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Connected Speech Features from Picture Description in Alzheimer's Disease: A Systematic Review

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Abstract. The language changes that occur over the course of Alzheimer's disease (AD) can impact communication abilities and have profound functional consequences. Picture description tasks can be used to approximate everyday communication abilities of AD patients. As various methods and variables have been studied over the years, current knowledge about the most affected features of AD discourse in the context of picture descriptions is difficult to summarize. This systematic review aims to provide researchers with an overview of the most common areas of impairment in AD discourse as they appear in picture description tasks. Based on the 44 articles fulfilling inclusion criteria, our findings reflect a multidimensional pattern of changes in the production (speech rate), syntactic (length of utterance), lexical (word-frequency and use of pronouns), fluency (repetitions and word-finding difficulties), semantic (information units), and discourse (efficiency) domains. We discuss our findings in the light of current research and point to potential scientific and clinical uses of picture description tasks in the context of AD.

Keywords: Alzheimer's disease, language tests, psycholinguistics, systematic review

INTRODUCTION

The most commonly diagnosed form of dementia is Alzheimer's disease (AD). In the majority of cases, AD patients present with an amnestic syndrome, in which learning and recall of recently learned information are impaired. AD patients also develop nonamnestic features such as deficits in language, visuospatial abilities, and executive functions [1]. Language is impacted at some level in most cases of AD, especially language production [2]. Language disturbances from one AD patient to another are reported to be quite heterogeneous [3, 4] and jeopardize AD patients' ability to interact with their environment and verbally communicate [5, 6]. Importantly, the breakdown of communication has been found to be the most difficult consequence of AD for caregivers to cope with [7] and is accompanied by more distress in their supporting role [8].

Language changes occurs in the earliest stages of the disease, including in the pre-AD stage of mild cognitive impairment (MCI) [9]. Most of studies aimed at characterizing the language profile in AD have employed language tasks capable of selectively assessing specific language functions, such as naming

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[10], syntax [11], or semantic processing [12]. In this type of study, difficulties with picture naming tasks [13–16] represent one of the most frequently reported language impairments [17, 18]. Some evidence indicates that this deficit can appear in early phases of the disease, even at pre-dementia stages, such as in individuals with MCI [15, 19] (for a comparative review of language differences in AD and MCI, see [9]). The nature of naming difficulties in AD is still matter of debate. On the one hand, naming difficulties could derive from the breakdown of semantic cognition, as was evidenced in both implicit (e.g., semantic priming effect [20–24]) and explicit (semantic categorization [25] and semantic knowledge tasks [15]) semantic abilities [26]. On the other hand, naming difficulties can be at least in part due to lexical access difficulties [27–29]. Indeed, AD patients can manifest naming difficulties for stimuli for which the semantic representation is intact [16]. These lexical access difficulties may also contribute to the consistent impairment of AD patients verbal fluency tasks [30]. Syntax is another facet of language that may be affected by AD, both in comprehension [31] and in expression [32]. With a focus on temporal and phonological features, Szatloczki and colleagues recently reviewed the evolution of language changes in tasks such as reading and naming tasks at different stages of AD. They concluded that more work needs to be done to validate new assessment methods for language function in AD [33].

Interestingly, low scores on standard language tests (such as confrontation naming and verbal fluency) do not fully reflect the actual performance of patients in normal conversation, as they tend to leave out the social and psychological context of language use [34]. Consequently, the assessment of isolated language functions as in naming, fluency, or syntax tasks might not capture the magnitude of problems encountered in everyday communication contexts [34–36]. One way to obtain an ecological approximation of spontaneous discourse abilities in patients is through the connected speech sample (i.e., spoken language production used in a spontaneous and continuous manner) yielded by a picture description task, a narrative task, or an interview [3, 37, 38].

Studies on connected speech in AD have measured different dimensions of connected speech and produced conflicting results. Some studies have found no differences in connected speech characteristics between AD and controls groups [39], while other studies report important differences. Some studies have reported deficits in speech production characteristics (such as melodic line and acoustic features) [40, 41], syntactic complexity (mean length of utterance) [3], lexical content (percentage of pronouns, type-token ratio, mean frequency of words) [42, 43], fluency (revisions and repetitions) [44, 45], and the semantic/discourse aspects of the speech ("emptiness" of speech) [46]. Many reasons could account for the conflicting results. One reason could be the fact that small samples are usually employed in these studies. This seems especially true regarding the longitudinal data available [3, 47, 48]. Moreover, it has been suggested that language deficits in AD can be heterogeneous [4, 49, 50] and not necessarily apparent in group analyses [39]. Another reason may reside in the methodological approaches of these studies. More specifically, the choice of the tasks and variables used to characterize connected speech varies from one study to another and can therefore yield different results [51]. The study of connected speech would greatly benefit from a comprehensive synthesis of the variables used to analyze different aspects of connected speech in AD and an overview of the main results. This would be helpful for a possible harmonization of connected speech analyses in AD.

An attempt at a comprehensive review of the literature on connected speech has been recently done. More specifically, using an unsystematic narrative review, Boschi, et al. [52] report a series of studies focusing on the analysis of linguistic characteristics of connected speech in the most prevalent neurodegenerative diseases, including AD. This work provides an overview of connected speech impairment elicited by a variety of tasks, including picture descriptions, narrative tasks, and interviews [52]. Their results point to a pattern of deficits on a wide range of variables, including speech rate and hesitations, increased use of pronouns, word finding difficulties, repetitions, revisions, neologisms, inflectional errors, use of discourse markers, low efficiency and cohesion, and uninformative speech that could be part of the signature of AD. Although the article by Boschi et al. (2017) provides a very useful overview of the literature in this field and include a description of databases and search terms, it suffers of some methodological limitations due to the use of an unsystematic narrative review approach. In fact, unsystematic narrative reviews are the traditional approach to summarize the literature on

a specific research topic. However, they are usually not based on a clear and objective method for the search and selection of the articles in the review [53]. In other words, unsystematic narrative reviews are likely to include only research selected by the authors and not all articles available [54]. This can lead to a subjective article selection bias that can affect authors' conclusions and interpretations. Systematic reviews can help overcoming these methodological limitations. Indeed, systematic reviews employ (and explicitly describe) methodological strategies to identify and select all the available publications on a specific research topic [55, 56]. Evidence shows that systematic reviews improve the reliability and the accuracy of the conclusions [57]. The systematic review has therefore become the reference standard for synthesizing evidence in health care because of its methodological rigor and is used to "support the development of clinical practice guidelines and inform clinical decision-making" [55, 56, 58].

