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Severity of Alzheimer's disease and language features in picture descriptions

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ABSTRACT

Background: Studies of connected speech of individuals with Alzheimer's disease (AD) report significant impairments relative to the language of cognitively intact participants. Considerably less research has focused on the association between dementia severity and language features.

Aims: The current study examines how scores on a dementia screening test (the Mini-Mental Status Examination, MMSE) correlate with features of connected speech.

Methods & Procedures: Thirty-five individuals with AD (range of MMSE scores = 3–25) and 35 cognitively intact participants provided picture descriptions. Ten language features were derived from their descriptions using an automated text analysis tool: total word number, percentage of content words, pronoun ratio, type-token ratio, mean word frequency, percentage of verbs, percentage of verbs in the most common morphological form in Hebrew, percentage of verbs in present tense, percentage of prepositions, and percentage of subordination markers. Information content was also analysed.

Outcomes & Results: Group differences emerged in five language features as well as in information content, attesting for substantial lexical impairment in AD. Within the AD group, MMSE scores were correlated with type-token ratio, with mean word frequency, and with the number of information units. No equivalent correlations were found within the control group.

Conclusions: Dementia severity associates with decreasing lexical diversity, increasing word frequency, and a reduction in relevant information content, but not with changes in grammatical features of language. A simple automated analysis of connected speech could be used clinically to define and track the decline in language abilities in AD.

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Dementia; connected speech; discourse; lexical impairment; Hebrew

Introduction

Relatively little research has focused on the association between the level of dementia and language features in connected speech, and the results of these studies are inconsistent (e.g., Ahmed, Haigh, de Jager, & Garrard, 2013; Hier, Hagenlocker, & Shindler,

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1985; Tomoeda & Bayles, 1993; Zimmerer, Wibrow, & Varley, 2016). In fact, most research on connected speech in Alzheimer's disease (AD) has focused on early stages of the disease, with an attempt to identify subtle changes in language that could assist in diagnosis (e.g., Drummond et al., 2015; Pekkala et al., 2013; Szatloczki, Hoffmann, Vincze, Kalman, & Pakaski, 2015; Tsantali, Economidis, & Tsolaki, 2013), and less attention to more severe decline. Studying clinicians' ratings of language abilities in 486 participants with AD, Weiner, Neubecker, Bret, and Hynan (2008) reported that dementia severity associated with the majority of language difficulties. Nevertheless, this work did not investigate quantitative measures of connected speech. The aim of the current study is to examine how dementia severity associates with language features and information content in picture descriptions.

Assessments of connected speech show that individuals with AD provide significantly fewer information units and more irrelevant information relative to control participants (e.g., Ahmed et al., 2013; Bschor, Kühl, & Reischies, 2001; Croisile et al., 1996; de Lira, Minett, Bertolucci, & Ortiz, 2014; Ehrlich, Obler, & Clark, 1997; Kavé & Levy, 2003), and often do not grasp or convey the overall message of the story (Ash, Moore, Vesely, & Grossman, 2007). The disease reduces propositional content (Kemper, Thompson, & Marquis, 2001), leads to an increase in the number of incomplete propositions (Brandão, Castelló, van Dijk, de Mattos Pimenta Parente, & Peña-Casanova, 2009), and to a decrease in the percentage of content words (Kavé & Goral, 2016). Persons with AD display significant word-finding difficulties that are evident in word errors (Altmann, Kempler, & Andersen, 2001; Forbes-McKay & Venneri, 2005), in empty phrases and indefinite terms (Nicholas, Obler, Albert, & Helm-Estabrooks, 1985), as well as in the retrieval of more frequent words (Kavé & Goral, 2016). In addition, pronoun use can indicate difficulties in word retrieval, as pronouns often carry less specific information than do full nouns. Indeed, persons with AD overuse pronouns and generate more pronouns that have no appropriate referents (e.g., Ahmed et al., 2013; Almor, Kempler, MacDonald, Andersen, & Tyler, 1999). This decline in language reflects significant semantic impairments (Altmann & McClung, 2008) and it begins early, most likely before the person is even diagnosed (e.g., Berisha, Wang, LaCross, & Liss, 2015; Garrard, Maloney, Hodges, & Patterson, 2005).

