Comprehension of *wh*-questions and relative clauses in Greek speaking individuals with Alzheimer's disease

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Περίληψη

Στην έρευνα εξετάζεται η κατανόηση δομών μετακίνησης σε 14 ελληνόφωνους ομιλητές με Νόσο Αλτσχάιμερ (ΝΑ) και 16 υγιείς ηλικιωμένους. Οι ασθενείς με ΝΑ παρουσίασαν χειρότερη επίδοση από τους υγιείς ηλικιωμένους σε όλες τις δομές, ενώ εντοπίστηκε επιλεκτική ασυμμετρία ανάμεσα σε δομές υποκειμένου και δομές αντικειμένου, εύρημα που υποδεικνύει ότι η κανονικότητα στη σειρά των όρων αποτελεί έναν από τους παράγοντες που επηρεάζει την επίδοση των ασθενών στην επεξεργασία της πρότασης. Η υψηλή συσχέτιση ανάμεσα στις επιδόσεις των ασθενών με ΝΑ στις δομές αντικειμένου και σε έργα εργαζόμενης μνήμης υποδεικνύει την επίδραση της εργαζόμενης μνήμης στη συντακτική επεξεργασία.

Λέξεις-κλειδιά: Νόσος Αλτσχάιμερ, κανονικότητα, ερωτηματικές προτάσεις, αναφορικές προτάσεις, ελεύθερες αναφορικές προτάσεις, εργαζόμενη μνήμη

1 Introduction

Alzheimer's disease (AD) is a progressive, neurodegenerative brain disorder associated with impairments in episodic memory, semantic memory, working memory (WM), executive functions, and language (Hodges & Patterson 1995). Regarding language, lexical retrieval problems, problems in semantic fluency, and difficulties in sentence comprehension are some of the deficits that have been observed (Kempler 2005).

Sentence comprehension has attracted great attention in psycholinguistic research. Studies on typical and atypical populations have shown that sentences with canonical argument order (e.g., actives, subject *wh*-questions, subject relative clauses (RCs)) are easier to comprehend compared to those with non-canonical argument order (e.g., passives, object *wh*-questions, object RCs). Difficulties to process object-extracted sentences have been attested in speakers with agrammatic aphasia (e.g., Hickok and Avrutin 1996, Grodzinsky 2000, Garaffa and Grillo 2008, Nerantzini et al. 2014, Varlokosta et al. 2014), in children with developmental language disorders (e.g., Stavrakaki 2001, Friedmann and Novogrodsky 2004), in typically-developing children (e.g., Friedmann et al. 2009, Varlokosta et al. 2015), even in typical adults (e.g., Gibson 1998). Evidence from AD suggests that sentence comprehension is also compromised. However, the nature of these deficits remains a controversial issue.

Some researchers suggest that individuals with AD have grammatical processing difficulties affecting the comprehension of syntactically complex structures that involve movement and non-canonical argument order, such as reversible passives (Grober and Bang 1995) and object RCs (Bickel et al. 2000, Marková et al. 2017). Grober and Bang (1995) argued that sentence comprehension declines as syntactic complexity increases, since individuals with AD had little difficulty comprehending non-reversible passives,

which can be understood on the basis of word meaning alone (e.g., *The package is carried by the boy*), while they made more errors on reversible passives, which require syntactic processing (e.g., *The boy is kissed by the girl*). Similarly, Bickel et al. (2000) showed that German individuals with AD performed high in center-embedded subject relatives (e.g., *The robe lying on the suit is made up of blue silk*) but at chance in center-embedded object relatives (e.g., *The robe, on which the suit is lying, is made up of blue silk*). Recently, Marková et al. (2017) showed that Slovak individuals with AD performed worse on center-embedded object relatives compared to OVS structures, center-embedded subject relatives, and subject and object right-branching relatives. Interestingly, non-canonical sentences were easier to process when a morphological cue, like case, was present on the first DP of a sentence. Similar asymmetries between constructions with canonical and non-canonical argument order have been attested in the interpretation of *wh*-questions. Salis and Saddy (2011) examined the interpretation of *wh*-questions in a case of mixed dementia and found worse performance on object (e.g., *Which zebra has the hippo bumped*) compared to subject referential questions (e.g., *Which zebra has bumped the hippo*), but no difference between subject (e.g., *Who has bumped the hippo*) and object non-referential questions (e.g., *Who has the hippo bumped*). Subject-object asymmetries in referential questions were not replicated in a subsequent study by Molympaki et al. (2013), which investigated the comprehension of *wh*-questions (referential, non-referential) and RCs (right-branching, center-embedded) in 10 Greek-speaking individuals with mild-to-moderate AD. Molympaki et al. (2013) reported subject-object dissociations only in right-branching relatives, but observed asymmetries in the performance of non-referential vs. referential questions and center-embedded vs. right-branching relatives. According to the authors, the prevalence of non-referential over referential questions and right-branching over center-embedded relatives cannot be attributed to a core grammatical processing deficit. Instead, they argue in favor of a processing account, suggesting that the different cognitive demands posed on the memory mechanisms by these sentence types affect sentence comprehension.

