The processing of lexical ambiguity: the effect of Mild Cognitive Impairment and Alzheimer's Disease in the monolingual lexicon

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Περίληψη

Στόχος της μελέτης είναι να εξετάσουμε την σχέση της γλώσσας και των επίκτητων γλωσσικών διαταραχών ως αποτέλεσμα νευροεκφυλιστικών νόσων όπως η νόσος Αλτσχάιμερ και συναφείς άνοιες. Συγκεκριμένα, διερευνήθηκε η σημασιολογική αμφισημία κατά την λεξική επεξεργασία σε ομιλητές της Ελληνικής με νόσο Αλτσχάιμερ, σε ομιλητές με ήπια νοητική διαταραχή και σε τυπικούς ομιλητές. Στην πειραματική μελέτη συμμετείχαν 60 άτομα και διαπιστώθηκε (α) η σημαντική επίδραση της άνοιας στη λειτουργία του νοητικού λεξικού από τα πρώτα στάδια της νόσου, και (β) η συσχέτιση των γλωσσικών δεδομένων με τα συμπεριφορικά δεδομένα γνωστικών δοκιμασιών της εργαζόμενης μνήμης και του γνωστικού μηχανισμού της αναστολής.

Λέξεις-κλειδιά: λεξική αμφισημία, γλωσσική επεξεργασία, ελληνικά, Ήπια Γνωστική Διαταραχή, νόσος Αλτσχάιμερ.

1 Introduction

Alzheimer's Disease (AD) is an irreversible neurodegenerative disease responsible for the majority of dementia cases and is characterized by a progressive decline of cognitive functions, with linguistic ability also affected. Earlier studies on the language breakdown in AD have noted that, as the disease progresses, any linguistic domain can be affected, for example phonological, lexical, syntactic or discursive features (Groves-Wright et al. 2004). In the first phase of AD, patients mainly lack lexical-semantic aspects of the language such as naming things or finding the right words; meanwhile in the moderate and severe phases of AD, communication starts to be non-fluent, which eventually ends up in the breakdown of comprehension (Tang-Wai and Graham 2008, Klimova and Kuca 2016). Research on patients with Mild Cognitive Impairement (MCI), often identified as a pre-AD phase, suggests that, besides the episodic memory deficits, language impairment may also occur; confrontation naming and semantic verbal fluency tasks might be able to differentiate patients with MCI from healthy individuals (Taler and Phillips 2008); however, findings have been controversial so far (see for discussion Lopez-Higes et al. 2014).

When examining semantic cognition, two main components are identified, storage and control. These systems are distinct and interactive (Jefferies 2013, Ralph et al. 2017), yet it is unclear how healthy aging and pathology may affect the organization and function of the mental lexicon. Semantic deficits in AD are often attributed either to the degradation of conceptual knowledge (Hogdes et al. 1992, Garrard et al. 2005, Lin et al. 2014) or the deregulation of control/access to this information (Bayles et al. 1991, Nebes and Halligan 1996). Such disruptions of the semantic networking are attested both in MCI and AD and have been largely attributed to breakdowns in inhibitory control (Taler, Klepousniotou, and Phillips 2008).

The current study aims at exloring the explanatory capacity of language processing evidence along the dementia continuum. To this aim, we examine lexical ambiguity resolution in Greek via the exploitation of homonyms. Homonyms are lexical items with the same phonological and orthographic sequence but with two or more semantically unrelated meanings – e.g. *bank* with meanings river side and financial institution (Lyons 1977). Homonymy is a useful tool for the examination of meaning activation and selection and, due to the fact that phonological and orthographic cues are constant and the frequency of each meaning measurable, it allows us to examine the integration of sentential context during ambiguity resolution. Earlier studies have identified sentential context, word frequency and word iconicity as some of the features that can affect lexical processing (Vu et al. 2000, Chen and Boland 2008); in particular, when the sentential context is neutral, the more frequent, dominant meaning of an ambiguous word is found to be activated more quickly than less frequent, subordinate meanings (Simpson and Krueger, 1991, Dopkins, Morris, and Rayner 1992, Lucas 1999, Sereno, Brewer, and O'Donnell 2003).