In contrast to this well-documented semantic impairment, early studies of language in AD have noted that grammatical aspects of language might be better preserved in this disease (e.g., Kempler, Curtiss, & Jackson, 1987; Schwartz, Marin, & Saffran, 1979; Whitaker, 1976). Blanken, Dittmann, Haas, and Wallesch (1987) reported that while patients provided shorter and simpler sentences, they had no significant difficulty in the use of inflection and function words. Croisile et al. (1996) documented a reduction in the use of subordinate clauses in AD, but no difference in grammatical errors between patients and controls. Kavé and Levy (2003) found that persons with AD used the same syntactic structures and the same morphological forms as did cognitively intact participants, and made very few structural errors. Nevertheless, other studies have noted that AD leads to grammatical difficulties as well. For example, Ahmed, de Jager, Haigh, and Garrard (2012) reported that a third of their participants with AD demonstrated reduction in at least one aspect of syntactic complexity (e.g., simpler sentences or more syntactic errors). Kemper et al. (2001) showed that AD accelerates age-related deterioration in both propositional content and grammatical complexity. In addition, Altmann et al. (2001) documented more errors of all types in 10 participants with AD relative to 15 cognitively intact participants, including errors that involved closed class words and morphosyntactic aspects of language.

Thus, there are indications of both semantic and grammatical difficulties in the language of individuals with AD. However, only few studies have examined the effect of dementia severity on quantitative features of connected speech. Hier et al. (1985) compared 16 participants with early-stage AD to 10 participants with late-stage AD. Greater severity was associated with an increase in the use of empty words, overuse of pronouns, errors in the selection of prepositions, and decreased relevance. Tomoeda and Bayles (1993) followed three persons with AD and found that the reduction in information units was the best measure of decline over time. Zimmerer et al. (2016) investigated data from 48 individuals with AD and reported that time post-onset (range 1–12 years) correlated with no general production measure (e.g., word count, rate of closed-class words, inflection rate, proportion of semantic and syntactic errors), but it did correlate with the use of formulaic expressions. Forbes-McKay, Shanks, and Venneri (2013) asked 15 participants with AD to provide speech samples three times, with a 6-month interval between testing sessions. They then scored samples on 12 measures that referred to articulation, phonological and semantic errors, content, and grammatical form, using a seven-point scale for each measure. Results showed that only the number of phonological errors deteriorated over time. Ahmed et al. (2013) studied nine participants with AD longitudinally, starting at the point of conversion from mild cognitive impairment to AD and up to moderate dementia which was diagnosed 19–30 months later. Half of the participants showed a decrease in total semantic units and an increase in the production of pronouns from the mild stage to the more severe stage, and the remaining participants demonstrated more variable impairments. These studies suggest that language deteriorates over time in AD, although there is no consensus regarding the features that best capture this deterioration.

Analyses of connected speech in AD have traditionally relied on labour-intensive manual coding. If such analyses are to become useful in clinical settings, they must be fast and simple (Forbes-McKay & Venneri, 2005). Recent advances in computational linguistics have introduced fully automated tools that might help clinicians assess spontaneous speech more easily. Most studies in this field combine natural language processing with machine-learning methods and attempt to discriminate between persons with and without cognitive decline (e.g., Bucks, Singh, Cuerden, & Wilcock, 2000; Fraser, Meltzer, & Rudzicz, 2015; Guinn, Singer, & Habash, 2014; Roark, Mitchell, Hosom, Hollingshead, & Kaye, 2011; Thomas, Keselj, Cercone, Rockwood, & Asp, 2005). For example, Fraser et al. (2015) defined 370 features from picture descriptions provided by 167 individuals with AD and by 97 healthy controls. These features were mapped onto four factors: acoustic, semantic, syntactic, and information, and all four factors differed significantly across groups. The authors explain that the features that comprised these factors were preselected to be useful in distinguishing individuals with AD from healthy individuals. Importantly, automated text analysis tools have the potential not only to differentiate between impaired and intact language, but also to assist clinicians in tracking language decline.