Several researchers have claimed that sentence comprehension deficits in AD are not due to a dysfunction of grammar but are rather affected by limitations in the memory system and/or in executive functions associated with sentence comprehension (Rochon et al. 1994, Waters et al. 1995, Caplan and Waters 2002). Caplan and Waters (2002), for instance, suggested that deficits in sentence comprehension are due to WM limitations because individuals with AD exhibit worse performance in sentences with more than one propositions (and verbs) (i.e., object-subject RCs: *The horse kicked the elephant that touched the dog*, conjoined sentences: *The elephant followed the lion and pulled the dog*, subject-object RCs: *The dog that the pig followed touched the horse*). Similarly, Rochonet al. (1994) showed that performance on object-subject RCs (e.g., *The horse kicked the elephant that touched the dog*) and on conjoined sentences (e.g., *The elephant followed the lion and pulled the dog*), which contain two propositions, was worse than performance on active conjoined theme sentences (e.g., *The pig chased the lion and the cow*), which contain one proposition.

Overall, previous research on individuals with AD has not reached firm conclusions with respect to the nature of the syntactic comprehension deficits observed, i.e., whether they result from genuine grammatical impairments or from limitations in WM. Moreover, the existing evidence regarding the role that canonicity and referentiality play in sentence comprehension is still quite scarce, as most studies have placed emphasis on RCs, while *wh*-questions or other movement structures have not been thoroughly examined. The current study examines whether (a) sentence

comprehension of Greek-speaking individuals with mild-to-moderate AD differs from the abilities of cognitively intact controls, (b) complex structures that involve movement and non-canonical argument order are differentially affected in Greek-speaking individuals with AD, i.e., whether canonicity and referentiality affect sentence comprehension, and (c) morphological cues, like case, affect sentence comprehension. In languages like English, sentence interpretation is determined on the basis of argument order; the first DP in a sentence functions as a subject, while the DP following the verb functions as its object. However, in morphologically rich languages with relatively free word order, like Greek, sentence interpretation is determined on the basis of morphological cues, like case; subjects are marked with nominative, whereas (direct) objects are marked with accusative case. Thus, case may facilitate sentence comprehension.

2 Methods

2.1 Participants

Fourteen Greek-speaking individuals with mild-to-moderate AD (mean age= 75.5; SD= ±7.9) and sixteen, age and education matched, healthy adults (mean age= 76.3; SD= ±7.8) participated in this study. Participants with AD were recruited from the Cognitive Disorders/Dementia Unit of the 2nd Department of Neurology, "Attikon" University General Hospital, National and Kapodistrian University of Athens, and were selected using the criteria of NINCDS-ADRDA for a primary diagnosis of AD (McKhann et al. 1984, 2011) in addition to the clinical consensus of a neurologist. Normal controls (NCs) were recruited from a center for elderly people in Athens. The mental stage of all participants was assessed on the basis of the Mini-Mental State Examination (MMSE) (Folstein et al. 1975, Fountoulakis et al. 2000). Participants had no vision or hearing problems, no depression, and no history of prior speech/language deficits, stroke or other neurological impairment. The two groups differed significantly on MMSE scores (Welch t-test, p=.000), but not on age (Welch t-test, p=.745) or education (Welch t-test, p=.783).

