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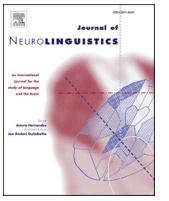

A finer-grained linguistic profile of Alzheimer's disease and Mild Cognitive Impairment

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ABSTRACT

Linguistic measures in spontaneous speech have shown promise in the early detection of Alzheimer's disease (AD), but it remains unknown which specific linguistic variables show sensitivity and how language decline relates to primary memory deficits. We hypothesized that a set of fine-grained linguistic variables relating specifically to forms of syntactic complexity involved in referencing objects and events as part of episodes would show sensitivity. We tested this in speech samples obtained from a picture description task, maximally isolating language deficits from the confound of episodic memory (EM) demands. 105 participants were split into Mild Cognitive Impairment (MCI), Mild-to-Moderate AD, and healthy controls (HC). Results showed that groups did not differ on generic linguistic variables such as number or length of utterances. However, AD relative to HC produced fewer embedded adjunct clauses, indefinite noun phrases, and Aspect marking, with moderate-to-large effect sizes. MCI compared to HC produced fewer adjunct clauses as well as fewer adverbial adjuncts. Together, these results confirm language impairment in AD and MCI at the level of specific linguistic variables relating to structures required for endowing narrative with specificity and episodic richness, independently of EM demands.

1. Introduction

Language is a universal aspect of human cognition and deeply intertwined with other cognitive domains, including memory. Thus, processing any utterance involves the retrieval of lexical concepts, which are stored in long-term semantic memory and codify general knowledge about the world (Binder, Rutvik, Graves, & Conant, 2009). To process sentences in which thoughts are articulated, these lexical concepts have to be inserted into grammatical structures. Sentences thus connect to semantic memory by necessity. Depending on their grammatical structure and the meanings encoded with it, they can also directly connect to episodic memory (EM) – e. g. the utterance *I saw a car was passing by* would typically be made only if the speaker actually remembers personally witnessing this event (unlike in *He said a car was passing by*, or *A car had passed by*, where this need not be the case). Beyond semantics, language also plays a well-established role in working memory (Baddeley, 2003) and in long-term memory encoding and retrieval (Feist & Cifuentes Férez, 2013; Feist & Gentner, 2007; Santin, van Hout, & Flecken, 2021). On theoretical and empirical grounds, therefore, language could be

Abbreviations: AD, Alzheimer's disease; MCI, Mild Cognitive Impairment; HC, healthy controls; MMSE, Mini-Mental State Examination; EM, episodic memory; SM, semantic memory; NP, noun phrase; VP, verb phrase.

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an important cognitive variable in a memory-related disease such as Alzheimer's disease (AD). Memory decline has also been observed, jointly with language impairment, in acquired aphasia (Lang & Quitz, 2012), primary progressive aphasia (Ash et al., 2013; Nilakantan et al., 2017; Win et al., 2017), developmental language disorder (DLD, Lee, 2018), and amnestic patients with hippocampal damage (Duff & Brown-Schmidt, 2012).

In the case of AD, empirical studies of language function have long documented early language change in tasks such as verbal fluency tests (Taler & Phillips, 2008). These tests are easy to use in clinical settings and serve as a tool to detect language change in a fast, non-invasive way, reflecting emerging deficits in domains such as semantic memory, executive functions, and lexical retrieval. However, they do not tap into language decline at a deeper, grammatical level, particularly in connected speech. Studies of spontaneous connected language in AD have shown in the case of written text, that language decline can precede and predict AD years if not decades before a final diagnosis (Garrard, Maloney, Hodges, & Patterson, 2005; Snowdon et al., 1996; van Velzen & Garrard, 2008). Linguistic analyses of spoken connected language in patients with probable or autopsy-proven AD have also revealed language deficits in early stages, particularly in the areas of semantics (Forbes-McKay & Venneri, 2005; Ahmed et al., 2013a; Ahmed, de Jager, & Haigh, 2013; Taler, Klepousniotou, & Phillips, 2009; Mueller et al., 2016) and syntax (Emery, 2000; de Lira et al., 2011). Language measures extracted from spontaneous language have also shown power to predict onset to Mild Cognitive Impairment (MCI) (Oulhaj, Wilcock, Smith, & de Jager, 2009), and machine learning classifiers have shown promise in identifying probable AD linguistically (Fraser, Meltzerb, & Rudzicza, 2016; Orimaye, 2017).