The current study examines the association between dementia severity and language features in AD, using a freely available automated text analysis tool that requires no manual coding. In addition, we count the number of information units, as suggested by Croisile et al. (1996). Dementia severity was operationally defined as the score on the Mini-Mental Status Examination (MMSE, Folstein, Folstein, & McHugh, 1975). Ten language features were selected from the output of the automated analysis to reflect both lexical and grammatical aspects of language. The tool is intended to evaluate essays provided by healthy individuals on a multitude of topics, and therefore it does not focus on errors, information content, or the relevance of the text to any particular stimulus. Hence, information content was analysed manually. We expected to find significant impairment in all language features as well as in information content. That is, we hypothesised that more severely demented individuals would show greater difficulties in all aspects of connected speech.

Method

Participants

The sample included 70 Hebrew speakers aged 65–91 years, 43 of them women, half diagnosed with AD and half cognitively intact (see Table 1 for full demographic details). We pooled patient data from previous studies (Dassa & Amir, 2014, 2015; Kavé & Goral, 2016; Kavé & Levy, 2003) and selected control participants to match individuals with AD in terms of age, age of immigration, and education. Healthy participants were selected from the same studies as the participants with AD as well as from Kavé, Samuel-Enoch, and Adiv (2009). Individuals were either born in Israel (N = 28) or immigrated to Israel as children or adolescents (N = 42). The number of participants born outside Israel and their mean age of immigration were identical across groups. All participants used Hebrew as their primary language at home and at work throughout their adult life. Years of formal schooling ranged between 8 and 19, and education level was matched across groups.

Thirty-five participants were diagnosed with AD according to the National Institute of Neurological and Communicative Disorders and Stroke and the Alzheimer's Disease and Related Disorders Association (NINCDS-ADRDA) criteria (McKhann et al., 1984) 1–7 years

Table 1. Demographic characteristics, by group.

		AD	Control
N		35	35
Number of women		23	20
MMSE	Mean	18.31	28.97
	SD	5.66	1.15
	Range	3–25	27–30
Chronological age (years)	Mean	77.89	76.71
	SD	6.25	4.21
	Range	65–91	70–85
Age at immigration (years)	Mean	10.71	10.71
	SD	4.83	5.26
	Range	1–18	1–17
Education (years)	Mean	11.50	11.83
	SD	2.30	2.76
	Range	8–16	8–19

The mean age at immigration is presented only for participants who were born outside Israel (21 in each group). Data on education could be confirmed for only 28 participants with AD. There were no significant group differences in any demographic variable, except for MMSE scores.

prior to the study (mean time from diagnosis = 3.11, *SD* = 1.55). In no participant the most prominent initial symptom was language difficulty. Participants lived both in the community and in nursing homes and their scores on the MMSE (Folstein et al., 1975) ranged from 3 to 25. Fourteen participants scored 18 or lower, 17 scored between 19 and 23, and four scored 24 or 25. Time post-onset as well as chronological age did not correlate with MMSE scores. Thirty-five community-dwelling cognitively intact volunteers served as control participants. They reported no history of neurological or psychiatric disease, complained of no cognitive decline, and scored 27 or higher on the MMSE. Participant recruitment received Institutional Review Board approval and was completed in accordance with the Helsinki Declaration.

Procedure

Each person was presented with the Cookie Theft picture from the Boston Diagnostic Aphasia Examination (Goodglass & Kaplan, 1983). The instructions were "I want you to tell me the story of this picture". Participants with AD who produced extremely limited speech were prompted to elaborate on their descriptions using a set of structured questions. Descriptions were recorded and the recording was stopped when a person indicated that she/he had finished, either by saying so explicitly or by becoming silent. Speech samples were transcribed and analyses were performed on the written transcriptions.

Automated analysis of picture descriptions

Samples were first manually stripped of all interjections (e.g., ah…), incomplete words (e.g., co…), words in languages other than Hebrew, and unrelated comments at the beginning or end of the description. The samples were then submitted to an automated text analysis tool (https://hlp.nite.org.il/WebStatisticalAnalyzer.aspx, version 17/6/2015), developed for scoring written essays in Hebrew (Ben-Simon & Cohen, 2011). The tool provided separate summary results for each sample. We analysed 10 features that reflect both lexical and grammatical aspects of language:

(1) Total number of words – this feature counts every letter string, as do standard word counts in any word-processing software.
(2) Percentage of content words out of all words – this feature counts all tokens of content words (e.g., nouns, verbs, adjectives, adverbs) and divides their sum by the total number of words.
(3) Pronoun ratio – in line with the quantitative analysis of sentence production in aphasia developed by Rochon, Saffran, Berndt, and Schwartz (2000), pronoun overuse was examined with an index of the proportion of pronouns out of all nouns and pronouns produced by each participant. This feature is not provided by the automated tool and was thus calculated manually from the percentage of nouns and pronouns that the tool provides. We first derived the number of pronouns from the percentage of pronouns and the number of nouns from the percentage of nouns. We then divided the number of pronouns by the total number of nouns and pronouns together. All pronouns were counted (e.g., personal, possessive, demonstrative pronouns), including repetitions.

(4) Type-token ratio – this feature counts the total number of unique words of all parts of speech and divides this sum by the total number of words.
(5) Mean word frequency – this feature is based on a word corpus of one million words which is built-in within the analyser. Frequency is first searched for each letter string relative to the corpus, using an algorithm that converts frequency to a scale of 10–53.6. The tool then calculates the mean frequency of all tokens in each sample. That is, the average frequency does not represent an average of occurrences per million but a mean of algorithmically transformed scores.
(6) Percentage of verbs out of all words – this feature counts all verb tokens and divides their sum by the total number of words.
(7) Percentage of verbs in the PAAL pattern out of all verbs – this feature counts all verbs in the most common verb pattern (called PAAL in Hebrew) and divides their sum by the total number of verbs. There are seven verb patterns in Hebrew that dictate the structure of all verbs in the language. These patterns convey morphological, syntactic, and semantic information (such as active vs. passive, transitive vs. intransitive, inchoative, causative, or reflexive). Each pattern specifies how the verb would be inflected and all verbs that appear in that pattern are similarly inflected. For example, the verbs "to stand" and "to wash" are in the PAAL pattern: *amad* (he stood) and *shataf* (he washed) are inflected in past tense, third person, singular, and masculine; *omedet* (she is standing) and *shotefet* (she is washing) are inflected in present tense, third person, singular, and feminine. The automated tool provides percentages for each pattern across tense, person, number, or gender. We focused on the PAAL pattern because it is the most common verb pattern.
(8) Percentage of verbs in present tense out of all verbs – this feature counts all verbs in present tense and divides their sum by the total number of verbs. The automated tool provides percentages of present tense, past tense, future tense, imperatives, and infinitives. Since pictures are primarily described in present tense (as opposed, for example, to autobiographical memories, e.g., Irish et al., 2015), we decided to focus on this tense. Note that unlike English, Hebrew has only one type of present tense.
(9) Percentage of prepositions out of all words – this feature counts all prepositions and divides their sum by the total number of words. Hebrew has free-standing prepositions as in English (e.g., *al*, "on"), as well as prepositions that are attached to the word (e.g., *ba'aron*, "in the cabinet"). All forms were counted.
(10) Percentage of subordination markers out of all words – this feature counts all indications of subordination, whether free-standing or bound, and divides their sum by the total number of words.

Analysis of information content

Following Croisile et al. (1996), the number of information units provided by each participant was recorded for the categories of Actors, Places, Actions, and Objects, with a total of 25 possible information units. The category of Actors included three characters: the mother, the boy, and the girl. The category of Places included two locations: the kitchen and the exterior seen through the window. The category of Actions included seven activities: the boy taking the cookie, the boy/stool falling, the mother drying or washing the dishes, the water overflowing, the girl asking for a cookie, the mother unconcerned by the overflowing, and the mother not noticing the children. The category of Objects included 13 items: the faucet, the water, the sink, the floor, the plate, the dishes on the counter, the counter, the cookies, the jar, the cabinet, the stool, the window, and the curtain. Participants were given credit for any mention of these information units even if they chose the wrong word to refer to the credited piece of information (e.g., "the *ladder* is falling" instead of "the *stool* is falling"). One author coded all speech samples. To examine coding reliability, the other author independently coded 10 speech samples, half provided by participants with AD and half provided by healthy controls. Inter-rater correlation for the total number of information units was high and significant (r = .96, p < .001).