To further assess both groups, two verbal WM tasks were administered – the digit ordering and the backward digit span task (MacDonald et al. 2001). Individuals with AD performed significantly worse than NCs in digit ordering (independent t-test: $t(28)$= -4,264, p=.000), in digit backward (independent t-test: $t(28)$= -5,345, p=.000), and in their composite verbal WM score (independent t-test: $t(28)$= -5,489, p=.000). Table 1 provides details on the demographic and cognitive profile of the participants.

Groups	Age	Education (years)	MMSE (n= 30)	Digit Ordering span (n=15)	Digit Backward span (n=14)	Composite Verbal WM score(n=29)
AD group	75.5 (±7.9)	5.4 (±4)	16.8 (±3.6)	5.1 (±3.2)	2.4 (±1.4)	3.7 (±2.8)
NC group	76.3 (±7.8)	5.8 (±3.3)	29.5 (±0.9)	10.1 (±3.2)	5.3 (±1.5)	15.4 (±4)

Table 1 | Demographic and cognitive profile of Greek-speaking participants

2.2 Materials and Procedure

A picture pointing task was used to assess the comprehension of *wh*-questions, RCs and free relatives (FRs). The task comprised 32 semantically reversible *wh*-questions, 16 non-referential (half subject (1) and half object (2)) and 16 referential (half subject (3) and half object (4)), 32 right-branching (RB) RCs (half subject (5) and half object (6)) and 32 free relative clauses (FRs) (half subject (7) and half object (8)) (Table 2). To assess the role of case, two versions of RCs and FRs were included. One version was introduced by the instruction *δikse mu* "show me" and required the head DP of the RC and the relative pronoun of the FR to be marked with accusative case for both subject (5a, 7a) and object (6a, 8a) dependencies, as the RC/FR was the object of the main verb. The second version was introduced by the instruction *kerδizi* "wins" and required the head DP of the RC and the relative pronoun of the FR to be marked with nominative case for both subject (5b, 7b) and object (6b, 8b) dependencies, as the RC/FR was the subject of the main verb.

Sentence type	**Examples**
Non-referential questions	
1. *who*-subject	*Pjos*$_i$t$_i$*fotoγrafise ton kloun*? 'Who photographed the clown?'
2. *who*-object	*Pjon*$_i$*fotoγrafise o kloun*t$_i$? 'Who did the clown photograph?'
Referential questions	
3. *which-NP*-subject	*Pjosvasiliast*$_i$*fotoγrafise ton kloun*? 'Which king photographed the clown?'
4. *which-NP*-object	*Pjonvasilia*$_i$*fotoγrafise o kloun*t$_i$? 'Which king did the clown photograph?'
Relative Clauses	
5. RB-subject	a. *δikse mu ton vasilia*$_i$*put*$_i$*fotoγrafise ton kloun*. (**accS-accO**) 'Show me the king that photographed the clown.' b. *kerδizi o vasilias*$_i$*put*$_i$*fotoγrafise ton kloun.* (**nomS-accO**) 'The king who photographed the clown wins.'
6. RB-object	a. *δikse mu ton vasilia*$_i$*pufotoγrafise o klount*$_i$ (**accO-nomS**) 'Show me the king that the clown photographed.' b. *kerδizi o vasilias*$_i$*pufotoγrafise o klount*$_i$ (**nomO-nomS**) 'The king that the clown photographed wins.'
7. FR-subject	a. *δiksemouopjont*$_i$*fotoγrafise ton kloun* (**accS-accO**) 'Show me whoever photographed the clown.' b. *Kerδiziopjost*$_i$*fotoγrafise ton kloun* (**nomS-accO**) 'Whoever photographed the clown wins.'
8. FR-object	a. *δiksemouopjon*$_i$*fotoγrafise o klount*$_i$ (**accO-nomS**) 'Show me whoever the clown photographed.' b. *Kerδiziopjos*$_i$*fotoγrafise o klount*$_i$ (**nomO-nomS**) 'Whoever the clown photographed wins.'

Table 2 | Examples of the sentence types

Participants were presented with one black-and-white picture on a computer screen (Fig. 1), while the experimental sentences were auditorily presented to them, and were asked to point either to the agent or to the theme of the action corresponding to the sentence they heard. The pictures depicted semantically reversible actions performed by two of three animate agents (people or animals) always of the same gender (grammatical and semantic). The task was administered in one session. To eliminate erroneous picture identification effects, the same transitive action verbs and the same nouns were used across sentence types.

