSE) (cf. Magni et al. 1996: 198–202), the Montreal Cognitive Assessment (MoCA) (cf. Conti et al. 2015: 209–214), the phonemic and the semantic fluences (cf. Spinnler/Tognoni 1987; Caltagirone et al. 1995: 461–470; Carlesimo et al. 1995: 471–488). The thresholds of the various tests were discussed with a neuropsychologist of the healthcare facility; they are summarized in Table 1, which also contains an overview of the selection's criteria.

Individuals diagnosed with dementia (in particular Alzheimer's disease, mixed dementia, frontotemporal dementia and Lewy's body dementia) who scored below the threshold in all the tests listed above, were included in the pathological group. Conversely, people with typical neurocognitive profile, without significant neurological and major sensory deficits, and scoring above the threshold in all neuropsychological tests, were included in the control group.

Pathological Group	**Control Group**
≥ 65 years old of age	≥ 65 years old of age
From Lombardy (Cremona and surroundings preferably)	From Lombardy (Cremona and surroundings preferably)
Monolingual language exposition	Monolingual language exposition
L1 Italian	L1 Italian
Diagnosis of dementia of the following types: • Alzheimer's disease • Frontotemporal dementia • Mixed dementia • Lewy's body dementia	Absence of neurological/major perceptual deficits
Neuropsychological tests scores: • MMSE < 24 • MoCA < 17,363 • Phonemic fluences < 17,35 • Semantic fluences < 7,25	Neuropsychologicall tests scores: • MMSE ≥ 24 • MoCA ≥ 17,363 • Phonemic fluences ≥ 17,35 • Semantic fluences ≥ 7,25

Table 1: Inclusion criteria

Since this pilot study was not part of a funded project, it was particularly challenging to find people who met the selection's criteria. Given that the data required for the selection are sensitive and reported in each person's medical record, only medical professionals have access to them. Therefore, once the thresholds for the selected neuropsychological tests had been determined, the neuropsychologist examined the database of the Istituto Ospedaliero Fondazione Sospiro Onlus to identify potential participants for the study. In the database, the only available score is from the MMSE, which is routinely administered every six months to monitor the cognitive functions of all residents in the medical facility. Therefore, initially, some individuals diagnosed with dementia were selected based on their most recent MMSE score. Then, among those who underwent neuropsychological assessment, only five had scores below all the thresholds considered. It is interesting to note that, as for other potential participants, although their MMSE and the MoCA scores were below the thresholds, their scores on the phonemic and semantic fluency test were not. This may be an interesting indication that the common tests used for assessing cognitive decline may not be sensitive enough. Therefore, in the end, it was decided to include only those patients who had poor scores.

Another issue encountered during participant selection was the search for healthy controls. Finding people who matched the age, level of education, and sex of the previously selected patients proved challenging, making one-to-one pairing difficult. Consequently, only four pairs could be formed in the end. Table 2 describes the final cohort obtained, while Figure 1 reports the results of the neuropsychological tests administered during participant selection, along with their statistical significance. The results are depicted using boxplots, showing the median and interquartile range. Statistical analysis was performed using the non-parametric Wilcoxon-Mann-Whitney test using R (cf. R Core Team 2022). Statistical significance (*$p < 0.05$) was achieved in all tests.

	Pathological Group (PG)	**Control Group (CG)**
Age	µ=91.50, s=4.04	µ=89.75, s=3.40
Level of education	µ=7.00, s=4.00	µ=8.50, s=3.32
Sex	2 F, 2 M	2 F, 2 M
MMSE	µ=17.45, s=1.84	µ=26.75, s= 2.36
MoCA	µ=9.66, s=2.22	µ=22.00, s= 4.23
Phonemic fluency	µ=11.93, s=5.87	µ=29.83, s= 13.09
Semantic fluency	µ=6.31, s=0.63	µ=15.31, s=4.50

Table 2: Description of the cohort: means (µ) and standard deviations (s)