Results

Table 2 presents raw scores on the 10 language features derived from the automated analysis, along with *t*-tests that compared these variables across groups. Six of the 10 comparisons were statistically significant using a .05 criterion. After applying the Bonferroni correction for multiple comparisons, the significance criterion was adjusted to .005, and only five comparisons remained significant. The groups differed in total

Table 2. Raw scores and group comparisons for the 10 language features.

		AD	Control	*t*-Test (*df* = 68)	*p*-Value (two-tailed)
Total number of words	Mean	110.49	59.77	3.549	.001
	SD	80.28	26.54		
	Range	13–314	25–175		
% content words of all words	Mean	61.72	72.16	−4.792	.000
	SD	10.73	7.04		
	Range	49.18–92.31	58.49–87.10		
Pronoun ratio	Mean	36.79	19.01	5.269	.000
	SD	16.35	11.40		
	Range	0–59.38	0–40.74		
Type-token ratio	Mean	0.73	0.87	−4.976	.000
	SD	0.15	0.08		
	Range	0.47–1	0.62–1		
Mean word frequency	Mean	33.82	30.77	4.493	.000
	SD	3.39	2.14		
	Range	23.33–38.51	26.54–35.42		
% verbs of all words	Mean	22.38	24.32	−1.471	.146
	SD	5.87	4.91		
	Range	12.90–38.46	14.29–35.59		
% verbs in PAAL form	Mean	69.78	62.73	1.953	.055
	SD	14.28	15.97		
	Range	31.25–92.86	23.08–85.71		
% verbs in present tense	Mean	65.34	66.08	−.192	.848
	SD	17.18	18.97		
	Range	25.00–100	9.52–92.31		
% prepositions of all words	Mean	15.28	18.10	−2.039	.045
	SD	6.50	5.21		
	Range	0–30.95	6.78–28.00		
% subordination markers	Mean	3.60	4.36	−1.134	.261
	SD	2.77	2.77		
	Range	0–10.94	0–9.46		

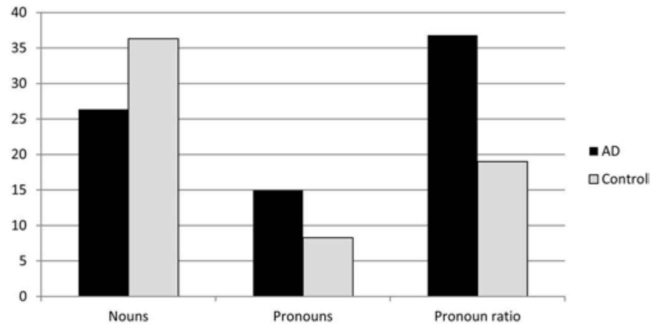

Figure 1. Percentage of nouns and pronouns out of all words and percentage of pronouns out of all nouns and pronouns, by group (all group differences were significant at the .001 level).

word number, percentage of content words, pronoun ratio, type-token ratio, and word frequency. Thus, individuals with AD produced more words than did control participants, but a lower percentage of content words. Figure 1 shows group differences in pronoun ratio as well as in the percentage of nouns and pronouns relative to all words, suggesting that persons with AD overused pronouns relative to control participants. In addition, individuals with AD had a lower type-token ratio and a higher mean of word frequency than did healthy participants. In contrast, there were no significant group differences in percentage of verbs, percentage of the PAAL pattern out of all verbs, percentage of present tense out of all verbs, percentage of prepositions out of all words, and percentage of subordination markers out of all words. An analysis that looked at the total number of information units showed a significant group difference, t (68) = 5.845, p < .005, suggesting that persons with AD provided less relevant content than did healthy participants (see Figure 2).