A critical issue, however, is how to measure language in spontaneous connected language in AD. Most previous studies have used relatively generic linguistic variables distributed across different domains of linguistic organization, in a bottom-up fashion. This has included variables such as speech rate, syntactic complexity (e.g. mean length of utterances, syntactic errors), lexical content (e.g. pronoun-noun ratio), semantic content (e.g. idea density), the type-token ratio, or fluency (e.g. pauses). None of these measures are linguistically very specific, nor do they tend to be selected for the specific context of AD in a hypothesis-driven fashion. Language decline in connected speech at generic levels of description is also found across multiple other neurodegenerative and neuropsychiatric diseases (Hinzen et al., 2018; Boschi et al., 2017), including Huntington's disease (Tovar et al., 2020), major depression (Zimmermann, Brockmeyer, Hunn, Schauenburg, & Wolf, 2016), and schizophrenia (Cokal et al., 2018, 2019). We therefore aimed to here pursue a more targeted approach to linguistic decline in AD.

Decline in EM is a central and early dimension of AD. Contrary to SM, EM is, by definition (Tulving, 2002), *specific*, capturing the occurrence of a given event in space, time, and as personally witnessed. Together, these features constitute the characteristic 'episodicity' of EM, as well as future-directed episodic thinking (Addis et al., 2009). Key to the present study is the fact that episodicity also corresponds to specific linguistic dimensions, when expressed in sentences. There are dedicated devices in all human languages that implement the required anchoring of information in a spatiotemporal and personal context. While a few studies have already considered relations between broad linguistic measures and episodicity in past- or future-directed tasks (Irish, Kamminga, & Addis, 2015; Schacter & Addis, 2007), we here aimed to select linguistic variables in a more fine-grained fashion, targeting the linguistic correlates for specificity and episodicity in the contents of thoughts expressed in sentences directly.

These correlates have both lexical and grammatical dimensions. At the lexical level, a loss of specificity could correspond to word-finding difficulties, when objects and events are to be named through words, or to substitutions of overly vague dummy nouns (*thing*, *stuff*) for more specific ones, along with an overuse of 'light' verbs (*go*, *get*, *do*, *be*, etc.) for more specific action names. Such difficulties have often been noted in the AD context (e.g., Ostrand & Gunstad, 2020), and are naturally predicted to relate to deficits of verbal fluency at the single-word level. At the grammatical level, noun phrases (NPs) can be generic (or maximally non-specific, e.g. the NP 'cats' in *I like cats*), in which case they often lack determiners, i.e. are of lesser grammatical complexity (Hinzen & Sheehan, 2015); indefinite-quantificational NPs can but need not have determiners (*Somebody arrived*, *I saw birds/a bird*); definite-specific NPs (e.g. *The dog barked*) require determiners, tend to be anaphoric, and differ from indefinite NPs in their formal-grammatical properties and distribution (see further Hinzen & Sheehan, 2015). Similar distinctions apply at the verbal level, where event reference can be generic (e.g. *I don't eat meat*; *I take the train to go to work*), non-specific (e.g. *I have gone to Paris*), specific through spatio-temporal adjuncts (e.g. *I went to Paris in the summer of 2013*), or through embedded adjunct clauses, which serve to specify causal and temporal relations between events (e.g. *I was cooking, when the doorbell rang*; *he climbed onto the stool in order to steal a cookie*). Relations between events are also established linguistically through explicit marking of Aspect (e.g., *He was washing the dishes* indicates that the cleaning was ongoing as and when some other event happened, Tense (temporal displacement as in *He fell of the stool* localizes an event of falling as happening prior to another), and Modality (as in *He may hurt himself*, which qualifies an event as a possibility relative to some ongoing situation in the actual world).

Here we aimed to investigate these dimensions of language in connected speech and in a context that maximally reduced memory demands, using a standardized picture description task. Although SM remains to be involved in such a task, insofar as lexical concepts have to be retrieved from memory, the visual presence of objects and events, as and when they are being referenced, facilitates this process (Schneider & Hayward, 2010). Demands on EM, on the other hand, are minimized in this type of task. We thus created a new annotation manual selecting linguistic variables related to specificity and episodicity in the presentation of linguistic information.

We predicted that the AD group would (i) not differ in formal-syntactic errors or in generic linguistic measures such as the number or mean length of utterances or the type-token ratio, but (ii) would diverge in the quantitative distribution of definite NPs and pronouns involving anaphoric dependencies with specific previously mentioned objects; (iii) and in grammatical devices involved in episodic event descriptions, through clausal embedding (adjunct and argument clauses) and adverbial and prepositional adjuncts. We (iv) also rated the use of NPs and VPs as either anomalous or not, and predicted a higher occurrence of anomalous NPs and VPs in the AD group. We also (v) predicted a decrease in temporal displacement, and in explicit marking of Aspect and Modality.

For the MCI group, we predicted a pattern similar to the AD group in relation to controls, though with a smaller effect. Given the

greater heterogeneity of the MCI group, participants of which may or may not go on to receive a diagnosis of AD, we expected that the linguistic profile might be more heterogeneous as well.