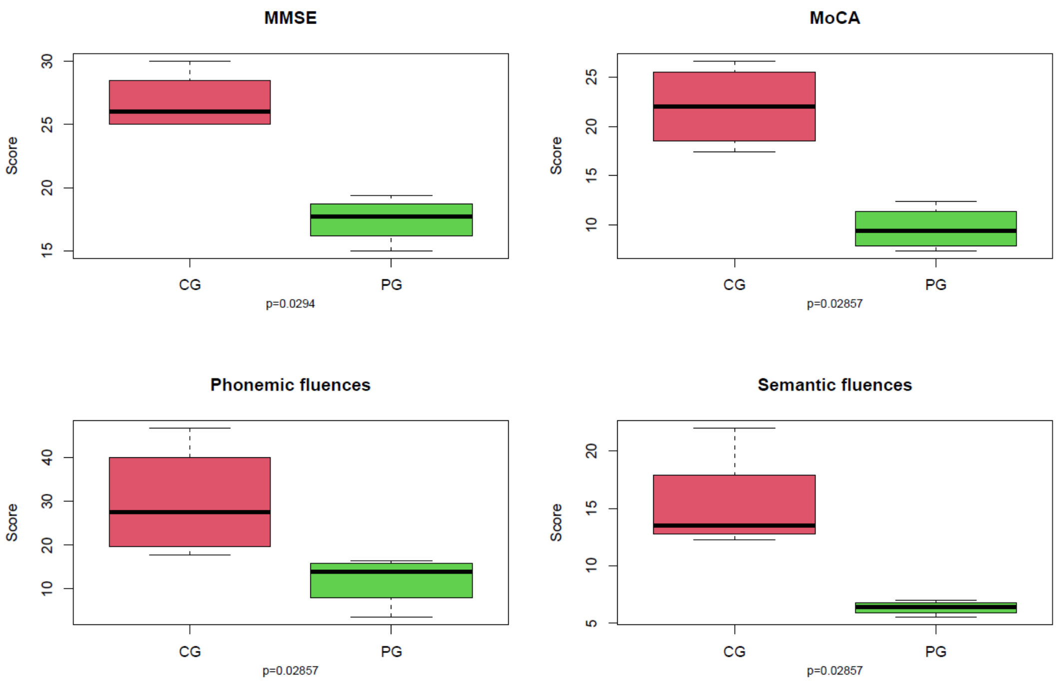

Figure 1: **Results of MMSE, MoCA, phonemic and semantic fluences and their statistical significance**

2.3 Materials and methods

All participants provided their informed written consent. The neuropsychological assessment and the audio-recorded linguistic tasks were conducted on separate days. For what concerns the linguistic tasks, the procedure was as follows: each participant was escorted to a quiet room at

Istituto Ospedaliero Fondazione Sospiro Onlus (CR) and remained there alone with the experimenter throughout the entire experimental session, which consisted of a semi-structured interview. The pre-determined questions asked to each participant were:

- "Could you please describe your daily routine?", task DAY
- "Could you please describe the job that you did?", task WORK
- "Could you please describe this picture?", task PICTURE

The picture that all subjects had to describe was taken from Ciurli et al. (1996). It represents a living room where various characters (presumably members of a family) engage in different activities – for example, a man reading a newspaper, and a young boy playing with cubes.

All speech samples were recorded using a Zoom H1n Portable Recorder, saved in WAV format at 96 KHz and 24-bit resolution. The recorder was positioned on the table in front of each participant during every experimental session.

2.3.1 Corpus transcription

First and foremost, each audio file was cut into three parts, each corresponding to the tasks described previously. This segmentation was accomplished using the latest version of the free audio software Audacity (cf. Audacity Team 2021). Afterwards, the content of each audio recording was manually transcribed using ELAN (2023), the software developed by the Max Planck Institute for Psycholinguistics for linguistic annotation. The steps followed using ELAN included the creation of the template, segmentation, and annotation. The segmentation of the speech flow was carried out using "utterances" as the reference unit. According to Cresti/Moneglia (2005), utterances – identified on a perceptual basis exploiting prosodic breaks – are considered the linguistic equivalent of speech acts introduced by Austin (1962). In particular, the acoustic features that correlate with prosodic breaks are f0 reset, final lengthening, drop in intensity, pauses and initial rush to the next prosodic unit (cf. Cresti 2018: 33–62; Calzà et al. 2021: 101–113). Orthographic transcription followed the conventions of written Standard Italian. It was enriched with annotations of spoken language phenomena such as speech fragments (i. e., incomplete words), overlappings, and paralinguistic/extralinguistic elements (i. e., laughs, coughs). The annotation of both the prosodic structure and the spoken language phenomena of the recorded speech samples was conducted following Leech's maxims of annotation (cf. Leech 2005: 17–29): this means that the annotation adhered to clear guidelines, particularly using L-AcT diacritics (cf. Cresti/Moneglia 2005), and it can be easily removed to revert back to the raw corpus format. Furthermore, in cases where participants spoke in their dialectal variety, a translation tier was also included. The accurate orthographic transcription and the translation of dialectal speech were made possible with the assistance of a member from the group El Zàch, affiliated with the Museo della Civiltà Contadina "Il Cambonino Vecchio" ('Museum of Peasant Civilization "Il Cambonino Vecchio"') in Cremona. Whenever there were uncertainties about how to write down particular words (either spelling or type of accent) the *Dizionario del dialetto cremonese* by Heilmann/Romano (1976) was consulted. Figure 2 illustrates an example of annotation of the speech samples. Each template included the following tiers:

- A parent tier with a time-aligned segmentation line containing the orthographic transcription of what was said by the participant (patient or control).
- A dependent tier containing the translation of what was said by participants speaking in dialect (i. e., TRADUZIONE).
- A dependent tier capturing participants' paralinguistic/extralinguistic elements, such as laughs and coughs (i. e., %exp)
- Another independent tier with a time-aligned segmentation line containing the orthographic transcription of what was said by the experimenter (i. e., SPERIMENTATORE).