Processing data of healthy adults quite often show a subordinate bias effect; in contexts supporting subordinate meanings, reading times for ambiguous words are found to be longer, as compared to those for an unambiguous control word matched in frequency (Rayner, Cook, Juhasz, and Frazier 2006). For the subordinate bias effect, however, to be evident two conditions need to be met (a) the homonym must be strongly polarized and (b) the reading time for the homonym in the subordinate context is compared with that for an unambiguous word matched to the homograph's form frequency (Binder 2003, Rayneret al. 2006, Sereno, O'Donnell, and Rayner 2006).

According to selective access models only the contextually appropriate meaning is activated (Duffy, Kambe, and Rayner 2001); meanwhile the context-sensitive access accounts propose that the dominant meaning is not activated if the context is sufficiently constraining towards a subordinate meaning; possible constraints can be frequency, type of context and strength of context (Vu et al. 2003). On the other hand, exhaustive access models suggest that the initial stage of multiple-meaning activation occurs prior to the selection of the contextually appropriate meaning and the suppression of the non-selected representation; such a model is the dual mechanism account by Gernsbacher and St. John (2000), according to which there is a first mechanism, described as the bottom-up, frequency-weighted activation of all homonym meanings, and a second mechanism, defined as the top-down suppression of contextually irrelevant meanings.

Research on healthy aging effects in language processing show that suppression processes are less available as age progresses, since challenges associated with rapidly mapping an ambiguous word form onto its proper interpretation can be amplified by advancing age (Lee and Federmeier 2012). Specifically, when older adults encounter ambiguity in the presence of semantically biasing sentence context information, their responses pattern like those of younger adults. However, age-related differences are observed when semantic support is lacking; only older adults with higher scores on verbal fluency are able to maintain a young-like performance (Lee and Federmeier 2012). Additionally, working memory (WM) is a critical factor in lexical ambiguity resolution (Gunter, Wagner, and Friederici 2003); the larger the working-memory capacity of an individual, the more attention and activation that individual can allocate to sustain multiple meanings of a homograph over time with attentional control regulating the interaction between perceiving environmental cues and allocating relevant perceptual processing resources. AD data showed no difficulty in activating

context-appropriate meanings of ambiguous words but had particular difficulty in resolving interference from context-inappropriate meanings of ambiguous words (Balota and Faust 2001, Vuong, and Martin 2011).

Given the above research findings we explore (a) which linguistic features drive ambiguity resolution along with other language external factors such as dementia severity and cognitive skills (inhibition and verbal working memory), and (b) whether top-down contextual cues override the close relationship between the word form of an ambiguous lexical item and its dominant meaning. To do so, we systematically assessed sentence context effects in homonym meaning activation in 60 monolingual speakers of Greek by means of a cross-modal priming paradigm, developed by Kaltsa and Papadopoulou (2019) following the design of Andreou et al. (2009).

2 Methodology

2.1 Experimental Design

The cross-modal priming task (Kaltsa and Papadopoulou 2019) examines the access of multiple meanings of ambiguous lexical items even in biasing contexts. To minimize frequency-driven meaning selection and thus avoid any subordinate bias effect equibiased homonyms were employed. Three types of sentential context are examined, 1st meaning-biased, 2nd meaning-biased and not related to either meaning. The cross-modal priming experiment was a speeded lexical decision task with the prime being an audio stimulus of sentences biasing the 1st, 2nd or neither meaning of a sentence-final homonym and the visual target words related to either the 1st or the 2nd meaning of the homonym examined. Participants were asked to indicate whether the visual target was a word or not in Greek by pressing one of two pre-specified buttons on the keyboard. Table 1 exemplifies the test items for the homonym word *αγγείο* (pot, vessel) and control item *χαρτί* (paper):

Sentential Context	**Visual Target 1st meaning**	**Visual Target 2nd meaning**
1st meaning-biased Έβαλε λίγο νερό στο αγγείο/χαρτί. He poured some water into the pot/paper.	βάζο (vase)	αίμα (blood)
2nd meaning-biased Ο γιατρός τρύπησε το αγγείο/χαρτί. The doctor cut through the blood vessel/paper.		
Unrelated Ήθελε να δει το αγγείο/χαρτί. She/he wanted to see the pot/vessel / paper.		