2. Material and methods

2.1. Sample

Data consisted of picture description speech sample transcriptions chosen from three separate previous studies, which were combined to create a larger sample of participants with three diagnoses: Control, MCI, and AD. The first set of participants came from an ongoing in-house study at St. George's University of London (SGUL) and were recruited from the St George's University Hospital's NHS Cognitive Disorders Clinic. Recruited patients were classified as either suffering from AD (n-13) or MCI (n = 12) according to the diagnostic criteria proposed by Petersen (2004). Twenty-five cognitively normal individuals were recruited as control participants. 10 control participants and nine participants with MCI came from Ahmed et al. (2013), and were originally recruited as part of the Oxford Project to Investigate Memory and Ageing (OPTIMA), a longitudinal study of the clinical, neuropsychological, biochemical and imaging correlates of ageing in community dwelling elderly persons with and without dementia. These participants were diagnosed according to the Consortium to Establish a Registry for Alzheimer's Disease (CERAD) criteria. An additional 14 MCI and 22 AD participants were recruited from the Pitt corpus of the Dementia bank (Becker, Boller, Lopez, Saxton, & McGonigle, 1994; grant support: NIA AG03705 and AG05133), in order to balance group sizes.

In total, participants formed three groups of $N = 35$ each, and were matched for age and education. Gender was not matched, and differed at a trend level between groups in a Kruskal-Wallis test ($p = 0.057$). The final sample is described in Table 1.

2.2. Speech elicitation and transcription

All data used in this study was previously obtained through the Cookie Theft picture description task from the Boston Diagnostic Aphasia Examination (Kaplan, Goodglass, & Weintraub, 1983) (though SGUL participants used the novel Cookie Theft task, see (Berube et al., 2019). Samples were then transcribed or transferred into CLAN (MacWhinney, 2000) using participant speech only (ignoring examiner speech), and separated into utterances. Utterances were defined here as syntactically independent units of propositional information providing new information, and in this sense differed from *clauses*, which are configurations of subjects and predicates (usually verbs), and can be syntactically either dependent or independent.

The samples were then tagged according to the current study's annotation scheme (see below in 2.3). Transcriptions were anonymized and linguistic raters were blind to participant data and diagnosis. 20% of each participant group's samples were double-annotated by a second rater who was not otherwise involved in this study, to assess the reliability of the first rating. Final reliability was calculated by dividing the total point-by-point agreements by the sum of total points possible, resulting in 92.6% reliability.

2.3. Linguistic annotation

Table 2 lists all linguistic variables assessed in this study. These variables fell into three broad syntactic domains: nominals (NPs), verb phrases (VPs), and clauses. Within these three domains, we distinguished grammatically distinct configurations that play a crucial role for the specificity of the referential information conveyed: e.g., whether a particular lexical NP is definite (e.g., *the girl on the stool*) or indefinite (e.g. *there is a mother*), events are characterized using verbal Aspect (e.g. *the stool is tipping over*), or embedded clauses are added to relate events to each other (e.g. *the stool is tipping over as she is reaching for the cookie*). Global measures of language were also used: the average number of utterances, 'formal grammatical errors' assessing the formal integrity of utterances, mean length of utterances (MLU), and the type-token ratio to measure vocabulary richness.

2.4. Data analysis

We performed between-group analyses using the non-parametric Kruskal-Wallis H test due to non-normal distribution of the data in at least one group, followed by post-hoc pairwise comparisons, using Dunn's (1964) procedure in SPSS. MLU and Type-token ratios

Table 1
Participant demographic and neuropsychological data.

	HC (N = 35)		MCI (N = 35)		AD (N = 35)	
	Mean	SD	Mean	SD	Mean	SD
Age (years)	68.114	9.11	68.514	8.133	68.629	9.277
Education(years)	14.871	3.003	14.343	3.253	14.2	2.576
Sex (f:m)	23 : 12		12 : 23		15 : 20	
MMSE	29.114	0.758	26.114	3.169	21.6	4.031
Letter Fluency*	17.32	4.661	14.71	5.923	9.23	4.514
Category Fluency*	22.40	5.642	16.29	5.952	9.48	4.794

Note: fluency measures were only available for 80 of the participants: 25 control, 24 MCI, 31 AD.

Table 2
Linguistic variable definitions and examples.