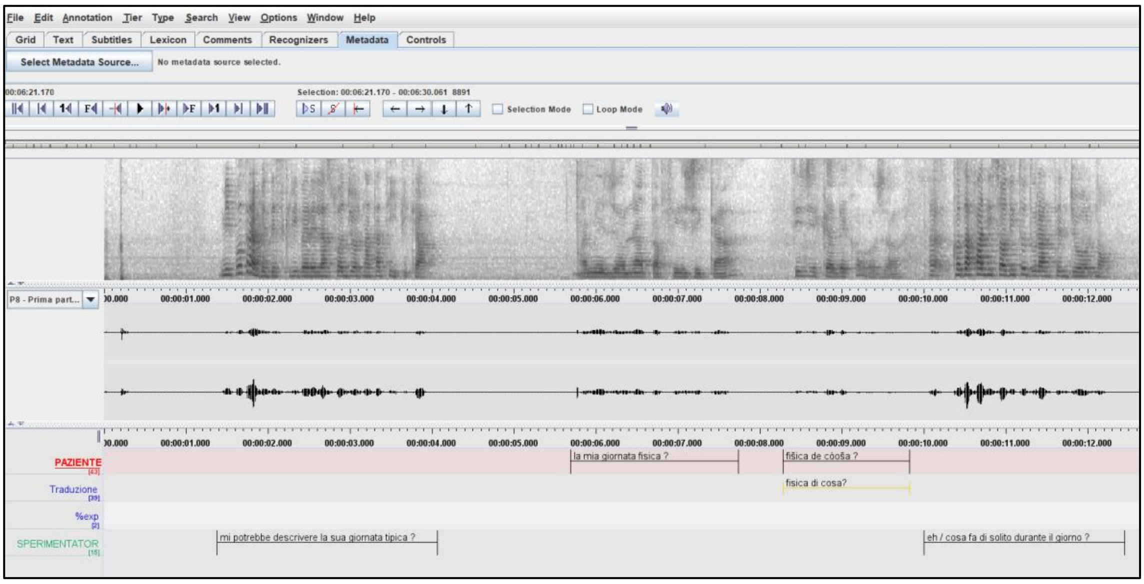

Figure 2: Annotation of one of the speech samples collected

2.3.2 Corpus analysis

A multidimensional parameter analysis was performed on the corpus using the NLP pipeline developed by Gagliardi/Tamburini (2022: 5234–5242). This pipeline is designed for exacting acoustic (SPE), lexical (LEX), readability (REA), syntactic (SYN), and LIWC – Linguistic Inquiry and Word Count (LWC) features from both oral and written texts through automated processing. Figure 3 shows the structure of the pipeline. For a detailed description, refer to Gagliardi/Tamburini (2022: 5234–5242), while for comprehensive descriptions and calculation details of each linguistic feature extracted, cf. Calzà et al. (2021: 101–113).