A systematic review with meta-analyses has been conducted to synthetize the available data on the word retrieval aspect of connected speech in AD patients [59]. More specifically, Kavé and Goral demonstrated that lexical access—or word-finding—difficulties usually observed in confrontation naming, were also apparent in connected speech in AD elicited by picture descriptions, interviews, picture sequence or film description, and other descriptions [59]. The study by Kavé and Goral exclusively focused on word retrieval, not considering variables of other linguistic domains such as pragmatics and syntax. A systematic review of the characteristic in different linguistic domains is thus necessary in order to better define the global portrait of the connected speech profile in AD, and to complement the findings by Kavé and Goral. In addition, since the constraints of the task used to elicit the connected speech sample are known to influence the most salient variables in AD connected speech [52], a systematic review should probably focus on a single task. To this effect, Mueller et al. recently published a systematic review of connected speech elicited by picture description tasks in both MCI and AD patients, concluding that the evidence of impairment in the former is inconclusive [60]. Picture-supported narratives have the advantage of providing a relatively constrained discourse task with expected topics, which is not the case for other ecological approximations of spontaneous speech such as open-ended autobiographical questions or conversations [61]. The expected topics allow a more standardized analysis of the lexicosemantic content of speech. Contrary to story retelling tasks, picture description affords the patient with pictorial support, helping persons with significant attentional, executive or memory deficits to produce a sample of connected speech [37]. This approach also has the advantage of capturing multiple aspects of language production using a single task, but the transcription and analysis processes has proven too time consuming for clinical use. As these steps become automated with emerging computational approaches, however, picture description tasks could represent a valuable tool for a rapid screening of language production abilities that can be implemented in the routine neuropsychological battery routinely used with these patients.

In current clinical practice, picture description tasks are administered as part of language batteries such as the Boston Diagnostic Aphasia Examination, in which the clinician counts and rates utterances and clauses [62]. However, this simple analysis does not exploit the richness of the discourse sample. Indeed, as stated by Ahmed and co-authors (2013), connected speech samples "provide a multitude of analytical dimensions" and can be used to extract variables from many different dimensions of connected speech. Unfortunately, the transcription of a verbal sample to a *verbatim* record and the analysis techniques used in research contexts are prohibitively time consuming and labor intensive, making multidimensional analyses difficult to import in clinical settings [63]. This limitation may prevent the wide use of picture description in dementia screening or assessment, despite convincing evidence that a combination of connected speech variables from different domains can discriminate AD patients from the healthy elderly [40, 46, 51, 64–66] and that different changes occurs at different stages of the disease [47]. The clinical and scientific relevance of picture description tasks in AD patients hinges on specific knowledge of the most relevant variables and on affected language dimensions. Because heterogeneity across patients has been reported [4], it remains unclear if a definite and reliable pattern of language changes occur in AD patients describing a picture. The specific characteristics of connected speech in different linguistic domains remain to be assessed in a systematic way for picture description tasks. The connected speech features of AD in the context of picture description tasks is a question of adequate breadth to warrant a systematic review [67]. A systematic review of

connected speech changes in AD as assessed by picture description tasks would provide a characterization, from a large sample, of the most affected dimensions and variables in this group of patients and could help clinicians and researchers choose relevant picture description tasks and develop guidelines for further therapies and studies based on synthesized evidence [56].

The main goal of the study is to systematically review the literature on the connected speech features that characterize AD patients specifically in picture description tasks and gain an overview of the most often affected language dimensions. We review and discuss the most often reported discriminant variables, complementing recent work with a summarization and quantitative appraisal of the available data concerning a specific task and patient group [52, 60]. The multidimensional nature of connected speech analysis and the great number of different variables reported makes summarizing results challenging. There is thus a need to group variables for a clear summarization. In the context of primary progressive aphasia, a progressive neurodegenerative disease characterized by relatively isolated language deterioration, Wilson et al. [68] used a classification model of connected speech adapted from the *Quantitative Production Analysis* [69, 70] encompassing the following dimensions: 1) speech rate and speech errors (such as phonological paraphasias); 2) other disruptions to fluency (such as repetitions and revisions); 3) lexical content (such as number of nouns, pronouns, etc.); and 4) syntactic structure and complexity (such as length of utterances, number of dependent clauses, etc.). An augmented version (including semantic and discourse dimensions) of this framework will be used in the current study. The semantic and discourse dimensions appear important additions to the framework because picture description tasks allow a more standardized assessment of the semantic content and its efficiency and organization compared to interviews.

METHODS

Review protocol

A comprehensive search was conducted in the electronic databases Medline (1946-2016), PubMed, Embase (1974–2016), and PsycInfo using 1) natural language in the title and abstract of references as well as 2) each database's specific descriptors as major topics to retrieve relevant studies (Table 1). We sought help from a professional librarian from the Institut Universitaire de Gériatrie de Montréal. Our last search was run on January 20, 2018. Reference lists of included articles were thoroughly searched for additional references relevant to the review. Additional references were obtained through a search on Google Scholar and Research Net, using the same natural language used in all databases. We followed the PRISMA-P statement [56] for the conduct of this review (Fig. 1 for PRISMA flow-diagram). Given that our goal is to identify the most commonly studied aspects of connected speech proven to be affected in AD patients and the dimension in which they belong, the systematic review appeared to be the appropriate methodology to match the breadth of our investigation [67].

Eligibility criteria

Inclusion criteria were the following: 1) experimental studies published in peer-reviewed journals, providing quantitative data from a picture description task; 2) presence of a control group; 3) AD is a focus of the study when more than one clinical population is studied; 4) detailed methodology is presented and verbal connected speech samples were collected; 5) no apparent conflict of interest is reported; and 6) article written in English or French. Thus, exclusion criteria were 1) absence of a control group; 2) AD not being the focus of study; 3) apparent conflict of interest between authors and the sponsor; 4) article not written in English or French; and 5) a study unpublished or published after January 20, 2018.

Extraction of language features and data summarization

In each article, we individually extracted the connected speech features that were statistically tested. For summarization and clarity, we categorized the extracted features under six language dimensions following Wilson et al. [68] and Ahmed et al. [3] (adding the semantic and discourse domains as distinct fifth and sixth dimensions). This six-class system is based on the abnormal discourse classification by Saffran et al. [69] and the quantitative production analysis (QPA) of Berndt [70]. The six dimensions in our review are 1) speech production and speech sound errors; 2) other disruptions to fluency; 3) lexical content (lexical features of the words used); 4) syntactic structure and complexity, 5) seman-

Table 1
Search terms and descriptors used for electronic database search

	Spontaneous speech (SS)	Mild cognitive impairment (MCI)	Alzheimer's disease (AD)
		Natural language (Title/Abstract) All databases	
	(connected OR spontaneous) AND (speech OR language OR discourse)	(mild cognitive impairment OR MCI)	Alzheimer*
Databases		**Descriptors**	
PubMed (MeSH Major Topic) and MEDLINE (MeSH Subject Heading)	Natural language processing Speech Speech acoustics Speech discrimination tests Speech disorders Speech language pathology Speech production measurement Verbal behavior	Mild cognitive impairment	Alzheimer disease
Embase (Subject Headings)	Connected speech Connected speech abnormality Conversation Conversation analysis Discourse analysis Language Disorders/et (Etiology) Language disability/di (Diagnosis) Narrative Narrative analysis Natural Language Processing Oral communication Speech Speech analysis Speech and Language Speech and Language Assessment Speech and Language disability Speech articulation Speech discrimination Speech disorder Speech disorders* Spontaneous speech Spontaneous language production Verbal behavior	Mild cognitive impairment	Alzheimer disease
PsycINFO/PsycARTICLES (Index Terms)	conversation conversation analysis discourse discourse Analysis narratives natural Language natural language processing oral communication speech speech and language disorder speech characteristics speech disorders speech pauses	Cognitive impairment	Alzheimer disease

tic content (semantic features of the information content provided), and 6) discourse/pragmatics. We added "Other variables" to accommodate variables that could not readily be assigned to one of the six categories, such as visual paraphasias (replacement of the target word by a word that shares visual features with the target, such as *umbrella* instead of *mushroom*), gestures, and response to errors.