Variables	Definitions	Examples
Formal-grammatical errors	Violations of grammatical well-formedness	1. Now he's looking out the window and the stool. 2. And then there was so the two this.
NP domain		
Definite NP	All definite NPs (excluding pronouns), divided by total NPs.	Definite NPs: The boy is standing on the stool. Indefinite NP: There are some cookies in a cookie jar.
Pronoun	Total number of pronouns, divided by total NPs.	Pronouns: He/she/it, you, I, this/that, these/those, there.
Definite NP anomaly	Formally definite referential NP that is anomalously used (vague, unclear or ambiguous reference, referent mis-identified or not introduced before).	1. The stuff is flowing out of the sink. 2. I bet she hasn't got them down there. 3. And this one picks it up.
Indefinite NP anomaly	Formally indefinite NP that is anomalously used (vague, re-introduced referent, or incorrect referent).	1. And bits literally falling out of there. 2. She wants something from a high place. 3. He's got his hand on a thing on the shelf.
VP domain		
Aspect	Grammatical category encoding how an event extends over time in relation to the point of speech.	1.The boy is falling. 2.The water has spilled. 3.He had stolen the cookies.
Tense	Grammatical category encoding the contextual embedding of an event in time relative to the time of speech.	The dog ate the cookies.
Modals	Grammatical devices expressing whether an event is possible, probable, certain or permitted.	She must be their mother.
Prepositional adjunct	VP adjunct providing additional information, particularly spatio-temporal.	The water is spilling onto the floor.
Adverbial adjunct	Adjunct (non-clausal) attaching to a VP or clause, encoding manner, circumstance, or epistemic aspect of an event.	Apparently, the kids are stealing some cookies.
VP composite score	Total composite score comprising all measures of spatio-temporal event specificity (aspect, tense, modals, prepositional adjuncts, adverbial adjuncts).	The mother is washing dishes at the sink and apparently doesn't see that the water is overflowing. [4 points total]
VP anomaly	Verb phrases which are vague, incorrectly connect or name actions, or insufficiently describe events.	The stuff is footle-ing not making notion that this is falling out.
Clausal domain		
Argument clause	Dependent clauses specifying information that is grammatically required by a subordinating verb, divided by total number of clauses.	The girl wants her brother to hand her a cookie.
Adjunct clause	Dependent clauses specifying further information that is not grammatically required, divided by total number of clauses.	The boy is standing on a stool which is tipping.
Coordinated clause	Grammatically independent clauses connected by a conjunction, divided by total number of clauses.	The mother is washing dishes and the kids are stealing cookies.
Independent simple clause	Clauses with no embedding or coordination, divided by total number of clauses.	The scene takes place in a kitchen.

were compared using one-way ANOVAs.

Variables that had values of zero for more than half of the participants were dichotomized and compared between groups using Fisher's Exact tests. Bonferroni correction for multiple comparisons was applied in all cases, by multiplying p-values by the number of comparisons, keeping a uniform significance threshold (α) of .05. All p-values are reported in their already corrected form.

3. Results

Two-tailed results from between group analyses for all linguistic variables are displayed in Table 3. Significant group differences in the nominal, verbal, and clausal domains, are displayed in Figs. 1–3, respectively.

3.1. General measures

Global measures of language (number of utterances, mean length of utterance (MLU), type-token ratio, and formal grammatical errors) did not distinguish groups.

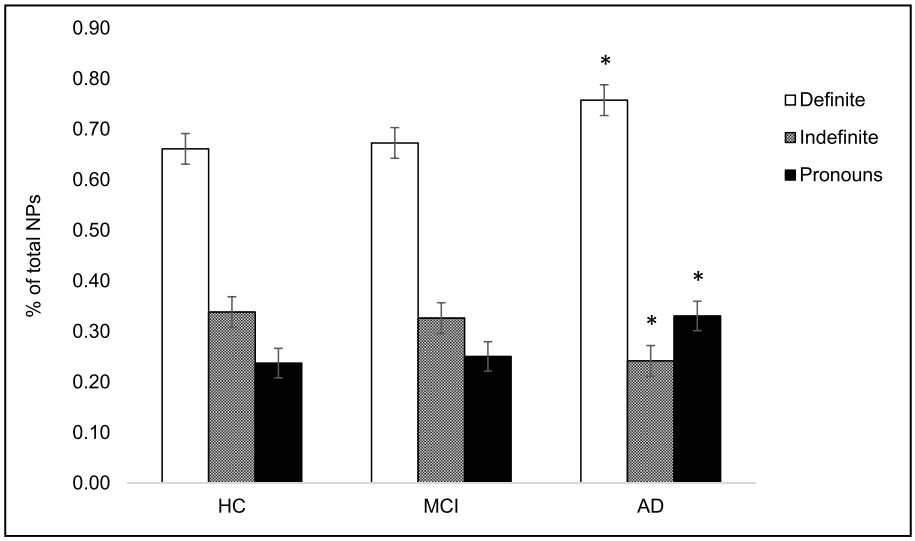
3.2. Nominal domain

Ratios of definite and indefinite NPs out of total lexical NPs differed significantly between groups (Fig. 1). Post-hoc pairwise comparisons showed that AD differed significantly from HC in producing more definite NPs and fewer indefinite NPs. The ratio of pronouns to all lexical NPs was also significantly higher in AD than in HC. A subsequent more fine-grained analysis revealed that this was due to a significantly greater amount of second person pronouns in the AD group as compared to controls ($p = 0.039$), while no

Table 3
Comparisons of linguistic variables across groups.