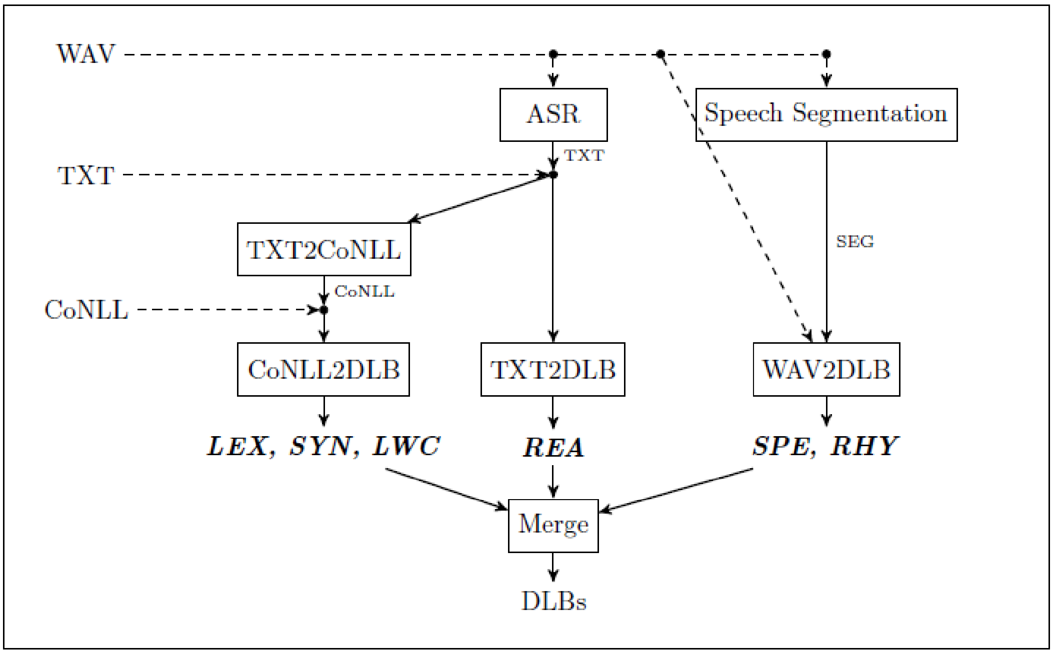

Figure 3: The whole structure of the pipeline

The pipeline was provided with input consisting of the speech recording of the participants and their corresponding manual transcription. Therefore, prior to using it, all audio files were edited using, again, the Audacity software to isolate the voice of the patients and controls. In addition, all audio files were converted to a format readable by the tool (WAV file in PCM 44.1KHz/16bit/Mono). For what concerns the manual transcriptions, they were all exported from ELAN in .txt format (containing only the participants' orthographic transcription tiers), and only the manually annotated prosodic breaks were retained. In particular, all terminal breaks were transformed into full stops (.), except for question marks (?), while all non-terminal breaks were transformed into commas (,). Once all features were extracted (151 in total), a statistical analysis was performed by comparing the control group and the pathological group through the non-parametric Wilcoxon-Mann-Whitney test in R.

3 Results

Results from the statistical analysis are reported in Tables 3, 4, 5, and 6. Due to space constraints, only the most statistically significant features (i. e., *$p < 0.05$) differentiating the pathological group (PG) from the control group (CG) have been reported. Specifically, Table 3 contains the means (μ), standard deviations (s), and p-values of significant features across all tasks (DAY, WORK, PICTURE) combined, while Table 4, 5, and 6 present the statistically significant results for each task considered individually. For the statistical analysis, the non-parametric Wilcoxon-Mann-Whitney test (WMW) was applied.

Feature	Code	ALL TASKS				
		PG		CG		WMW
		µ	s	µ	s	p-value
(A) LEXICAL FEATURES (LEX)						
Content density: Open-class words	LEX_OCW	0.27	0.05	0.32	0.04	0.02842
Content density: Closed-class words	LEX_CCW	0.73	0.05	0.68	0.04	0.02842
Content density: OCW/CCW	LEX_ContDens	0.38	0.10	0.48	0.08	0.02842
Part-of-speech rate	LEX_PoS_AUX	0.04	0.03	0.06	0.02	0.04036
	LEX_PoS_DET	0.08	0.02	0.12	0.03	0.004513
	LEX_PoS_INTJ	0.07	0.05	0.02	0.02	0.01004
	LEX_PoS_PUNCT	0.25	0.04	0.18	0.03	0.0001955
Spatial Deixis rate	LEX_SDEIXIS	0.00	0.01	0.01	0.01	0.04929
Relative pronouns rate	LEX_RPRO	0.01	0.01	0.02	0.01	0.01165
Lexical richness: type-token ratio	LEX_TTR	0.51	0.07	0.41	0.06	0.001115
Mean number of words in utterances	LEX_NW	172.17	123.12	524.25	361.27	0.001433
(B) LINGUISTIC INQUIRY AND WORD COUNT FEATURES						
Linguistic processes	LWC_Prepos	0.05	0.03	0.09	0.03	0.01209
Affective processes	LWC_Affett	0.01	0.01	0.02	0.01	0.03002
	LWC_Emo_Neg	0.00	0.00	0.01	0.01	0.00184
	LWC_Tristez	0.00	0.00	0.00	0.00	0.002448
Cognitive processes	LWC_Causa	0.00	0.00	0.01	0.01	0.01172
	LWC_Inibiz	0.00	0.00	0.00	0.00	0.01647
Perceptual processes	LWC_Vista	0.00	0.01	0.01	0.01	0.03339
	LWC_Udito	0.01	0.01	0.01	0.01	0.03114
Relativity	LWC_Futuro	0.00	0.01	0.00	0.00	0.02771
	LWC_Sopra	0.00	0.00	0.00	0.00	0.001084
	LWC_Sotto	0.00	0.00	0.00	0.00	0.01934
	LWC_Inclusi	0.01	0.01	0.02	0.01	0.004584
Personal concerns	LWC_Lavoro	0.00	0.00	0.00	0.00	0.02771
	LWC_Raggiun	0.00	0.00	0.00	0.00	0.01828
	LWC_Svago	0.00	0.01	0.01	0.01	0.009973
	LWC_Sport	0.00	0.00	0.00	0.00	0.007054
	LWC_Metafis	0.00	0.00	0.00	0.00	0.0003834
	LWC_religio	0.00	0.00	0.00	0.00	0.03669
	LWC_Morte	0.00	0.00	0.00	0.00	0.03669
Spoken categories	LWC_riempiti	0.00	0.00	0.01	0.00	0.00395
Linguistic Processes	LWC_Lui_lei	0.00	0.00	0.00	0.00	0.007054
	LWC_Loro	0.00	0.00	0.00	0.00	0.01647
	LWC_Condizio	0.00	0.00	0.00	0.00	0.0003834
	LWC_P_pass	0.01	0.02	0.01	0.01	0.009142
	LWC_Noi_Verb	0.00	0.00	0.00	0.00	0.0009539
	LWC_Loro_Ver	0.00	0.00	0.01	0.01	0.0009639