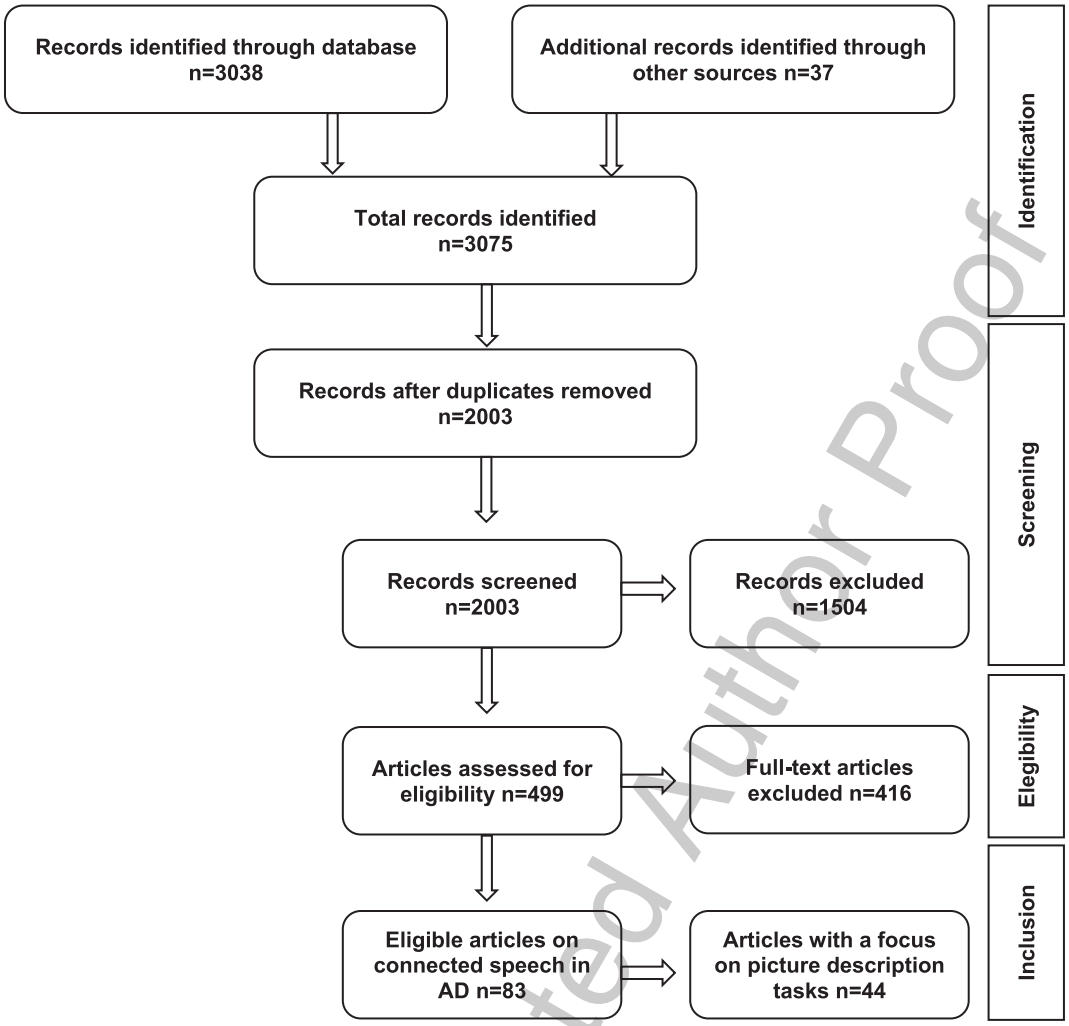

Fig. 1. Flow chart of the review process.

RESULTS

Study characteristics

Stimuli

A total number of 3,075 articles were retrieved after the literature search process. Subsequently, 2,003 duplicates were eliminated, of which 499 were assessed for eligibility. Moreover, 457 did not meet inclusion criteria, for a final total of 44 studies that focused on picture description by AD patients (see Fig. 1 for a detailed flow-chart). Of these, 27 studies (61%) made use of the Cookie Theft Picture from the Boston Diagnostic Aphasia Examination (BDAE) [62]. Nine of those studies [41, 45, 47, 66, 71–75] used the Cookie Theft Picture in conjunction with other pictures/stimuli. Other single-picture stimuli used include various Norman Rockwell pictures [48, 76–79], the Picnic Scene [41, 80] from the Western Aphasia Battery [81], the Tripping Woman Picture [47, 66, 82] from Semenza and Cipolotti [83], and the Bank Robbery picture [4, 6, 84] from the *Protocole Montréal-Toulouse d'examen linguistique de l'aphasie* [85]. The remainder of articles used pictures from a children's book [86] or depictions of various domestic/everyday scenes [45, 51, 87]. In five articles, sequences of multiple pictures were presented, illustrating either the adoption of a dog [44], the chain of events leading to a traffic accident [6, 65, 88], or four sets of different daily life scenes [89].

Languages

The language spoken by participants was English in 26 of the studies. Other languages were French

[4, 6, 84, 88, 90], Brazilian Portuguese [44, 65, 91], Hebrew [43, 92, 93], Chinese [72, 73], Japanese [87, 94], Finnish [95], Italian [74] and German [96].

Diagnostic criteria and disease severity

Fifteen of the articles surveyed reported results from patients diagnosed with "probable AD", 26 included patients with "mild AD" and 24 included persons with "moderate AD". Two studies included patients with "severe AD" [93, 96]. The most commonly reported diagnostic guidelines are those of the NINCDS-ADRDA [97] in 26 studies (59%). Seven studies reported Global Deterioration Scale scores [98] and seven reported Clinical Dementia Rating Scale scores [99]. MMSE [100] scores were reported in 25 of the 44 articles surveyed (57%).

Aims of studies included in the systematic review

Ten studies (23%) compared AD patients to other clinical syndromes, such as semantic dementia [51], the logopenic variant of primary progressive aphasia [39], fluent aphasia [74, 78, 101], right-brain damage [71], vascular dementia [42, 95], and Parkinson's disease [102]. Seventeen studies (39%) statistically tested an effect of disease severity. Thirteen studies (30%) statistically contrasted results from more than one task. Twelve of the articles (27%) were concerned strictly with comparing AD patients to a control group.