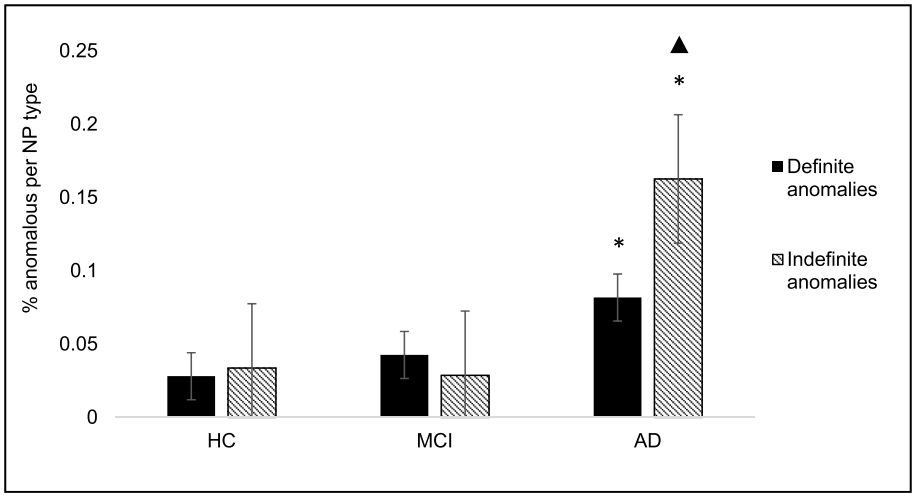
Variable	Means ± SD		Test		P-values and Cohen's d					
					HC-MCI		HC-AD		MCI-AD	
					p	d	p	d	p	d
Utterances	HC	12.886 ± 1.418	Kruskal-Wallis H	.788	1	.06	.974	.06	1	.09
	MCI	12.886 ± 1.292								
	AD	12.971 ± 1.115								
MLU	HC	11.14 ± 3.445	ANOVA	.063	.071	.08	.279	.28	1	.22
	MCI	9.500 ± 3.010								
	AD	9.928 ± 2.419								
TTR	HC	0.656 ± 0.098	ANOVA	.252	1	.08	.358	.44	.609	.24
	MCI	0.648 ± 0.117								
	AD	0.618 ± 0.100								
Formal-grammatical errors	HC	0.1289 ± 0.005	Fisher's Exact		1	.09	1	.03	1	.05
	MCI	0.0095 ± 0.003								
	AD	0.0179 ± 0.007								
% Definite	HC	66.138 ± 16.71	Kruskal-Wallis H	.036*	1	.14	.048*	.56	.140	.54
	MCI	67.307 ± 14.115								
	AD	75.768 ± 10.81								
% Indefinite	HC	33.862 ± 16.71	Kruskal-Wallis H	.036*	1	.14	.048*	.56	.140	.54
	MCI	32.667 ± 14.11								
	AD	24.205 ± 10.81								
Pronoun ratio	HC	23.765 ± 1.682	Kruskal-Wallis H	.007*	1	.03	.011*	.71	.080	.67
	MCI	25.091 ± 2.075								
	AD	33.091 ± 2.410								
Definite anomaly	HC	2.81 ± 0.732	Kruskal-Wallis H	.007*	.399	.41	.005*	.78	.305	.43
	MCI	4.26 ± 0.715								
	AD	8.18 ± 1.494								
Indefinite anomaly	HC	3.371 ± 1.056	Kruskal-Wallis H	.004*	1	.16	.031*	.63	.006*	.77
	MCI	2.871 ± 1.061								
	AD	16.269 ± 4.325								
Aspect	HC	0.773 ± 0.037	Kruskal-Wallis H	.040*	.529	.33	.034*	.64	.712	.29
	MCI	0.703 ± 0.043								
	AD	0.639 ± 0.040								
Tense	HC	0.017 ± 0.037	Fisher's Exact		1	.08	.891	.39	.318	.41
	MCI	0.034 ± 0.097								
	AD	0.045 ± 0.070								
Modals	HC	0.035 ± 0.045	Fisher's Exact		1	.16	1	.35	1	.14
	MCI	0.050 ± 0.065								
	AD	0.063 ± 0.076								
Prepositional adjunct	HC	0.404 ± 0.156	Kruskal-Wallis H	.120	.456	.29	.400	.31	.136	.45
	MCI	0.385 ± 0.246								
	AD	0.461 ± 0.185								
Adverbial adjunct	HC	0.146 ± 0.017	Kruskal-Wallis H	.016*	.020*	.70	1	.12	.085	.55
	MCI	0.081 ± 0.016								
	AD	0.141 ± 0.020								
VP composite score	HC	1.378 ± 0.262	Kruskal-Wallis H	.249	.192	.41	1	.13	.608	.25
	MCI	1.255 ± 0.346								
	AD	1.351 ± 0.288								
VP anomalies	HC	4.98 ± 0.998	Kruskal-Wallis H	.059	.050	.56	.122	.46	1	.09
	MCI	9.02 ± 1.311								
	AD	11.55 ± 2.122								
Argument clause ratio	HC	16.33 ± 1.845	Kruskal-Wallis H	.188	1	.03	.152	.44	1	.33
	MCI	16.17 ± 1.858								
	AD	20.71 ± 2.059								
Adjunct clause ratio	HC	30.2 ± 1.828	Kruskal-Wallis H	.001*	.003*	.93	.004*	.78	1	.02
	MCI	20.15 ± 2.028								
	AD	20.71 ± 2.453								
Coordinated clause ratio	HC	27.5 ± 2.224	Kruskal-Wallis H	.027*	.066	.62	.053	.55	1	.06
	MCI	36.26 ± 2.922								
	AD	37.08 ± 3.357								
Independent simple clause ratio	HC	25.98 ± 2.778	Kruskal-Wallis H	.281	1	.06	.200	.41	.612	.25
	MCI	27.43 ± 3.841								
	AD	21.51 ± 3.442								