(C) READABILITY FEATURES (REA)						
Lexical readability index	REA_LEXICAL	76.74	23.95	49.21	9.65	0.01209
(D) ACOUSTIC FEATURES (SPE)						
Silence segments duration	SPE_SILMEAN	2.59	1.15	1.53	0.52	0.01727
	SPE_SILSD	2.14	1.18	1.04	0.53	0.01727
	SPE_SILMEDIAN	1.96	1.01	1.25	0.39	0.03872
Verbal rate	SPE_VR	1.73	0.70	2.55	0.61	0.01727
(E) SYNTACTIC FEATURES (SYN)						
Utterance length	SYN_SLENM	61.04	61.05	152.89	63.48	0.0002012
Global dependency distance	SYN_GRAPHDISTM	3.33	0.69	4.36	1.09	0.008293

Table 3: Mean values, standard deviations and results from the non-parametric Wilcoxon-Mann-Whitney test reported for significant features considering all tasks together. Statistical significance: *p-value < 0.05

Feature	Code	TASK DAY				
		PG		CG		WMW
		µ	s	µ	s	p-value
(A) LEXICAL FEATURES (LEX)						
Part-of-speech rate	LEX_PoS_AUX	0.02	0.01	0.05	0.02	0.02857
Mean number of words in utterances	LEX_NW	173.00	107.71	497.25	69.91	0.02857
(B) LINGUISTIC INQUIRY AND WORD COUNT FEATURES						
Linguistic processes	LWC_Prepos	0.05	0.03	0.09	0.03	0.01209
Affective processes	LWC_Affett	0.01	0.01	0.02	0.01	0.03002
	LWC_Emo_Neg	0.00	0.00	0.01	0.01	0.00184
	LWC_Tristez	0.00	0.00	0.00	0.00	0.002448
(E) SYNTACTIC FEATURES (SYN)						
Utterance length	SYN_SLENM	61.04	61.05	152.89	63.48	0.0002012
Global dependency distance	SYN_GRAPHDISTM	3.33	0.69	4.36	1.09	0.008293

Table 4: Mean values, standard deviations and results from the non-parametric Wilcoxon-Mann-Whitney test reported for significant features considering the task DAY. Statistical significance: *p-value < 0.05

Feature	Code	TASK WORK				
		PG		CG		WMW
		μ	s	μ	s	p-value
(A) LEXICAL FEATURES (LEX)						
Part-of-speech rate	LEX_PoS_PUNCT	0.23	0.03	0.15	0.03	0.02857
Lexical richness: type-token ratio	LEX_TTR	0.50	0.07	0.36	0.07	0.02857
Mean number of words in utterances	LEX_NW	194.75	175.33	883.25	391.36	0.02857
(B) LINGUISTIC INQUIRY AND WORD COUNT FEATURES						
Affect words	LWC_Emo_Neg	0.00	0.00	0.01	0.00	0.02652
	LWC_Tristez	0.00	0.00	0.00	0.00	0.02107
Perceptual processes	LWC_Rif_gen	0.00	0.00	0.00	0.00	0.02107
Personal concerns	LWC_Sotto	0.00	0.00	0.00	0.00	0.02107
	LWC_Inclusi	0.00	0.00	0.02	0.01	0.02107
Personal concerns	LWC_Metafis	0.00	0.00	0.00	0.00	0.02107
Others	LWC_riempiti	0.00	0.00	0.01	0.00	0.02652
	LWC_Lui_lei	0.00	0.00	0.00	0.00	0.02107
	LWC_Condizio	0.00	0.00	0.00	0.00	0.02107
	LWC_Voi_Verb	0.00	0.00	0.00	0.00	0.02107
	LWC_Loro_Ver	0.00	0.00	0.01	0.00	0.02107

Table 5: Mean values, standard deviations and results from the non-parametric Wilcoxon-Mann-Whitney test reported for significant features considering the task WORK. Statistical significance: *p-value < 0.05

Feature	Code	TASK PICTURE				
		PG		CG		WMW
		μ	s	μ	s	p-value
(A) LEXICAL FEATURES (LEX)						
Part-of-speech rate	LEX_PoS_DET	0.08	0.03	0.15	0.01	0.02857
(B) LINGUISTIC INQUIRY AND WORD COUNT FEATURES						
Function words	LWC_Articol	0.14	0.02	0.22	0.02	0.02857
Cognitive processes	LWC_Proc_Sen	0.01	0.01	0.04	0.01	0.02652
Personal concerns	LWC_Svago	0.00	0.00	0.01	0.01	0.02652
	LWC_Sport	0.00	0.00	0.01	0.00	0.02107