Next, we computed Pearson correlations to examine the association between MMSE scores and the 10 language features. As shown in Table 3, within the control group no correlation reached significance. Within the AD group, MMSE scores were negatively correlated with the total number of words, so that participants who were more severely demented produced more words. To verify whether this correlation represented

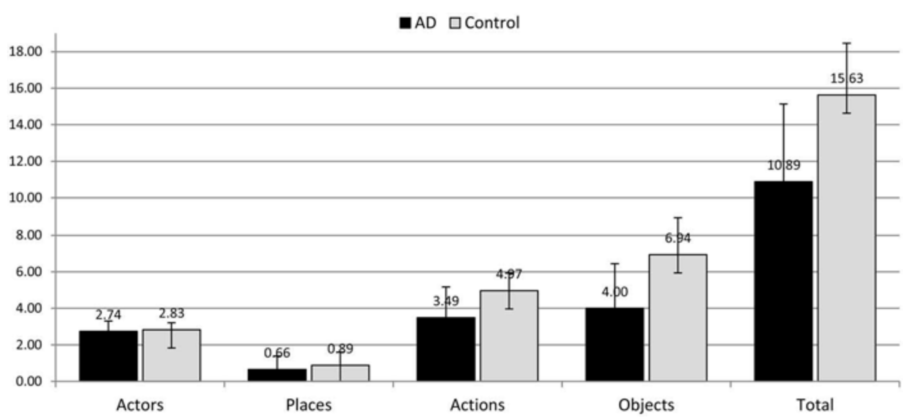

Figure 2. Mean number of information units, by group.

Table 3. Correlations between MMSE scores and the 10 language features, by group.

	AD	Control
Total number of words	−.355*	.133
% content words of all words	.305	.066
Pronoun ratio	−.277	−.002
Type-token ratio	.572**	−.077
Mean word frequency	−.339*	.052
% verbs of all words	.323	−.229
% verbs in PAAL form	−.208	.153
% verbs in present tense	−.075	.242
% prepositions of all words	−.012	.134
% subordination markers	.074	−.158

*p < .05; **p < .01.

increased verbosity but no increase in content, we examined whether the number of words correlated with the number of information units. Within the control group, the correlation was positive and significant, $r = .535$, $p < .01$, so that healthy participants who produced more words also provided more relevant content. In contrast, no significant correlation emerged within the AD group, $r = .115$, ns. Furthermore, within the AD group, MMSE scores were positively associated with the type-token ratio, so that lower MMSE scores were associated with a lower type-token ratio (e.g., more repetition). MMSE scores were also negatively correlated with word frequency, so that greater dementia severity was associated with production of more frequent words. No other correlations between MMSE scores and language features reached significance. Finally, within the AD group, MMSE scores were positively correlated with the total number of information units, $r = .428$, $p < .05$, so that participants with lower MMSE scores provided fewer information units.

Discussion

Our results replicate previous work that documented impairment on various aspects of connected speech in AD (e.g., Ahmed et al., 2012, 2013; Altmann et al., 2001; Forbes-McKay & Venneri, 2005). In addition, dementia severity was associated with specific lexical impairments. Nevertheless, some language features did not differ across groups and did not correlate with dementia severity.

First, group differences were found in total word number, as individuals with AD provided significantly more words than did healthy participants. This finding is somewhat surprising given previous reports in which there was either a reduction in word output in AD (e.g., Croisile et al., 1996; de Lira et al., 2014; Hier et al., 1985) or no group differences (e.g., Bschor et al., 2001; Kavé & Goral, 2016; Nicholas et al., 1985). In addition, total word output was positively correlated with MMSE scores, so that individuals who were more demented spoke more rather than less. Group differences as well as the documented correlation could have resulted from the fact that persons with AD were prompted to continue speaking while healthy adults were not. Prompting reflected the experimenter's judgement that the picture was not described in full, and in this way it might have indirectly reflected dementia severity. In the absence of prompting, individuals with AD are unlikely to produce more words than do controls. Moreover, within the AD group there was no correlation between word number and the total number of information units, suggesting that participants with AD produced more words but their verbosity was not associated with increased relevant content.