Table 1 | Cross-Modal Priming Paradigm

30 homonyms were examined along with the same number of control items for all sentential contexts. Homonyms and control items were selected with the use of three pre-tasks testing for (a) competing meaning frequencies in ambiguous items (with a high frequency 1st meaning (M: 74.8%) and a low frequency 2nd meaning (M: 38.4%)), (b) visual targets with the same word length and frequency across conditions and (c) same level of familiarity for all test items (N: 50 monolingual Greek speakers per task) (see Kaltsa and Papadopoulou 2019 for detailed analysis). 360 experimental items and 360 fillers were developed and distributed in 6 sessions. The sentential length for all primes was 5-7 words (M: 5.6; SD: 0.6) and they did not differ

statistically among conditions tested. For the filler items, visual targets were either illegal non-words (e.g. *νκομός*) or pseudo-words that do not violate Greek phonotactic rules (e.g. *κρέζα*) so as to support the lexical decision component of the task.

2.2 Participants

60 adult monolingual speakers of Greek participated in the study equally distributed to three groups; healthy controls (HC hereafter), speakers with MCI (MCI hereafter) and speakers with mild AD (AD hereafter). HC matched in age (M= 73.5), sex (F= 11), years of education (M= 10.4) and type of profession to two groups of speakers with MCI and mild AD and were screened with the Montreal Cognitive Assessment tool (MoCA) (M= 27.95). Participants of the MCI and AD groups were recruited from the Greek Association of Alzheimer's Disease and Related Disorders (Alzheimer Hellas) and were neurophychologically assessed with the use of the following tasks: Mini Mental State Examination (MMSE –Greek version) (Folsteinet al. 1975, Fountoulakiset al. 2000), Rivermead Behavioral Memory Test (RBMT-story Direct and delayed recall) (Wilson et al. 1989), Rey Osterrieth Complex Figure Test (ROCFT-copy and delayed recall) (Osterrieth 1944), Rey Auditory Verbal Learning Test (RAVLT) (Rey 1958), Trail Making Test part-B (Tombaugh 2004), Verbal Fluency Test (FAS) (Kosmidis et al. 2004), Functional Rating Scale for Symptoms of Dementia (FRSSD) and Functional Cognitive Assessment Scale (FUCAS) (Kounti et al. 2006), Perceived Stress Scale (PSS) (Cohen et al. 1983) and Neuropsychiatric Inventory (NPI) (Cummings et al. 1994). All participants cognitive screening also included the Digit Span Backwards Recall of the Wechsler Adult Intelligence Scale (WAIS) as a measure of verbal working memory and the Nonverbal Stroop Card Sorting Test as an inhibitory control measure. Table 2 presents the cognitive screening scores per group:

	HC	**MCI**	**AD**
Verbal Working Memory Digit Span Backwards Recall of the Wechsler Adult Intelligence Scale (WAIS)	17.7 (SD= 5.6)	12 (SD= 3.4)	10.1 (SD= 2.7)
Inhibition Nonverbal Stroop Card Sorting Test	52.7 (SD= 7.9)	60.7 (SD= 18.4)	75.8 (SD= 15.6)

Table 2 | Cognitive Measures per Group

3 Results

From the cross-modal priming task we obtained accuracy scores on visual word recognition and online data that included reaction times (RTs) on each visual target. In this paper, we will present and discuss only the RTs so as to examine the processing functions across the three groups. To analyze the RTs we performed repeated measures analysis of variance (ANOVA) with Ambiguity (homonyms *vs*. controls), Meaning Frequency (1st meaning high frequency *vs*. 2nd meaning low frequency) and Context (1st meaning bias *vs*. 2nd meaning bias *vs*. unrelated) as the within subjects variables and Group (HC *vs*. MCI *vs*. AD) as the between subjects

variable; follow-up t-test comparisons were also conducted where necessary. Figures 1, 2 and 3 show the RTs in visual word recognition per condition for HC, MCI and AD groups respectively:

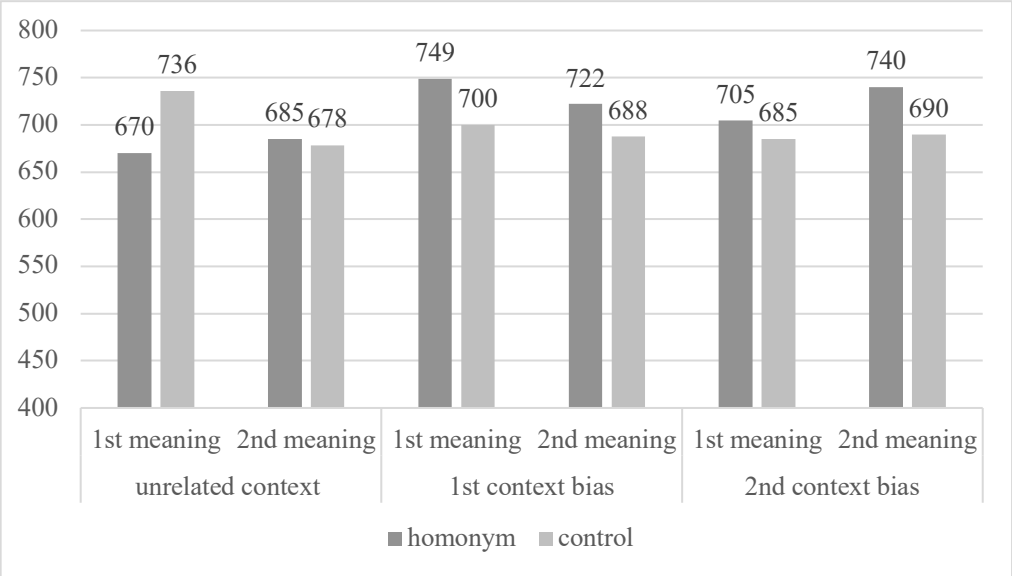

Figure 1 | HC group: Lexical Recognition RT data in msecs

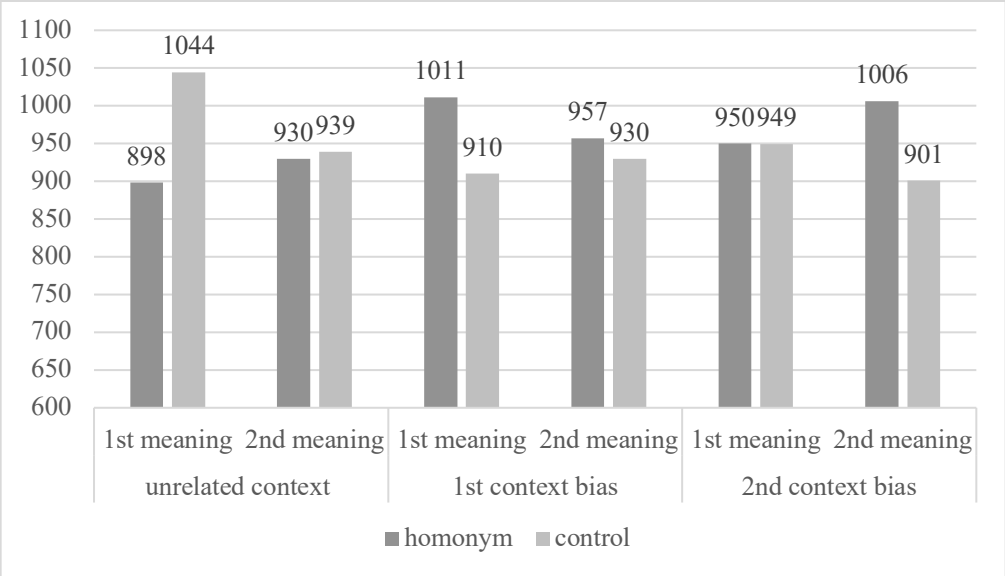

Figure 2 | MCI group: Lexical Recognition RT data in msecs

The analysis showed (a) a main effect of Group [$F_{1(2, 57)} = 15.143$, $p < .001$, $\eta^2_p = .347$; $F_{2(2, 81)} = 1.560$, $p < .001$, $\eta^2_p = .975$] with HC processing considerably faster than MCI and AD groups and MCI faster than AD group (all comparisons: $p < .001$),(b) a main effect of Ambiguity [$F_{2(1, 81)} = 51.134$, $p < .001$, $\eta^2_p = .387$] with RTs for control items significantly shorter (M=1044) than for homonyms (M=1099) and (c) an interaction among all factors, that is ambiguity, meaning frequency and sentential context [$F_{1(2, 114)} = 5.210$, $p = .007$, $\eta^2_p = .184$; $F_{2(2, 162)} = 45.524$, $p < .001$, $\eta^2_p = .360$]. Additional analysis revealed that within the HC data set sentential context effects were evident with shorter RTs for unrelated context (M=692) followed by 2nd

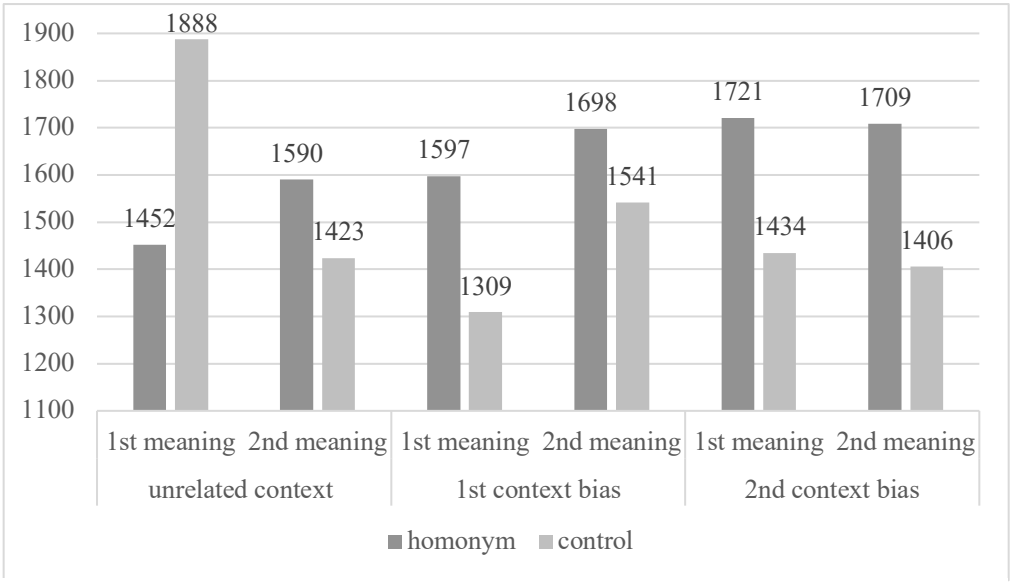

Figure 3 | AD group: Lexical Recognition RT data in msecs