Table 6: Mean values, standard deviations and results from the non-parametric Wilcoxon-Mann-Whitney test reported for significant features considering the task PICTURE. Statistical significance: *p-value < 0.05

Results from the statistical analysis are also reported in Figures 4, 5, and 6 using boxplots. Due to space limitations, only the most statistically significant features (i. e., *p < 0.05) differentiating the PG from CG only when all tasks are considered together are reported. Specifically, Figure 4 contains the results for each significant lexical and syntactic feature, Figure 5 contains the results for each significant acoustic feature and Figure 6 contains the results for each significant readability, linguistic inquiry and word count feature.

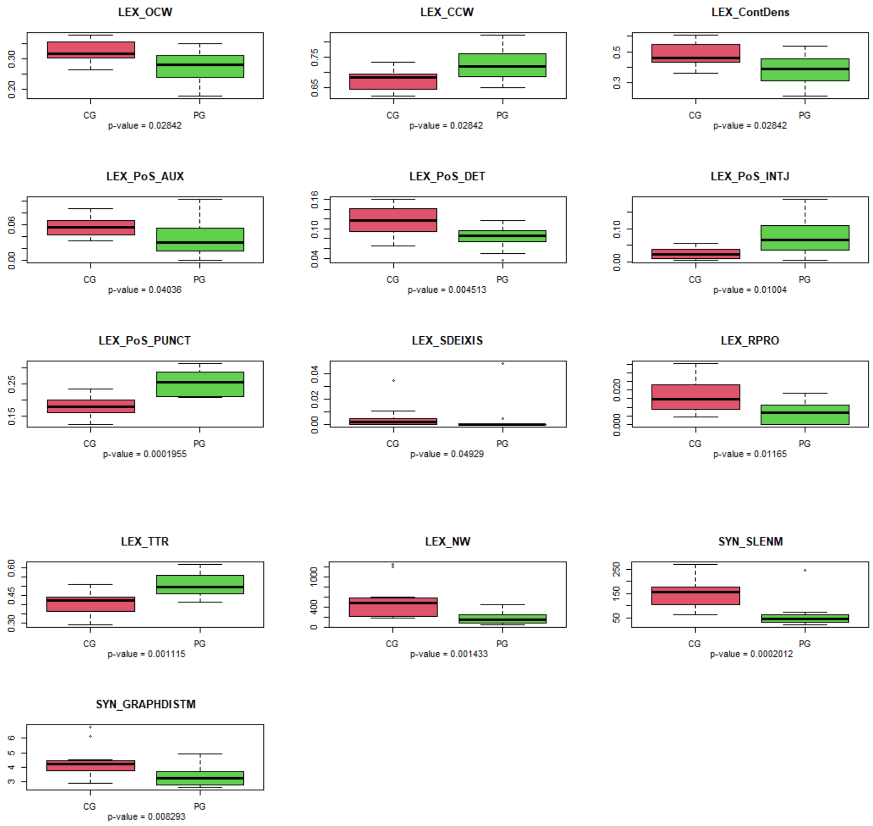

Figure 4: Boxplots (median and interquartile range) reporting the results from the non-parametric Wilcoxon-Mann-Whitney test for each significant lexical and syntactic feature, considering all tasks together.

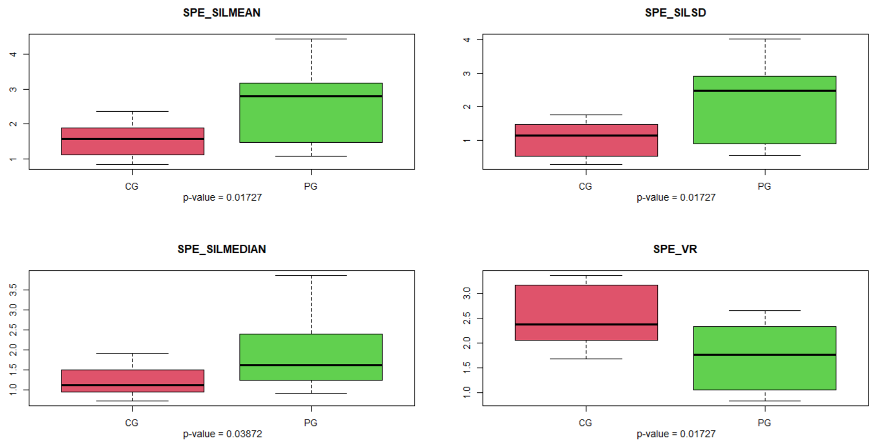

Figure 5: Boxplots (median and interquartile range) reporting the results from the non-parametric Wilcoxon-Mann-Whitney test for each significant acoustic feature, considering all tasks together.