* Indicates significance at $\alpha = .05$ (all p-values corrected).



* = Significantly different from controls.

Fig. 1. Distribution of NP types across groups * = Significantly different from controls.



* = Significantly different from controls; ▲ = significantly different from MCI.

Fig. 2. Anomalous NPs by type (definite, indefinite) across groups * = Significantly different from controls; = significantly different from MCI.

significant differences were seen in first and third-person pronouns.

Finally, the rate of anomalies in formally definite NPs was significantly higher in AD compared to HC as well. Anomalies in formally indefinite NPs occurred more often in MCI and AD in comparison to HC, with statistically significant differences between both HC and MCI from AD (Fig. 2).

3.3. Verbal domain

Aspect marking occurred less in both MCI and AD compared to HC, and differences were significant between HC and AD. In addition, MCI produced significantly fewer adverbial adjuncts than HC.

3.4. Clausal domain

Measures of clausal connectivity showed a smaller proportion of embedded adjunct clauses between HC and both MCI and AD, with both MCI differing significantly from HC and AD differing from HC. The use of coordinated clauses increased linearly between groups from HC to MCI to AD, though between-group differences were not significant. (Fig. 3).

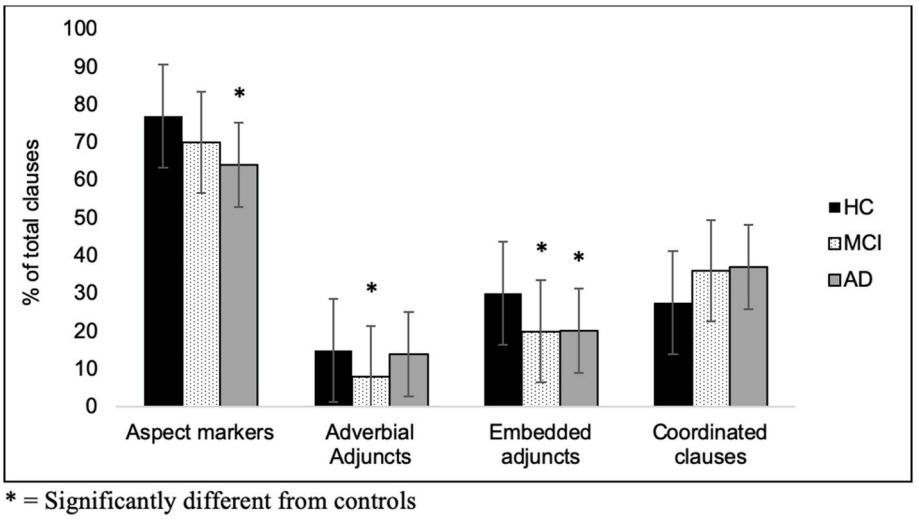


Fig. 3. Group differences in linguistic variables from verbal and clausal domains * = Significantly different from controls.