Transcription rules and analysis

Twenty-five articles (57%) did not specify if one or more transcribers validated the transcriptions used for analysis. Three studies (7%) explicitly report using automated techniques for the analysis of transcripts [40, 43, 51]. The most often-used multidimensional analysis guidelines is a variant of the QPA [69]. A recent, augmented version of the QPA is presented in Wilson et al. [68], building on work by Berndt [70], which is used in three articles and the current review. Other popular grids of analysis are the methods described in Croisile et al. [90] and in Tomoeda and Bayles [48], which were used in four and three articles, respectively.

Connected speech variables

The variables tested in the reviewed articles are reported in Table 2 and are organized by their respective domain of connected speech (Fig. 2), totaling 412 statistical tests. Some of the variables found to be significantly different in AD patients are reported in more than one article. To identify the most-often discriminant variables (Fig. 3) across different articles, variables bearing different names but measuring the same connected speech features (e.g., "information units" and "content units") were grouped together. The eight most often reported significant variables were selected for discussion with a heuristically defined cutoff based on the proportion of significant statistical tests: for inclusion in Fig. 3, a variable had to be tested at least four times and show a significant difference between AD patients and controls on more than 50% of tests. It must be noted that some variables that could be sensitive in distinguishing AD from controls may be underrepresented in this review because they have not been consistently measured across studies. Conversely, some variables that are less sensitive may be overrepresented because they are very routinely assessed in the analysis of connected speech although they are not specifically conceived to differentiate speech characteristics between AD and controls.

Speech rate (speech production)

Speech rate is defined as the number of words divided by the duration of the speech sample [68]. The following variables were also considered a measure of speech rate and included Syllables per minute, Number of words per minute, Phonation rate (Proportion of an utterance that is vocalized, versus silence), and Rate of speech. AD patients spoke slower in 78% of cases (7/9).

Utterance length (syntactic complexity)

Various measures of syntactic complexity exist, the most common of which is Mean length of utterance (MLU), i.e., the average number of words per utterance [68]. An utterance is defined as a sentence or any effort to express a thought that is terminated by a pause with a falling inflection [62]. Although not technically identical, we counted the following measures under Utterance length: Phrase length, Mean clause length, C-Unit length, Number of words per C-Unit, and Words per clause. AD patients produced shorter utterances in 56% of cases (5/9).

Pronoun use (lexical content)

We define pronoun use as quantitative differences in usage of pronouns. In pronoun use, we included: Pronoun-to-noun ratio, Number of noun phrases with a pronoun, Anomia index (noun/(noun+pronoun)), % of pronouns of all words, and Pronoun use. We did not include "referential cohesion" or "pronouns without

Table 2
Connected speech variables in the 44 reviewed articles (*significant difference for AD patients)

First Author [ref]	Year	AD	Controls	Language	Production	Syntactic	Lexical	Fluency	Semantic	Discourse	Other variables
Ahmed [3]	2013	9	9	English	Distortions Phonological paraphasias *Speech rate	Embeddings *MLU *Words in sentences *Syntactic errors *Nouns with determiners *Verbs with inflections	Closed class words *Pronouns *Verbs	Incomplete sentences *False starts *Filled pauses *Repaired sequences	*Total semantic units *Subjects *Objects *Actions	*Idea density *Efficiency	
Ahmed [46]	2013	18	18	English					Total semantic units *Component measures (nouns and verbs)	Idea density *Efficiency	
Ahmed [39]	2012	18	18	English	Distortions Phonological paraphasias *Speech rate	MLU *Syntactic errors *Words in sentences *Embeddings *Verbs with inflections *Nouns with determiners	Open/Closed class words *Pronouns *Verbs	Repaired sequences Incomplete sentences *Filled pauses *False starts			
Ash [86]	2007	20	10	English	*Speech rate	*MLU	*Word finding difficulty	*Quantity of essential material reported	*Accuracy of content Global connectedness *Maintenance of the theme *Coherence *Local connectedness		
Bayles [76]	2004	30	40	English	Number of words				*Information units	Global connectedness	
Bschor [96]	2001	41	40	German	Number of words				Feat: no difference on number of features (adjectives) *Objects *Locations *Actions Features		

Carlomagno [74]	2005	21	18	Italian	*Number of words *Words per minute			*Correct information units *Paraphasias (lexical)	*Information (crucial, non-crucial, wrong) *Correct information units per minute *Percent correct information units	Informative gestures *Miniturns
Chapman [78]	1998	10	10	English					Pragmatics (communicative intentions) *Pragmatics (drawing inferences)	Linguistic level (not different from controls); includes hesitations, circumlocutions, semantic paraphasic errors, paragrammatic errors, neologisms. *Cognitive level (memory. attention, problem solving)
Chapman [79]	1995	12	12	English		Reference: pronoun to referent ratio and referential errors			*Frame of interpretation *Propositions supporting frame of interpretation *Propositions disrupting frame of interpretation *Structure of information (fewer narrative for AD)	
Cherney [71]	1993	10	10	English	*Rate of speech *Total utterances			Essential units	Elaborations Irrelevancies Off-topic comments Incorrect utterances *Efficiency ratio	

(*Continued*)

Table 2
(*Continued*)

First Author [ref]	Year	AD	Controls	Language	Production	Syntactic	Lexical	Fluency	Semantic	Discourse	Other variables
Choi [94]	2009	27	20	Japanese		Total number of sentences Total number of phrases Number of phrases per sentence			*Information units	*Number of main concepts *Narrative efficiency	
Croisile [90]	1996	22	24	French	Phonemic paraphasias *Total number of words produced	Grammatical errors Number of independent clauses Number of incomplete clauses Total number of clauses *Number of subordinate clauses	*Nouns *Verbs *Adjectives/adverbs *Functors	Revisions Repetitions *Word-finding difficulties	Subjects Places *Objects *Actions *Total information units Semantic substitutions	*Implausible details Modalizations *Words per information unit	
Cummings [41]	1985	30	70	English	*Melodic line	*Grammatical competence *Phrase length			*Information content		
De Lira [91]	2014	37	26	Portuguese	*Number of words				*Number of information units		
De Lira [44]	2011	60	61	Portuguese	Phonemic paraphasias	Subordinated sentences *Coordinated sentences *Reduced sentences		*Word finding difficulties *Repetitions *Revisions	Semantic substitutions		
Drummond [65]	2015	14	41	Portuguese	Total number of words Narrative time		Number of open-class words *Number of closed-class words *Referential cohesion (adequate use of pronouns, explicit referents and no repeated-name-penalty phenomenon)	*Repeated words		*Type of discourse narrative versus descriptive *Narrative structure: complete versus incomplete Index of discourse effectiveness *Total macropropositions *Total micropropositions *Irrelevant micropropositions	