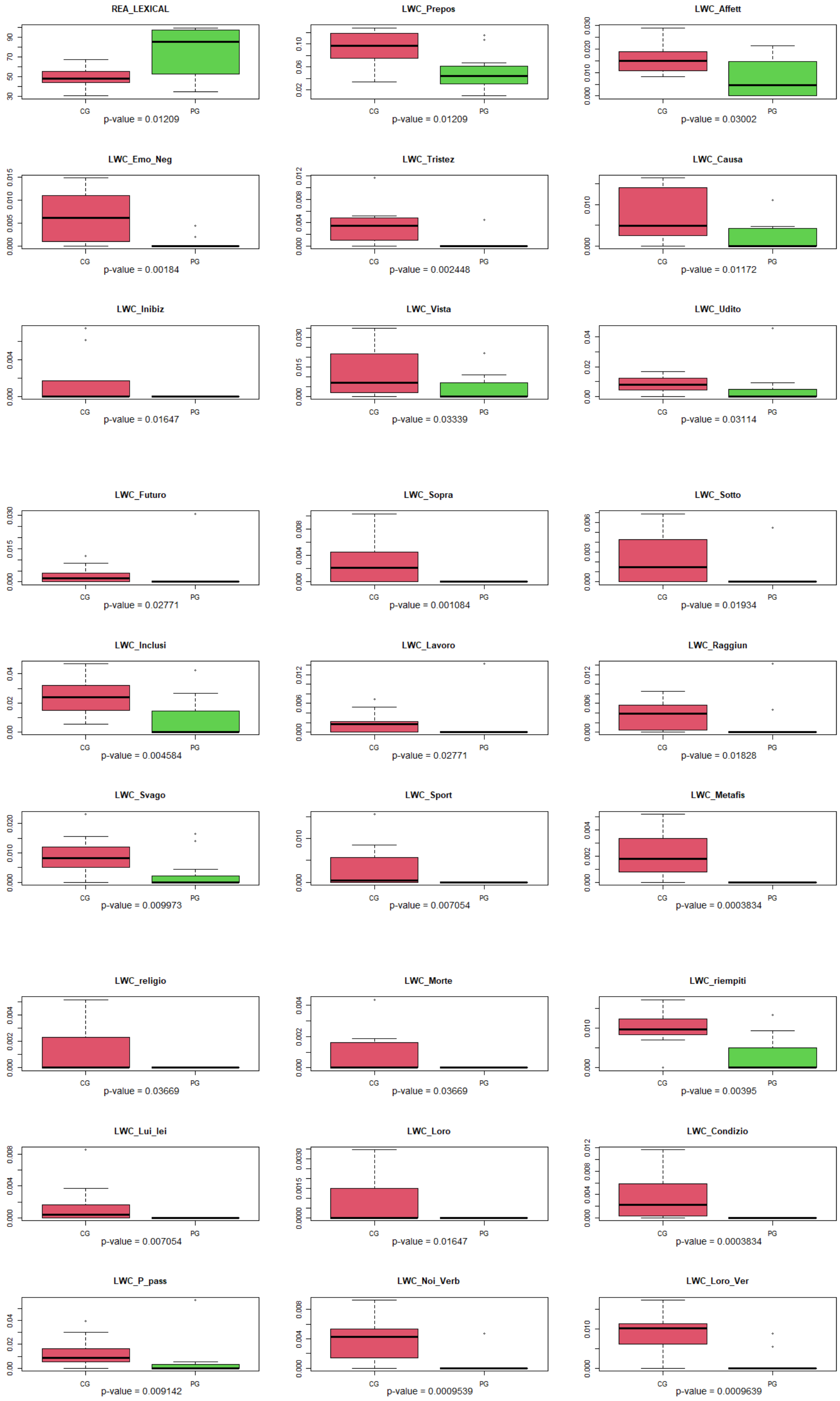

Figure 6: Boxplots (median and interquartile range) reporting the results from the non-parametric Wilcoxon-Mann-Whitney test for each significant readability, linguistic inquiry and word count features, considering all tasks together.

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5 Discussion

The statistical analysis carried out on each of the indices yielded some significant results. Given that the enrolled patients suffered from either Alzheimer's dementia or mixed dementia (i. e., cognitive frailty caused by the combination of Alzheimer's disease and cerebrovascular pathology), the findings will be discussed in light of the literature (reported in section 1.2) about speech alterations in patients affected by Alzheimer's type dementia.