3.5. Gender effects

Because of a nearly significant difference between males and females both within-groups and between-groups, an additional analysis was run to explore potential gender effects within and across groups for all linguistic variables. Results were not significant post-correction for any variables ($p > 0.05$).

3.6. Post hoc analysis of NP anomaly subtypes

In order to understand the pattern of anomalies across different grammatical domains (NPs and VPs), a qualitative post-hoc analysis of the subtypes of anomalies was performed. Table 4 lists the percentages of error type out of the total errors found in each group. As transpires from this table, in AD, the most prominent anomalies occurring in definite NPs concerned pronoun use, while in indefinite NPs, the main problems concerned anomalies of referencing, and in VPs, problems of syntax and vagueness of content were prominent. Examples of each anomaly type can be found in supplementary materials.

4. Discussion

These results provide a new window into language changes in both MCI and AD relative to healthy controls, measured at the level of spontaneous speech. They highlight that language changes that occur are not necessarily measurable at the level of generic or coarse-grained linguistic variables such as the number of utterances, formal-grammatical integrity of utterances, mean length of utterances, or the type-token ratio. By contrast, at every level of grammatical complexity distinguished here – NPs, VPs, and clausal configurations –

Table 4
Anomalies by type.

12345667	% of errors by diagnosis		
Definite NP anomalies	HC	MCI	AD
Determiner problem	40%	15.38%	6.97%
False definite	0%	19.23%	18.60%
Pronoun problem	60%	65.38%	52.32%
Vague/nonsensical	0%	0%	17.44%
Word choice	0%	0%	4.65%
Indefinite NP anomalies			
Determiner problem	56.25%	61.11%	40.62%
Unclear reference	31.25%	38.89%	43.75%
Word choice	12.50%	5.55%	15.63%
VP anomalies			
Action Naming	19.35%	19.64%	15.49%
Adjunct problem	19.35%	19.64%	23.94%
Tense	22.58%	3.57%	8.45%
Syntax	25.80%	30.35%	26.76%
Vague/nonsensical	12.90%	26.78%	25.35%

differences emerged in specific and fine-grained linguistic variables.

These linguistic changes are informative for the cognitive changes involved. Thus, in the domain of NPs, we confirmed our hypothesis that AD would show differences relating to specificity in referencing objects. This was evident not only through the significantly higher number of definite NPs and fewer indefinite NPs in AD relative to HC, but also through the more frequent occurrence of anomalous definite NPs in AD relative to HC, and of anomalous indefinite NPs in both MCI and AD relative to HC. The cognitive function of indefinite NPs is to introduce new referents into the discourse, which can be picked up by definite NPs or pronouns later (e.g. *A boy is stealing some cookies*. *He then eats them*/*The boy's sister is watching*). Production of *fewer* and more often *anomalous* indefinite NPs in MCI and AD, along with *more* definite NPs in AD, therefore suggests a difficulty in establishing new discourse referents and creating referential connections as required for relating events in a narrative. When definite NPs have more referents *not* introduced before by an indefinite, they are more likely to be anomalous themselves and/or to obtain their reference directly from the context, i.e. the visually presented objects in the picture as shared with the interlocutor (Schneider & Hayward, 2010). Reliance on 'exophoric' reference – anchoring definite referents directly in a shared visual context rather than linguistically or anaphorically through an NP previously used in the discourse – has been noticed previously in other anomalous speech profiles (developmental disorders: Fine, Bartolucci, Szatmari, & Ginsberg, 1994, March, Wales, & Pattison, 2006). Testing the distribution of definite and indefinite NPs with speech elicitation tasks not based on picture descriptions (where referents are always visually present) is needed in order to confirm the pattern of referencing change in AD and its prodromal phases.

In the domain of VPs, two variables showed between-group differences: the Aspect marking ratio was lower from HC to MCI and to AD, and adverbial adjuncts, which were fewer in MCI compared to HC. This result is interpretable in terms of the specificity in the referencing of events, which both Aspect and adverbial adjuncts imply: describing a stool as *tipping over* is to depict an event as happening or ongoing, as and when the speech event takes place. Similarly, describing an action through an adverbial adjunct like *forgetfully* or *quickly* provides further descriptive information for a given event. Reduction of such grammatical elements therefore suggests a cognitive difference in the conceptualization and the specificity of event referencing.