Duong [4]	2005	46	53	French		Syntactic index: number of complex clauses/ total clauses) Transitional markers	Referential index			Lexical index (IU/total words) Microprositions Right shifts Macropropositions Macropropositions per element Narrative structure (complete versus incomplete)	
Duong [84]	2003	5	27	French					*Repetition of expected ideas	*M/R ratio: modalizing words/referential words	
Ehrlich [45]	1997	16	16	English	Total number of words	Number of C-Units Clauses per C-Unit *Number of words per C-Unit	Pronouns without reference (anaphora) *Deictic terms (indefinites)	*Fragment index (Fluency: include false starts, filled pauses, immediate repetitions, incomplete clauses)	*Information Units	*Correct target propositions (semantic) *Efficiency index (target propositions/total words) Self-referential and extraneous statements (tangentiality)	
Forbes [82]	2002	22	22	English	Phonemic paraphasias *Melodic line (intonational color)	Grammatical form		*Word finding delays/difficulties	*Semantic paraphasias *Information conveyed	*Information content	*Error monitoring *Response to word-finding delay/difficulty *Visual paraphasias
Forbes-McKay [66]	2005	30	240	English	Melodic line Articulation Phonological paraphasias	Grammatical form Phrase length		*Word finding delays	*Pictorial themes *Semantic paraphasias	*Information content	*Error monitoring *Response to word finding delays Visual paraphasias

(*Continued*)

Table 2
(*Continued*)

First Author [ref]	Year	AD	Controls	Language	Production	Syntactic	Lexical	Fluency	Semantic	Discourse	Other variables
Forbes-McKay [47]	2013	31	30	English	Articulation Phonological paraphasias	*Grammatical form Phrase length			*Semantic paraphasias *Pictorial themes	*Information content	*Visual paraphasias *Response to word finding delays *Error monitoring
Fraser [40]	2016	167	97	English	*Mel-frequency cepstral coefficients (MFCC): skewness (MFCC 1), skewness (MFCC 2), kurtosis (MFCC 5), kurtosis (VEL(MFCC 3)), skewness (MFCC 8), skewness (MFCC 12) *Phonation rate *Words Not-In-dictionary (including phonological paraphasias, distortions and unrecognizable words)	*Sentence fragments (ROOT->FRAG) *Adverbs with deictic function (ADVP->RB) *Prepositional phrase rate (PP) *Verb phrase rate *Verb phrase with auxiliary *Verb phrase with gerund *Verb phrase with gerund and prepositional phrase *Various verb phrase structures (VP->VBG_PP, VB->IN_S, VB->AUX_ADJP, VB->AUX, VB->VBD_NP)	Brunet's index (vocabulary richness) Type-Token Ratio (vocabulary richness) Moving-average type-token ratio (MATTR, vocabulary richness) *Pronoun to noun ratio *Number of noun phrases with a pronoun *Frequency (use of frequent words) *Verb frequency *Nouns *Word length *Noun phrases with a determiner (NP->DT_NN) *Honoré's statistic (vocabulary richness) *Inflected verbs *Verbs	*Average cosine distance (index of repetitive content) *Cosine cutoff: 0.5 (repetitive content) *Interjections (INTJ->UH)	*Key word: window, sink, cookie, curtain, counter, stool, mother *Info unit: window, curtain, cookie, sink, girl, girl's action, dish, stool, woman		
Giles [37]	1996	48	18	English	Total time				*Information units	*Information units per second	
Groves-Wright [125]	2004	28	14	English					*Information units	*Main concepts *Efficiency *Conciseness ratio	

Hier [42]	1985	26	15	English	Palitatlia *Total words	Fragments (missing word but semantically correct) Subordinate clauses Mean clause length Prepositional phrases *Errors in prepositions	*Unique words *Anomia index (nouns/(nouns+pronouns)) *Empty words	*Aposiopesis (abrupt termination of sentence)		*Relevant observations *Conciseness index Gratuitous comments	Perseverations
Kavé [93]	2018	35	35	Hebrew	*Total word number		*% of Content words of all words *Pronoun ratio *TTR *Mean word frequency % Verbs of all words % Verbs in PAAL form % Verbs in present tense % Prepositions of all words % Subordination markers		*Information units		
Kavé [43]	2016	20	20	Hebrew	Total number of words		Type-token ratio (all words) Type-token ratio (nouns) *% Content words of all words *% Nouns of all words *% Pronouns of all words *Mean frequency of all words *Mean frequency of nouns *Mean word length in letters				

(*Continued*)

Table 2
(*Continued*)

First Author [ref]	Year	AD	Controls	Language	Production	Syntactic	Lexical	Fluency	Semantic	Discourse	Other variables
Kavé [92]	2003	14	48	Hebrew		Total number of sentences Syntactic errors *Words per clause *Clause type (independent, dependent, incomplete) *Sentence type (simple declarative, head-complement, existential, relative, conjoined, and impersonal)	Proportion of verbs out of nouns and verbs Proportion of inflected verbs Proportion of verb roots out of verb forms *Pronoun use		Actions Places *Objects *Actions *Total units	*Semantic errors	*Circumlocutionary comments
Kong [89]	2016	13	20	English					*Main Concept Score	Number of Absent concepts *Number of Accurate and complete concepts Number of Accurate but incomplete concepts Number of Inaccurate concepts *Number of Accurate and complete concepts per minute	
Lai [72]	2012	30	30	Chinese		Conceptual-epistemic Conceptual-evaluative Non-conceptual: inferential *Non-conceptual: contrastive *Non-conceptual: elaborative					

Lai [73]	2009	30	30	Chinese		Incomplete clauses Simple declarative sentence Head complement sentence Relative sentence Question sentence Syntactic errors: functors, tense confusion, ambiguous classifiers, unintelligible sentences *Independent clauses *Dependent clauses *Existential sentence *Conjoined sentence *Impersonal sentence *Unintelligible sentences	*Word-finding difficulties	*Actors *Places *Objects *Actions *Total units	*Incoherence	*Circumlocutionary comments (external)
March [75]	2006	26	26	English			*Noun use *Person deixis *Spatial deixis				
McNamara [102]	1992	15	141	English							*Undetected errors *Reformulation *Lemma
Nicholas [101]	1985	19	30	English	Number of total words Literal paraphasias Verbal-phonological paraphasias Unrelated verbal paraphasias Neologisms	"Ands"	*Indefinite terms *Conjunctions *Deictic terms *Pronouns without antecedents	*Repetitions	*Thematic elements (8) *Semantic paraphasias	*Empty phrases	Comments Judgments

(*Continued*)

Table 2
(*Continued*)

First Author [ref]	Year	AD	Controls	Language	Production	Syntactic	Lexical	Fluency	Semantic	Discourse	Other variables
St-Pierre [88]	2005	29	29	French						Related utterance *Relevant utterance *Irrelevant utterance	
Sajjadi [51]	2012	20	30	English	*Speech rate *Unit length *Combined phonological errors	Discourse markers Number of clauses per T-unit *Complete T-units *Elliptical T-Units *Abandoned T-units *Complex units *Number of arguments per verb *Verb agreement errors	Open-and closed-class word errors *Number of open- and closed-class words	Spontaneity *Hesitation markers *Editing breaks	Circumlocutions *Semantic errors *Information content	*Pictorial themes	
Shimada [87]	1998	23	17	Japanese					*Amount of information conveyed	Number of relevant and irrelevant descriptions (total) *Efficiency of description *Number of relevant descriptions	
Ska [6]	2005	46	53	French		*Syntactic index (complex phrases/total phrases) *Transition markers				Number of micropropositions Number of shifts in list of micropropositions *Lexical index (expected information/total) *Number of expected macropsopositions *Narrative scheme elements	