In general, upon examining significant indices and their boxplots, patients, compared to healthy controls, produced shorter texts with a reduced number of words per utterances and master an impoverished lexicon characterized by a reduction in open-class words. Even though there appears to be a higher use of closed-class words by patients, a closer examination of the various parts of speech reveals that this is primarily due to a significant presence of interjections, indicating disfluent and hesitant speech. Regarding other closed-class words, such as determiners and auxiliaries, they are less present in pathological speech. The reduced use of determiners is particularly notable in the PICTURE task. Additionally, the rate of relative pronouns and the spatial deixis are also reduced in patients' speech. However, all the significant parameters are majorly altered when all tasks are considered together. From a syntactic perspective, mean utterance length and mean global dependency distance (i. e., long-distance dependencies) are the most altered in dementia patients, especially in the DAY task, indicating a reduced structural complexity. In general, the findings reported so far are in line with the existing literature, which typically describes lexical deficits stemming from word-retrieval difficulties, decreased verbal fluency, and syntactic simplification (cf. Hoffmann et al. 2010: 29–34; Ferris/Farlow 2013: 1007–1014; Szatloczki et al. 2015; Chen/Gordon 2019; Martines-Nicolás et al. 2019; Varlokosta et al. 2023).

Among all the acoustic features considered, only the silence segments duration, and, verbal rate are significant. Patients' higher duration of silence periods (an indication of the need for more time to think about what to say) and lower duration of the speech time are in accord with the existing literature (cf. Sajjadi et al. 2012: 847–866; Martínez-Sánchez et al. 2013: 325–331; Szatloczki et al. 2015).

The only significant readability feature is the lexical-based one, but only when considering all tasks together. As for LIWC features, the WORK task is the most effective one. By looking at the boxplots, it is clearly visible that all significant indices have higher values in the CG compared to the PG. Controls used more function words (i. e., determiners, prepositions, pronouns) than patients. This is in line with what has been found with the lexical parameters. Healthy controls even used a higher amount of past tense verbs which were elicited in the WORK narrative task and hence requires a certain time orientation. They also used more conditional and future tenses, and their verbs presented a higher number of inflections. Moreover, it emerges that healthy controls have more awareness of their physical frailty (deafness, blindness) due to age, as they used more terms related to sight and hearing. They are even more prone to express their emotions, in particular negative ones, which appear especially in narrative tasks. As a matter of fact, healthy participants expressed nostalgia for past times when they were at home and busy working, having a different type of daily routine. The last thing to add is that the control group used more terms related to spatial relativity, cognitive processes (e. g., causation and inhibition), and personal concerns (e. g., work, achievement, leisure, religion, death, sport and metaphysics). Even in this case, the results appear to align with existing literature where AD patients are reported to exhibit deficits in verb inflection, along with experiencing spatial disorientation, impairments in self-awareness and introspection, emotional flattening, and difficulties with mental time travel (cf. Colombo et al. 2009: 1069–1078; Auclair-Ouellet 2015: 41–64; Bond et al. 2016; Puthusseryppady et al. 2020; Requena-Komuro et al. 2020; Heilman/Nadeau 2022: 99–116; Schaffner et al. 2022).

The fact that, overall, the results obtained are in line with the existing literature provides evidence for the advantage of using NLP techniques to study language in pathological aging. Additionally, the results are similar, though not identical, to those found in other studies that utilised the same pipeline but applied it to pathological cohorts speaking different Italian varieties (cf. Beltrami 2016: 2086–2093; Martinelli/Gagliardi 2022: 711–732). This underlines the need to continue gathering linguistic data from across the Italian peninsula to ensure proper validation of NLP methods (cf. Gagliardi 2022: 110–122).

6 Concluding remarks

This study analyzed the speech samples collected from 4 Alzheimer's patients and 4 healthy controls matched by age, level of education, and sex, all living in Lombardy. Two narrative tasks and a picture description task were used to collect the linguistic material which was manually transcribed using the ELAN software. An NLP pipeline was employed to extract acoustic (SPE), lexical (LEX), readability (REA), syntactic (SYN), and LIWC – Linguistic Inquiry and Word Count (LWC) features. The results suggest that the most statistically significant features differentiating the pathological group from the control group are the lexical and LIWC features, followed by the acoustic and syntactic parameters. Additionally, the most effective task was the one in which participants had to describe the job they retired from, followed by narrating their typical day and, lastly, the picture description.

To conclude, this preliminary study suggests that the use of NLP techniques can be fruitful, as they produce results generally consistent with existing literature. However, the study's preliminary nature allows for certain shortcomings. In particular, the number of participants enrolled in this study is too small, necessitating the collection of more speech samples from patients living in Lombardy. Moreover, there is a need to include in our cohorts more patients affected by different types of dementia, to clearly outline their peculiar trajectories of linguistic decline. Lastly, in the case of the Italian language, there is also the challenge of significant regional variation, making it fundamental to continue creating clinical speech corpora with linguistic data from different parts of the nation to generalize the results obtained through NLP methods.

Declarations

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Ethical Approval

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Bioethics Committee of the University of Bologna (Prot. n. 00940021, 4/04/2023).

CRediT Author Statement

MLPC: Investigation, Data Curation, Formal analysis, Writing - Original Draft. **GG**: Conceptualization, Writing - Review & Editing, Supervision.

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