context bias (M=705) and last by 1st context bias (M=715) (all comparisons: $p < .001$). Moreover, evidence for higher priming for the 1st than the 2nd meaning visual targets in unrelated context was found across all groups (see for HC Figure 1: 1st meaning target < 2nd meaning target; 670 < 685; see for MCI Figure 2: 1st meaning target < 2nd meaning target; 898 < 930; see for AD Figure 3: 1st meaning target < 2nd meaning target; 1452 < 1590; all comparisons: $p < .05$).

Prime	Visual Target	Sentential Context		Verbal Working Memory	Inhibition
Homonym	1st meaning	1st context bias	*r*	-.393	.544
			p	.002	< .001
		2nd context bias	*r*	-.426	.546
			p	.001	< .001
		unrelated	*r*	-.373	.512
			p	.003	< .001
	2nd meaning	1st context bias	*r*	-.371	.537
			p	.004	< .001
		2nd context bias	*r*	-.393	.535
			p	.002	< .001
		unrelated	*r*	-.395	.495
			p	.002	< .001
Control	1st meaning	1st context bias	*r*	-.303	.469
			p	.019	< .001
		2nd context bias	*r*	-.333	.512
			p	.009	< .001
		unrelated	*r*	-.338	.529
			p	.008	< .001
	2nd meaning	1st context bias	*r*	-.371	.543
			p	.004	< .001
		2nd context bias	*r*	-.342	.512

			p	.007	< .001
		unrelated	*r*	-.302	.529
			p	.019	< .001

Table 3 | Correlation analysis of RTs to cognitive screeing scores (N: 60)