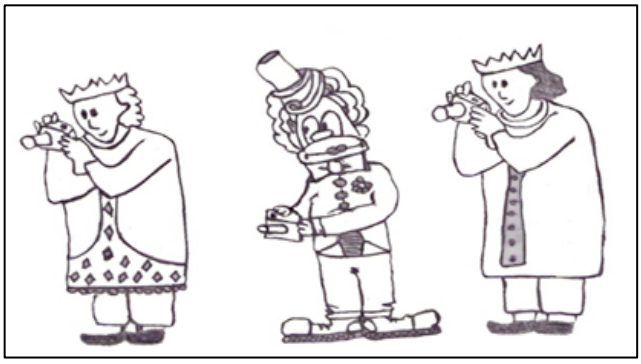

Figure 1 | Example of the pictures accompanying the experimental sentences

3 Results

The AD group performed significantly worse than the NC group on all *wh*-questions (Fig. 2) (*who*-subject: independent t-test: $t(13,691) = -3,531$, $p=.003$; *who*-object: $t(16,421) = -3,196$, $p=.005$; *which-NP*-subject: $t(13,698) = -4,365$, $p=.001$; *which-NP*-object: $t(17,664) = -4,844$, $p=.000$)). No significant differences were observed across conditions in either group.

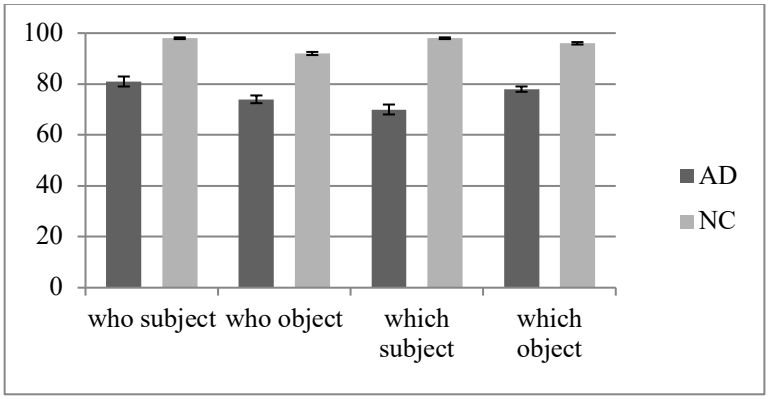

Figure 2 | Proportions correct for *wh*-questions per question type

Participants with AD performed relatively low (below 75%) across conditions compared to NCs, who performed at ceiling (Fig. 3). As indicated by independent samples t-tests, participants with AD differed significantly from NCs on RB-subject ($t(13,994) = -6,937$, $p=.000$), on RB-object ($t(14,494) = -7,698$, $p=.000$), on RB-subject-accS-accO ($t(13,788) = -6,683$, $p=.000$), on RB-subject-nomS-accO ($t(13,572) = -5,048$, $p=.000$), on RB-object-accO-nomS ($t(16,034) = -6,837$, $p=.000$), and on RB-object-nomO-nomSRCs ($t(14,681) = -6,377$, $p=.000$).

Within the AD group, dissociations between subject and object dependencies were revealed, with object dependencies being significantly harder than subject ones (paired t-test: $t(13)= 2,744$, $p=.017$). However, no difference was attested between object-extracted RCs in which the relativised DP was marked with accusative case (RB-object-accO-nomS) and object-extracted RCs in which the relativised DP was marked with nominative case (RB-object-nomO-nomS) in the AD (paired t-test: $t(13)= 0,322$, $p=.752$) or in the NC group (paired t-test: $t(15)= 1,775$, $p=.096$). Similarly, no difference was obtained between subject-extracted RCs in which the relativised DP was marked with accusative case (RB-subject-accS-accO) and subject-extracted RCs in which the relativised DP was marked with nominative case (RB-subject-nomS-accO) in the AD (paired t-test: $t(13)= -0,718$, $p=.486$) or in the NC group (paired t-test: $t(15)= 0,000$, $p=1,000$).