Second, persons with AD produced a smaller percentage of content words, more pronouns relative to nouns and pronouns, a lower type-token ratio, and more frequent words as compared to cognitively intact participants. These findings are in line with earlier work (e.g., Almor et al., 1999; Ehrlich et al., 1997; Hier et al., 1985; Nicholas et al., 1985), suggesting that the language of individuals with AD becomes less informative or emptier. We note that the existence of many pronouns also entails a reduction in the percentage of content words, although the opposite is not true. That is, samples with few pronouns can still have reduced percentages of content words, for example, when the percentage of another type of closed class word is high. Nevertheless, to minimise the interdependence between the percentage of content words and the percentage of pronouns, we calculated a pronoun ratio that was based on the total number of nouns and pronouns rather than on the total number of words. This ratio was higher in the AD group relative to the control group, demonstrating difficulty in word retrieval in connected speech. Since the number of pronouns in the language is limited, an increased use of pronouns also leads to reduced type-token ratio. Similarly, pronoun frequency most likely increased overall word frequency. Thus, regardless of the variable under study, quantitative results point to significant impairment in word retrieval in connected speech in AD, as shown earlier. The fact that persons with AD also conveyed less thematic content provides further support to the conclusion that connected speech in AD is semantically impoverished.

Importantly, three of the five variables that were impaired in individuals with AD relative to healthy participants also correlated with MMSE scores within the AD group. Namely, dementia severity was associated with total word output, type-token ratio, and word frequency. Because there was no correlation between age and any of the variables within the control group, it is safe to assume that it was not age per se that affected the deterioration in these features. Previous studies of the effects of dementia severity on connected speech have relied on time post-onset (e.g., Zimmerer et al., 2016) or on a comparison of patient groups at different stages (e.g., Bschor et al., 2001; de Lira et al., 2014; Hier et al., 1985). Disease progression was also examined longitudinally within the same individuals (e.g., Ahmed et al., 2013; Forbes-McKay et al., 2013). The results of these previous studies were far from uniform, partly because each study defined dementia severity differently and analysed a different set of language features, and partly because language profiles in the AD group were not entirely homogeneous. Thus, a direct comparison of the results of these previous findings to the current findings is not possible.

Unlike our prediction, MMSE scores did not correlate with the use of verbs, the most common morphological verb form, present tense, prepositions, or subordination. The results mirror early conclusions that the impairment in connected speech in AD is primarily semantic rather than grammatical (e.g., Blanken et al., 1987; Kavé & Levy, 2003; Schwartz et al., 1979; Whitaker, 1976). While grammatical aspects of language might not be fully preserved in AD when compared to cognitively healthy controls (e.g., Ahmed et al., 2012; Altmann et al., 2001; Croisile et al., 1996), these aspects appear to be better preserved than are semantic aspects of language. This differential pattern of impairments has been explained by a modular view that sees a clear dichotomy between declarative (i.e., semantics) and procedural (i.e., grammatical) aspects of language (Ullman, 2001; Ullman et al., 1997). Alternatively, Bates, Harris, Marchman, Wulfeck, and Kritchevsky (1995) have argued that the disease affects the accessibility to less frequent language features, whether semantic or syntactic. According to Bates et al. (1995), differences in the onset of lexical and grammatical difficulties in AD are due to a gradual difficulty that first affects the least frequent or least automatic features of language. It is thus possible that we found no association between dementia severity and grammatical aspects of language because the majority of our sample was moderately impaired, and that such an association would have been present had we studied more severely demented individuals.

We acknowledge that our study has some limitations. First, the use of the MMSE as an indication of dementia severity might not be ideal because this test provides no in-depth measures of cognitive abilities. Yet, we note that reliance on MMSE scores has been primarily questioned in the context of identifying early-stage dementia (e.g., Votruba, Persad, & Giordani, 2016), but this test is acceptable in tracking severity levels among individuals who have already been diagnosed with AD (e.g., Perneczky et al., 2006). As the test is very common in clinical settings, showing language decline relative to MMSE scores could be highly relevant. Second, the automated tool that we used does not provide an analysis of errors that could be helpful in understanding the impairment in AD. Third, deterioration is best followed longitudinally within the same participants rather than across individuals. As has been shown by Ahmed et al. (2013), disease progression is heterogeneous and it is thus possible that not all individuals with AD would deteriorate in the same way. We believe that the observation that MMSE scores associate with certain aspects of language but not with others could be valuable in directing clinicians' attention to the particular domains that should be assessed in individuals with severe dementia.

In sum, the current study shows that severity of dementia is most strongly associated with lexical diversity and with the frequency of the selected words. The simple automated analysis of connected speech that was applied here could be used clinically to define and track the decline in language abilities in AD. Future research should examine these variables in other languages.

Disclosure statement

No potential conflict of interest was reported by the authors.

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