Smith [80]	1989	18	18	English	Total syllables Syllables per minute Total words *Total time	Total number of clauses Elements per clause	Specifications per element Deictics per element Unique words Anomia index		Total content units	Elements Relevant observations Conciseness index *Idiosyncratic versus appropriate utterances *Content units per minute *Syllables per content units *Elements per clause	
Tomoeda [77]	1996	63	52	English	*Total words			*Aborted phrases *Ideational repetitions *Revisions	Circumlocutions *Information units	*Conciseness	Frustrations
Tomoeda [48]	1993	3	3	English	*Total words			Revisions Aborted phrases *Ideational repetitions	Circumlocutions *Information units	*Conciseness	Frustrations
Vuorinen [95]	2000	13	20	Finnish	Number of words per minute				*Eight central themes		
Zraick [126]	2011	8	21	English	*Syllables produced *Words spoken				Objects Localizations Actions Figures *Sum of total information units		

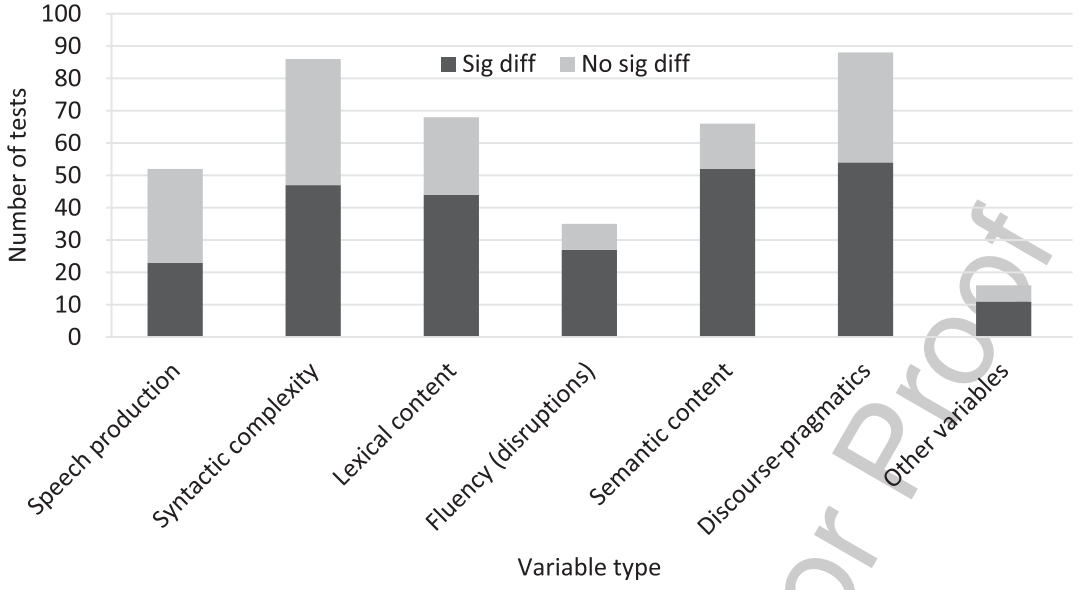

Fig. 2. Summary of tested variables by domain of connected speech.

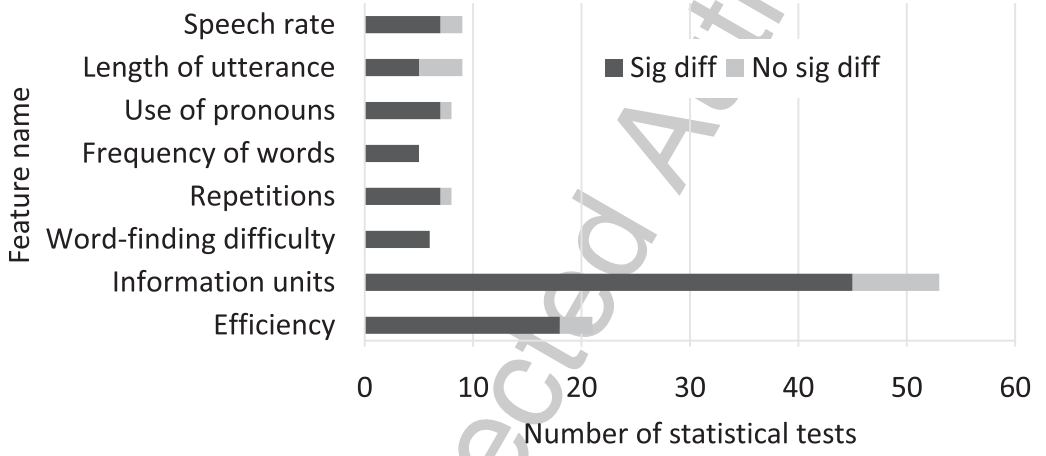

Fig. 3. Most commonly reported discriminant variables from AD picture description.

referents (anaphora)", because these measures are qualitatively different from the unequivocal quantitative measure of the number of pronouns used. We also excluded "person deixis", as it is not expressed exclusively using personal pronouns and authors treated it separately from anaphoric pronoun use [75]. AD patients used more pronouns in 88% of cases (7/8).

Word frequency (lexical content)

We refer to Word frequency as a measure of the average "rarity" of the words used by the speaker. A high-frequency word is one that is more common in a corpus of reference for a given language. We included the following variables: Verb frequency, Mean frequency of all words, and Mean frequency of nouns. AD patients used words with higher frequencies in 100% of cases (5/5).

Repetitions (disruptions to fluency)

Different authors have used varying definitions of repetition. It can be understood as the immediate, contiguous repetition of the same word [44, 90], repetition of a single word in the same clause [65], cosine distance between clauses (the average amount of identical words in any two utterances, as represented in the vector space) [40] or the inappropriate repetition of an idea [77]. These various definitions were all considered and grouped: Ideational repetitions,

Average cosine distance, Cosine cut-off (number of pairs of utterances whose cosine distance is less than 0.5, normalized by total number of unique utterance pairwise comparisons), and Repeated words. AD patients repeated themselves significantly more than controls in 88% of cases (7/8).

Word-finding difficulty (disruptions to fluency)

Word-finding difficulties (WFD) are described in Croisile et al. [90] as the absence of production of the target item, indicated by a pause or the production of an indeterminate term. AD patients presented more of these difficulties in 100% of studies (6/6).