The clausal domain is the most complex structural unit distinguished here, as it includes NPs and VPs as proper parts. Within this domain, highly significant group differences emerged in patterns of clausal connectivity, both between AD and HC and between MCI and HC. Indeed, the domain of clausal adjuncts was the only domain in which a consistent effect relative to controls emerged in both the MCI and AD groups, while MCIs were otherwise linguistically very similar to controls, suggesting that most of our variables show sensitivity only after clinical onset of AD. Crucially, differences in clausal connectivity reflect cognitive differences as well: clauses embedded as adjuncts (e.g. *while the water is flowing, the stool is tipping*; *the boy is stealing the cookie, without his father noticing*) play the crucial cognitive role of linking events, creating connections and hierarchy between them through relations such as simultaneity or cause and effect. Therefore, a reduction in such grammatical elements depicts a decrease in specificity when referencing events. A reduction in adjunct clauses in AD groups has been detected previously in studies targeting syntactic complexity more generally (Orimaye et al., 2017; de Lira et al., 2011). However, in both cases, this measure was defined as capturing 'nominalized' adjunct clauses ('reduced sentences') as in 'Here is the boy asking his mother to keep the dog', which do not exhaust the exact syntactic category of adjunct clauses that we targeted here. Adjunct clause reduction was not the only indication of a loss of event specificity: an *in*crease in coordinated clauses is congruous with this conclusion as well, as coordination of clauses (with *and* or *or*) serves to depict multiple events without one being conceptualized hierarchically as a part of one another.

An increase in coordination and decrease of clausal embedding in spontaneous speech has been noticed in several other clinical groups before, including Huntington's disease (Hinzen et al., 2018; Tovar et al., 2020) and schizophrenia (Cokal et al., 2018), and there is evidence of problems of comprehension of embedded clauses as well, in schizophrenia (Cokal et al., 2019), and aphasia (Zimmerer, Deamer, Varley, & Hinzen, 2019). Within AD, the present findings are, to our knowledge, novel, and adjunct clauses, which should largest effect sizes in the group comparisons in this study, have to our knowledge not been explored in the foregoing other diagnostic groups. Important questions arise from the high sensitivity of the vulnerability of embedding in the language profile of cognitive disorders, and how differences in the patterns observed could relate to the different neural substrate and neurocognitive differences involved.

Importantly, while the rate of pronouns to total NPs was greater in AD than HC, subsequent investigation showed that the proportion of third person pronouns was not significantly different between groups, and that only the proportion of second person pronouns (almost always in addressing the interlocutor, or making generic statements) did. All pronouns lack lexical descriptive content; however, third person pronouns differ from first- and second-person pronouns in that they can be either anaphoric (i.e. picking out a previously mentioned discourse referent) or deictic (picking out a visually present and salient referent shared in the context with the interlocutor). The fact that third person pronouns did *not* occur more frequently in AD than in HC fails to support the idea that there is a problem in AD with retrieving lexical descriptive content *per se*, which would be naturally reflected in an over-use of pronouns lacking such content (as previously reported: Ahmed et al., 2013a).

The post-hoc analysis of NP and VP anomaly sub-types further illuminates this issue. This analysis revealed, in line with the foregoing conclusion, that in all three anomaly domains (VP, Definite NP, Indefinite NP), pure word-finding difficulties (lexical retrieval or naming based errors) were not prominent. In particular, in the VP domain, most anomalies occurred in clausal connections, particularly in formal aspects of syntax and prepositional and adverbial adjuncts. Definite NP anomalies most commonly occurred in the use of pronouns, and often involved problems where a referent could not be linked, or was incorrectly linked, to a previously introduced referent, confirming a problem with anaphoricity. Indefinite NP anomalies often occurred as unclear referents, or involved determiner problems (using an indefinite article where it should be definite or a pronoun). In general, these patterns suggest a linguistic issue that goes beyond a lexical or semantic memory impairment. As suggested by the moderate-to-large effect sizes involved, a speech profile combining NP-related anomalies and clausal adjuncts might form a promising classifier for detecting AD, which should

be explored in future studies and across different languages.

In summary, this study reveals a more fine-grained linguistic profile of spontaneous speech in MCI and AD as elicited with a picture description task. Significant group differences emerged in linguistic variables measuring aspects of specificity in the referencing of objects and events, but not in generic linguistic variables. It is important to confirm and expand this sensitivity in further studies of spontaneous speech using elicitation tasks requiring more creative use of reference than picture descriptions do, and across other languages. Language measures based on spontaneous speech are easy to obtain and analyses can, in part, be automated, which can provide a promising avenue for using language in efforts of early detection and the monitoring of disease progression, as well as illuminating how memory and language decline in AD relate.

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Informed consent

All participants provided informed consent.

Data availability

Anonymized data supporting this study's findings is available upon request by contacting the authors.

Author statement

Kayla Chapin: Conceptualization, Methodology, Formal analysis, Writing- Original Draft. Natasha Clarke: Resources, Data curation, Investigation. Peter Garrard: Supervision, Conceptualization, Resources. Wolfram Hinzen: Supervision, Conceptualization, Methodology, Writing- Reviewing and Editing.

Declaration of competing interest

The authors declare no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jneuroling.2022.101069.

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