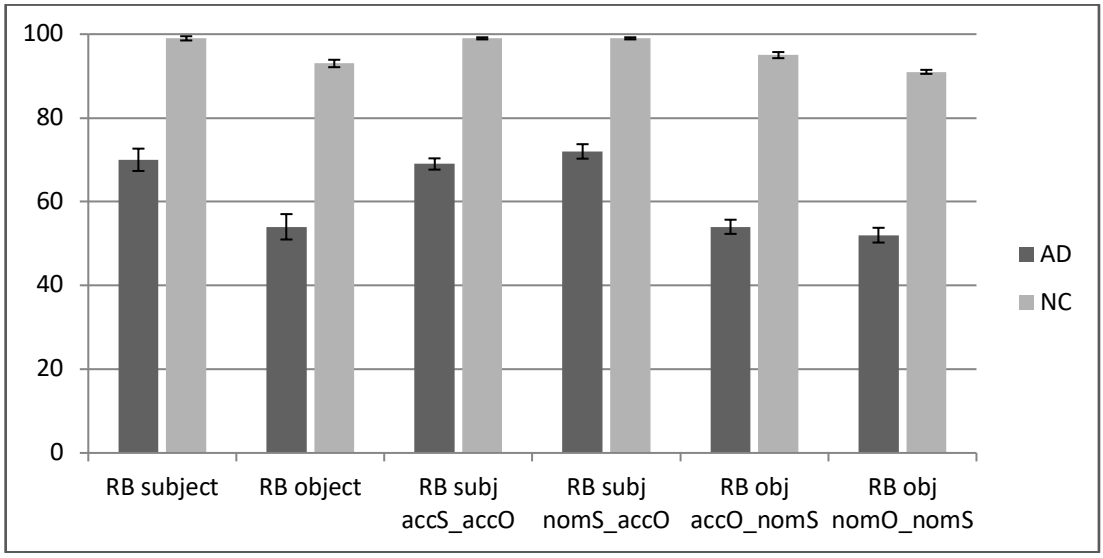

Figure 3 | Proportions correct for RCs per sentence type

The AD group had difficulties in the interpretation of FRs compared to controls, who performed at ceiling (Fig. 4). By using independent samples t-tests, we observed that participants with AD differed significantly from NCs on FR-subject ($t(14,014)= -5,965$, $p=.000$), on FR-object ($t(14,674)= -6,390$,$p=.000$), on FR-subject-accS-accO ($t(14,051)= -4,986$, $p=.000$), on FR-subject-nomS-accO ($t(13,502)= -7,094$,$p=.000$), on FR-object-accO-nomS ($t(15,010)=-4,097$, $p=.001$), and on FR-object-nomO-nomS ($t(28)=-7,986$,$p=.000$). No significant differences were obtained between subject- and object-extracted FRs (paired t-test: $t(13)= 1,302$, $p=.215$) in the AD group. Regarding the role of case, a significant difference was attested in subject FRs with lower performance in FR-subject-nomS-ccO compared to FR-subject-accS-accO (paired t-test: $t(13)=3,017$, $p=.010$), and in FR-object, with lower performance in FR-object-nomO-nomS compared to FR-object-accO-nomS (paired t-test: $t(13)= 4,694$, $p=.000$). In the control group, no significant difference was yielded between FR-subject-accS-accO and FR-subject-nomS-accO (paired t-test: $t(15)= 1,000$, $p=.333$) or between FR-object-accO-nomS and FR-object-nomO-nomS (paired t-test: $t(15)= 0,899$, $p=.383$).

Last, participants with AD performed worse on RB-object RCs compared to FR-object (paired t-test: $t(13)= 7,524$, $p=.000$), on RB-object RCs compared to object-extracted non-referential questions (paired t-test: $t(13)= -4,601$, $p=.000$), and on RB-object RCs compared to object-extracted referential questions(paired t-test: $t(13)= -5,443$, $p=.000$). Moreover, they performed worse on FR-object compared to object-

extracted non-referential questions (paired t-test: t(13)= -2,188, *p*=.048) and on FR-object compared to object-extracted referential questions (paired t-test: t(13)= -3,459, *p*=.004). In the NC group no significant differences were observed across conditions.