Information units (semantic content)

An information unit is defined as a truthful, nonredundant piece of information about the stimulus picture [103]. We included the following variables under the umbrella term "information units": Content units, Total semantic units, Subjects, Objects, Actions, Component measures, Quantity of essential material, Locations, Correct information units, Essential units, Information conveyed, Information content, Number of content units, Repetition of expected ideas, Pictorial themes, Number of relevant descriptions, Key words, Places, Main concept score, and Localizations. AD patients provided fewer information units on 85% of the statistical comparisons (45/53).

Efficiency and idea density (discourse)

Efficiency is the rate at which information is conveyed [46], and idea density (or conciseness) is the average number of ideas expressed per given number of words. Efficiency is based on speech duration and not on words spoken. We group idea density and efficiency because they both reflect the ability, at the discourse level, to produce relevant content efficiently. The following terms were included as corresponding to efficiency/idea density: Correct information units, Efficiency ratio, Narrative efficiency, Words per information units, Index of discourse effectiveness, Efficiency index, Information units per second, Conciseness, Conciseness ratio, Conciseness index, Number of accurate and complete concepts per minute, Efficiency of description, and Lexical index (ratio of the number of expected information units provided on the total number of words uttered). AD patients required more time or words to convey information in 86% of the measures (18/21).

DISCUSSION

In this systematic review, we aimed to determine the different connected speech dimensions affected in AD patients in picture description tasks. Through an exhaustive review of 44 articles, we compiled a total of 412 statistical tests of a wide array of variables, from which we isolated the most often reported as discriminant between AD patients and controls. The following eight variables belong in different dimensions of connected speech: speech production (rate of speech), syntactic complexity (MLU), lexical content (use of pronouns and word frequency), disruptions to fluency (repetitions and word-finding difficulties), semantic content (information units), and discourse (efficiency). These results highlight the importance of a multidimensional assessment of connected speech to aid in differential diagnosis of AD and for monitoring communicative abilities with disease progression.

Speech production

Among the variables belonging to the category of speech production, rate of speech seems to be the variable showing a consistent difference between AD and controls. AD patients are reported to have, on average, a slower speech output (fewer words per minute) than the healthy elderly. While neural correlates of rate of speech have never been investigated in AD, it has been associated with damage to the left inferior frontal gyrus in primary progressive aphasia [104]. In individual AD patients, speech rate was not found to consistently decline with disease progression, and the measure has proven unstable on test-retest of patients [3]. These observations cast doubt on the reliability, and consequently on the clinical usefulness of this measure. However, acoustic features of speech (such as spectral characteristics of the voice signal) should not be discounted, as recent analyses have proven sensitive to articulatory changes associated with AD [40, 105].

Syntactic complexity

Concerning the syntactic aspects of connected speech, the average length of utterance was the most often studied variable in AD patients. It was found to be shorter for AD patients, which is interpreted as shorter and more simple sentences. A caveat of this measure is its sensitivity to the boundary placement in the transcription process, i.e., what is considered an utterance. It may thus be inconsistently calculated

across different studies [68]. This is especially worrisome considering that most of the articles included in this systematic review did not specify transcription rules and guidelines nor explicitly state validation of the transcribed data. Our results are not consistent with the results presented in Boschi et al. for picture description tasks. Indeed, 5 out of 9 of the articles included in the present systematic review showed a statistically significant difference, whereas Boschi et al. report significant differences in only 2 out of 6 articles. It must be noted that this discrepancy is probably due to the fact that our systematic review included a greater number of articles with different datasets and transcription guidelines. Moreover, 3 of the 6 papers that did not show significant difference in Boschi et al. were based on the same connected speech dataset (DementiaBank). Although length of utterance may not be the most reliable index of syntactic complexity, its shortening appears to be detectable in picture descriptions of AD patients. Recently, Garrard et al. [106] have proposed a systematic tool for the automatic alignment of transcripts and automatic quantification of discrepancies. Such a system could be helpful to ensure reproducibility of studies and standardized data preparation for computerized analyses. In spite of these difficulties, syntax as a connected speech variable may not be discarded, as we know that AD patients exhibit changes in both the comprehension [31, 107] and expression of syntax [32, 108]. Comprehension of complex syntax is thought to place a heavy demand on working memory [107], which leaves AD patients at a disadvantage.

Lexical content

Evidence of lexical content impairments was measured using two main variables, namely use of pronouns and frequency. AD patients showed increased reliance on pronouns compared to controls. This has been attributed to their semantic impairment and lexical access difficulties. The use of pronouns allows them to maintain relatively fluent speech in the face of lexico-semantic difficulties, substituting a pronoun in the place of a target noun they are unable to accurately name (*she* instead of *mother*, *this* instead of *kite*, etc.). An alternative hypothesis is that the use of pronouns is related to working memory deficits [109], an explanation known as the "working memory impairment hypothesis". Almor et al. [109] argue that an increased use of pronouns in connected speech is linked to working memory problems but neither to dementia severity nor semantic impairment. These authors suggest that AD patients struggle to keep a fresh activation of semantic representations in working memory and thus rely on pronouns and very high-frequency words (see discussion below).

In their picture descriptions, AD patients tend to use more high-frequency words than controls. In the studies surveyed, this effect appeared in overall lexical content [93] and specifically in verbs [40] and nouns [43]. Word frequency has been tested five times in three articles in our review, and its effect on AD connected speech is not well documented. In confrontation naming tasks, however, various psycholinguistic variables have been shown to significantly impact the performance of AD patients: age-of-acquisition, name agreement, word frequency, and familiarity [110, 111]. How these variables impact the multiple dimensions of connected speech in a picture description task remains unclear, but their analysis is particularly well suited for computational analyses. In fact, automated algorithms could help extract psycholinguistic variables from connected speech transcriptions relying on open access databases [112]. Our results also highlight that the often-tested variables of TTR and open/closed-class word ratio are not sensitive to the lexical and semantic impairment of AD patients. In other words, the supposed reduction in vocabulary and WFDs of AD patients cannot be reliably be measured using these common metrics in picture descriptions. However, vocabulary size can be investigated with other metrics that may be more sensitive to impairment. Recent work in natural language processing successfully enriched speech transcripts of MCI patients with semantic information from word embeddings and boosted classification accuracy [113]. Another example is how Hoffman et al. have applied latent semantic analysis [114] to extract the semantic diversity (the number of different contexts in which they appear) of words used by patients with semantic dementia [115]. Hence, vocabulary richness may be a valuable construct to study neurodegenerative diseases, despite disappointing results from previously used metrics such as TTR and open/closed-class word ratio.

Disruptions to fluency

Disruptions of fluency in AD connected speech have been detected with repetitions and word-finding difficulties. Measures of repetitive content are operationalized in different ways between authors. When understood as the immediate, contiguous produc-

tion of the same word [44, 90], we are inclined to interpret repetition as a consequence of WFD as in Forbes-McKay and Venneri [66]. Indeed, less anomic patients were reported to produce fewer repetitions [101]. The inappropriate repetition of an idea [77] and cosine distance between clauses (the extent to which two given utterances contain the same words) [40], however, could be attributed to memory deficits typically associated with AD. Hence, different measures of repetitiveness may reflect distinct cognitive/behavioral mechanisms, but it seems that all these distinct measures of repetitiveness are sensitive to AD in picture description tasks.