Lastly, the correlation analysis of participants' RTs to the cognitive screening scores, verbal working memory (Digit Span Backwards Recall) and inhibition (Nonverbal Stroop Card Sorting Test)showed significant correlations suggesting that lexical processing across participants and across conditions is affected by their processing capacity resources(see Table 3). An additional between group comparison of the cognitive scores showed that regarding verbal working memory skills MCI and AD groups perform similarly and score significantly lower to HC group [$F_{(2,\ 38)}$ = 15.937, p< .001, η^2_p = .456;HC > MCI, p = .005; HC > AD, p< .001], whereas when testing inhibition HC and MCI groups perform similarly and significantly better to the AD group [$F_{(2,\ 38)}$ = 12.363, p< .001, η^2_p = .394;HC > AD, p< .001; MCI > AD, p = .018].

4 Discussion & Conclusive Remarks

The study set out to examine the integration of sentential context information during lexical ambiguity resolution in healthy speakers of Greek along with speakers that suffer with dementia; specifically, individuals with MCI and early stage AD. When analyzing the architecture and function of the mental lexicon in impaired and unimpaired individuals one needs to identify the disruptions of the semantic networking that relate to healthy aging and the ones to dementia. The data of the current study offer support in that direction since processing appears to vary significantly among groups: AD and MCI groups exhibited significantly longer processing times than the HC group, while the AD group showed very slow lexical recognition processes compared to the other two groups. This finding supports a deregulation in the control of information integration (for similar findings see Bayles et al. 1991, Nebes and Halligan 1996) in AD and MCI individuals, particularly especially evident in the AD group.

Lexical ambiguity resolution appears to be significantly affected by parameters such as contextual information, meaning frequency and word iconicity (Vu et al. 2000, Chen and Boland 2008) with more frequent, dominant meanings of homonyms found to be activated more quickly than less frequent, subordinate meanings in neutral contexts that do not require the integration of sentential biasing (Dopkins, Morris and Rayner 1992, Sereno, Brewer, and O'Donnell 2003). The data analysis showed that (a) ambiguity (homonyms *vs*. contol lexical items) affected lexical processing with longer RTs required for homonyms and (b) low meaning frequency had an inhibitory effect on all participants, HC, MCI and AD, with word recognition RTs to visual targets related to the 1st meaning significantly shorter to the visual targets related to the 2nd meaning when the sentential context was neutral.

Additionally, studies on healthy aging that examine the mapping processes of ambiguous word forms onto an appropriate interpretation have shown that parsing can be challenge has age advances; specifically, Lee and Federmeier (2012) observed age-related differences for healthy speakers when semantic support was lacking. Our findings show that sentential context had no facilitatory effect in lexical processing since neutral sentential contexts triggered faster responses than sentential contexts that

biased either towards the 1st or 2nd meaning. The ambiguity and frequency effects in our dataset suggest a bottom-up lexical processing that is highly constrained by word frequency in support of exhaustive access models (see Gernsbacher and St. John 2000).

Last we examined the interrelation between cognitive capacity and language processing and the analysis showed the expected positive relationship between the two. Similarly to earlier work (see Gunter, Wagner, and Friederici 2003) the larger the working memory capacity of an individual, the better control of perceptual processing resources. The correlation analysis showed that the breakdown of performance in the cognitive tasks is reflected in the deregulated access to language information and depends on the severity of the disease along the dementia continuum. Quite interestingly, though, depending on whether verbal working memory or inhibition was examined, the MCI group would perform similarly to the AD group or the HC group, respectively, suggesting that cognitive screening alone is not sufficient to profile an individual across the dementia continuum. Considering that a speeded language measure can successfully indicate the degree to which processing skills are intact we conclude that there is a high discriminatory value of language measurements that needs to be further highlighted in future research.

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