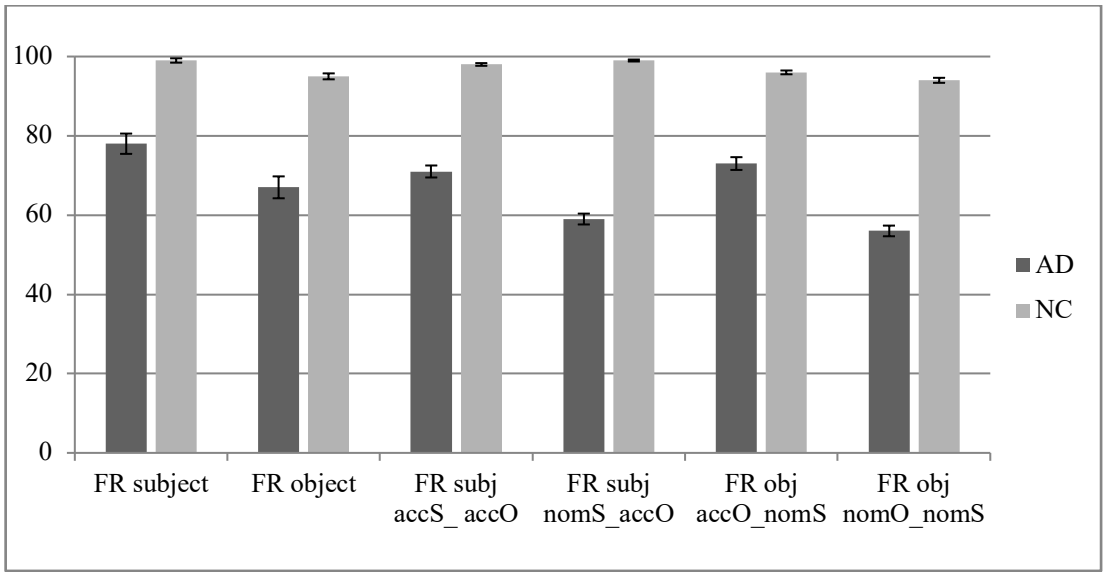

Figure 4 | Proportions correct for FRs per sentence type

To investigate whether WM capacity affected performance of the participants with AD in the object constructions, which are inherently more demanding due to their non-canonical argument order, the accuracy scores of object dependencies and WM tasks were correlated (Table 3). WM capacity correlated significantly with object referential and non-referential questions as well as with RB-object RCs. However, no significant correlation was obtained between WM capacities and performance on FR-object. Furthermore, WM was significantly correlated with RB-object-nomO-nomS RCs, but not with RB-object-accO-nomSRCs or FR-object-accO-nomS. Last, a trend was revealed in the comparison of WM scores and performance on FR-object-nomO-nomS, but no significant linear relationship was confirmed between them.

Correlations	Standard Error	*t* value	r	r^2	*p*-value
who-object: WM	0.347	2.585	0.598	0.358	0.024*
Which-NP-object: WM	0.241	2.213	0.538	0.290	0.047*
RB-object: WM	0.195	2.731	0.636	0.404	0.020*
FR-object: WM	0.235	1.450	0.401	0.160	0.175
RB-object-nomO-nomS: WM	0.380	2.670	0.611	0.373	0.020*
RB-object-accO-nomS: WM	0.439	1.094	0.301	0.091	0.295
FR-object-nomO-nomS: WM	0.315	2.044	0.508	0.258	0.064
FR-object-accO-nomS: WM	0.422	0.966	0.269	0.072	0.353

Table 3 | Linear regression model on AD individual's accuracy (object extracted sentences) and WM scores.

4 Discussion

The present study aimed to investigate whether factors such as canonicity, referentiality and case marking affect sentence comprehension in Greek-speaking individuals with mild-to-moderate AD.