Even though word-finding difficulties increase with normal aging, AD patients experience more WFDs, or anomia, than healthy elderly people. In normal aging, this phenomenon is largely attributed to lexical access difficulties. As we noted in our introduction through discussion of picture naming and verbal fluency, the increased prevalence of WFD in AD could be linked to a combination of impaired lexical access and a degradation of semantic cognition. WFD does occur in picture description tasks, but one drawback of its use as an outcome variable in picture description tasks is that it may be difficult to assess in a standardized manner. It has been defined as "the absence of production of the target item, indicated by a pause or the production of an indefinite term" and as "indicated by a pause, an immediate repetition of a previous word or production of an indefinite term" [90]. Thus defined, this measure requires careful and time consuming manual examination of both the audio and transcribed speech data to be properly operationalized. One observation of interest is that the words retrieved after a word-finding pause tend to be of higher frequency for AD patients [116], a finding that highlights the importance of this variable when administering picture description tasks. In a recent review of word retrieval in connected speech, Kavé and Goral argue for the importance of assessing word retrieval in speech, and not only in single-words naming tasks [59].

Semantic content and discourse

In the discourse and semantic domains, the most often reported significant variables are efficiency and number of information units, respectively. Speech of AD patients becomes noninformative and empty with disease progression [101]. The lower efficiency and the fewer number of information units conveyed by AD patients may reflect deficits in lexical access, semantic impairment, or both. The question of the extent to which each of these mechanisms is shared by the naming difficulties of AD patients is still a matter of debate [16]. Alternatively, discourse efficiency has also been linked to executive function [117], which is known to be impaired in AD [118]. In the discourse domain, AD patients also have more trouble maintaining the theme, despite the pictorial support of picture description tasks [42, 86]. Information units and efficiency remain by far the most-often reported variables in picture description tasks, as they can serve as a quantitative measure of the so-called *emptiness* of AD discourse captured through picture description tasks. This emptiness is not solely attributable to the perceptual analysis of the picture, as deficits in information content were also observed in interviews [51] and informal conversation [119] with AD patients.

Limitations and further study

A better understanding of the relationship between connected speech and other language tests such as confrontation naming and verbal fluency could help delineate difficulties caused by impaired lexical access versus semantic degradation in AD discourse. Kavé and Goral [43] have argued that scores on confrontation naming were in fact associated with WFD in connected speech, whereas verbal fluency tasks were not as useful to predict lexical retrieval in a picture description task. This discrepancy is attributed to the more similar cognitive demands of picture naming and picture description, whereas the latter is less reliant on executive function compared to lexical fluency tasks. The relationship between connected speech variables and performance on confrontation naming of animals, objects, and especially unique entities such as famous people and buildings, however, needs further study [52].

From a methodological point of view, a clear majority of studies (60%) used the Cookie Theft Picture from the BDAE, which depicts an everyday scene that can be described in short and simple language, using very high-frequency words (e.g., girl, boy, mother, water, etc.). Some authors have emphasized the need for more complex pictures to shed light on early, subtle connected speech abnormalities [47, 65, 66, 82]. Not all variables, however, seem to be affected equally by heightened complexity, as is the case with deixis [75], meaning that results obtained with one picture description task are not necessarily generalizable to others.

A minority (30%) of the studies reported in this review were published from 2011 onwards, a year that saw the publication of the revised NINCDS-ADRDA criteria for AD [1]. Thus, we cannot exclude that some patients from earlier studies would receive a different diagnosis today, nor that the stages of disease and mixed-profile presentations correspond to present-day diagnostic criteria. Although connected speech disturbances caused in AD patients have been described as heterogeneous across patients [4], a consistent multidimensional pattern of connected speech impairment has successfully been extracted with machine learning techniques and a factor analysis [40]. These computational results overlap with much of the previous research summarized in this review (Fig. 1). Another critical issue that emerged in the research summarized in this review is the transcription process itself. As we stated in our discussion of syntactic content, most articles did not specify transcription guidelines, and this should be addressed in future research to ensure reproducibility of results [106].

Our systematic review included only connected speech studies elicited by picture description. A major advantage of picture description tasks is their ability to quickly capture a multidimensional sample of language variables [3]. The recent advances in computing techniques may enable short, automated analyses of discourse samples [63]. Hence, picture description tasks are of obvious interest in clinical settings, where a simple three-minute, 150-word discourse sample offers a wealth of information about a patient's cognitive status and communicative abilities [51]. Moreover, picture description tasks provide an opportunity for cost-efficient multiple time-point testing in situations when one or more comprehensive language examinations from a speech-language pathologist are not feasible. For example, they could be used to routinely monitor the communicative skills of AD patients, as these critical abilities are known to decline with disease progression and are accompanied by various negative outcomes [8, 120, 121]. Additionally, picture description tasks could inform efficient communication strategies for caregivers and possible interventions with the patient that are tailored with its language profile.

Our results reveal that a wide array of language variables has proven useful to distinguish AD patients from the healthy elderly and to follow the course of disease progression, highlighting the need to go beyond tasks such as verbal fluency and confrontation naming and consider connected speech as provided by picture description tasks [37]. Current literature on the connected speech of AD patients favors a multidimensional approach [3, 40, 47], but the need for standardization of analytic procedures has been underlined [52]. A recent review of connected speech in neurodegenerative diseases has added a valuable contribution in this direction by synthetizing a great quantity of the available evidence [52].

Conclusion

The present study represents the first attempt to systematically revise the literature on connected speech elicited by picture description in AD. The results give an overview of the multiplicity of variables studied in this field and the main results. Our review highlights the importance of using a multidimensional analysis approach capable of extracting and measuring syntactic, lexical, fluency, and semantic features in spontaneous speech in AD. This approach leads to a comprehensive overview of the language production abilities of each patient. This information can be relevant not only for patient characterization and differential diagnosis but can also help caregivers and, eventually, contribute to refining intervention strategies. We also suggest the importance of developing automatic analysis tools to make the assessment of connected speech more suitable for clinical settings. Most of the analyses conducted in the articles surveyed rely on error-prone and time-consuming methods. This has recently been reported in a connected speech review by Boschi et al. [52] and is confirmed in our study. As programmers continue to meet computational challenges relevant to the study of normal and pathological discourse analysis, new technology stemming from these advances will enter hospitals and nursing homes, to the benefit of the patient, caregivers and the healthcare system (see Aluísio et al. [63] for one effort in this direction). We thus expect picture description tasks to become an important tool of speech-language-pathologists aiming to promote choice, dignity and engagement in meaningful activities through person-centered care [122]. Automated procedures have also been shown to produce reasonable accuracy in the classification of patients with AD [40, 64, 123] and primary-progressive aphasia [124]. With a focus on existing data, this review identified multidimensional variables that should become a target for the new computational tools that are to facilitate AD research and management.

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