Our results confirmed that sentence comprehension of Greek-speaking individuals with mild-to-moderate AD differs from the abilities of cognitively intact controls. Individuals with AD performed significantly worse than controls on all structures, including subject- and object-extracted ones. Our results also confirmed that structures involving movement and non-canonical argument order are differentially affected in individuals with AD. Subject-object asymmetries were observed in right-branching RCs but not in *wh*-questions or FRs. These findings are in line with previous findings on sentence comprehension in Greek-speaking individuals with AD (see Molympaki et al. 2013) and suggest that canonicity can only partially affect performance in AD. Moreover, participants with AD performed worse on object-extracted right-branching RCs compared to object-extracted FRs, object non-referential questions and object referential questions. They also performed lower on object FRs compared to object non-referential and object referential questions. These asymmetries could potentially indicate an interplay between length and canonicity in sentence comprehension. Right-branching RCs and FRs are longer than referential and non-referential *wh*-questions because they involve two as opposed to one verbs. It seems that longer object-extracted sentences, like object right-branching RCs and FRs, are harder to comprehend than shorter ones, like referential and non-referential *wh*-questions. This assumption though was only partially confirmed by our verbal WM tasks. As predicted, WM capacity correlated significantly with performance on object right-branching RCs. However, it also correlated with performance on object referential and non-referential questions, while no significant correlation was obtained between WM capacities and performance on object FRs. Additionally, with respect to referentiality, our results on the comprehension of *wh*-questions do not confirm Molympaki et al. (2013), as there were no differences between non-referential and referential questions. Referentiality, thus, seems not to affect performance in AD.

Last, our results indicate that morphological case does not facilitate object comprehension in AD. No differences were observed in right-branching RCs between the two object conditions which bear different case on the relativised head; performance on RB-object-accS-nomO was similar to performance on RB-object-nomS-nomO RCs, despite the fact that performance on the later strongly correlated with performance on WM. The lack of asymmetry between the two conditions indicates that difficulties in the comprehension of object right-branching RCs do not depend on the case of the relativised head, thus, case does not seem to provide cues to facilitate comprehension of object dependencies.

The role of case in facilitating comprehension of object dependencies has recently been discussed in post-stroke aphasia. Varlokosta et al. (2014) observed subject-object asymmetries in the comprehension of *wh*-questions and RCs in Greek-speaking individuals with agrammatic aphasia, despite the presence of morphological case on the *wh*-word in *wh*-questions and on the relativised head in RCs. They concluded that morphological case does not provide cues that resolve intervention effects in object dependencies in agrammatic aphasia. Similar conclusions were reached by Friedmann et al. (2017) and by Terzi and Nanousi (2018). Specifically, Friedmann et al. (2017) argued that case does not resolve intervention in object dependencies because only syntactically active features, i.e., features attracting movement, are relevant in the computation of intervention effects. Terzi and Nanousi (2018) claimed that although case does not facilitate the computation of intervention in object dependencies, it may be a feature that contributes to the recovery of grammatical functions because subject-extracted RCs with accusative case on the relativised subject appear to be harder to interpret.

The present research provides evidence that morphological case does not offer cues that can resolve intervention effects in object dependencies in AD, as well. However, the fact that no difference was observed between subject-extracted RCs in which the relativised DP was marked with accusative case and subject-extracted RCs in which the relativised DP was marked with nominative case indicates that case in AD does not contribute to the recovery of grammatical relations. Nonetheless, case affected the comprehension of subject and object FRs; FR-subject-nomS-accOwere significantly worse than FR-subject-accS-accO, and FR-object-nomO-nomS were significantly worse than FR-object-accO-nomS. Low performance on the FR-object-nomO-nomS condition may be due to the fact that nominative case on the object relative pronoun may render its grammatical function harder compared to accusative case on the FR-object-accO-nomS condition, which facilitates the recovery of the object grammatical function. Notably, performance on the FR-object-nomO-nomS condition correlated with performance on WM, even though this correlation did not reach significance. However, an explanation along these lines cannot account for the asymmetry observed between FR-subject-nomS-accO and FR-subject-accS-accO, since accusative case on the subject in the later condition should have rendered it harder than the former one, in which the subject is marked with nominative case. It is clear that the role of morphological case in the sentence comprehension of speakers with AD requires further investigation.

To conclude, in line with some previous studies, it was shown that individuals with AD have difficulties in comprehending syntactically complex constructions. The selective subject-object asymmetries observed in right-branching RCs suggest that canonicity is only one of several factors affecting sentence processing in AD. Further research is necessary to assess the effect of canonicity and length, as well as the role that case or other morphological cues, like gender or number, play in the sentence comprehension of individuals with AD.

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