Using determiners as contextual cues in sentence comprehension: A comparison between younger and older adults

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Abstract

Younger adults use both semantic and phonological cues to quickly and efficiently localize the referent during sentence comprehension. While some behavioral studies suggest that older adults use contextual information even more strongly than younger adults, ERP studies have shown that this population, as a group, is less apt at using contextual semantic cues to predict upcoming words. The current study extends the investigation of contextual cue processing in auditory sentence comprehension beyond semantic cue processing, by comparing younger and older adults in their ability to use phonological cues in indefinite articles (a/an) to localize the referent in an eye-tracking visual world paradigm. Our results suggest that both age groups use such phonological information for referent localization, but with different timelines: younger adults use the cues to anticipate an upcoming word, whereas older adults show delayed cue processing after the target word has been spoken. Together with findings from semantic context processing, these results support a model of sentence comprehension in which the use of contextual cues continues with aging, but is no longer as efficient as in the young system for anticipatory word retrieval.

Keywords: aging; sentence comprehension; context; determiners; indefinite articles; eye-tracking.

Introduction

Do older adults process sentences differently from younger adults? The answer to this question is not only interesting from the viewpoint of understanding the language system, but also from the more general perspective of how aging changes the principles of cognitive processing. One such principle is the use of contextual information to facilitate processing of an upcoming stimulus. A large body of research suggests that individuals routinely use contextual information in both reading and listening; for example, upon hearing "The boy will eat the …" listeners quickly look at the edible object among all other objects on the screen (e.g., Altmann & Kamide, 1999). Similarly, upon reading "The day was breezy so the boy went outside to fly ..." participants anticipate the word "kite" and its appropriate determiner "a", showing not only anticipation of the lexical representation but also of its phonological form (Delong et al., 2005, 2012). Do older adults also use contextual information?

Some behavioral studies suggest that older adults use sentential context to process a target word as much as, or even more than, younger adults, especially when the target is presented amid visual or auditory noise (e.g., Madden, 1988; Pichora-Fuller, Schneider, & Daneman, 1995). However, more recent ERP studies have shown that older adults are less likely to use contextual information during sentence comprehension to anticipate the upcoming word (e.g., Federmeier, Kutas, & Schul, 2010; Federmeier, McLennan, Ochoa, & Kutas, 2002; Wlotko, Federmeier, & Kutas, 2012).

Most of these ERP studies have focused on N400, a negative potential that reflects implicit aspects of semantic access, and is larger in magnitude for words that contradict contextually-induced expectations (Kutas & Federmeier, 2000). For example, Federmeier, Van Petten, Schwartz, and Kutas (2003) found that N400 in response to conflict between a word and the sentential context was delayed by over 200 ms in older, compared to younger, adults. Subsequent work endorsed this finding, by showing that N400 reduction in response to strongly-constraining context was smaller and significantly delayed in older adults, especially those with lower reading spans (Federmeier & Kutas, 2005). Federmeier et al. (2010) further showed that the differences in using contextual cues was still visible between younger and older adults, even when the working memory load of the task was minimal, although older adults with higher verbal fluency scores showed ERP patterns that more closely resembled that of younger adults.

The ERP studies reviewed above suggest that older adults, as a group, are less likely to use contextual information to pre-activate potential target representations. To determine whether this age group showed any trace of context use for pre-activating linguistic information, DeLong, Groppe, Urbach, and Kutas, (2012) measured N400 responses to indefinite articles "a" and "an" for upcoming nouns whose cloze probability given the context was parametrically manipulated to be between 0 and 100% (e.g., "Dale was very sorry and knew he owed Mary *a check/an apology* for what he had done."). The main finding was that N400 in response to nouns showed graded sensitivity to nouns' cloze probability in both younger and older adults, but these N400 correlations had a later onset

and lasted longer in the older adults (see also Wlotko et al., 2012). Importantly, unlike younger adults, older adults did not show any effects on the articles, indicating that at that early point they had not yet anticipated the phonological form of the upcoming word. A second finding of the study was a prolonged increased frontal positivity to less likely nouns in young adults and a subset of older adults with high verbal fluency. Together, these findings led the authors to propose that older adults may in fact use contextual cues for pre-processing of the linguistic representations, even though the delayed timeline of this effect might lead one to conclude otherwise.

We test this possibility by comparing younger and older adults in a visual world eye-tracking paradigm. Participants viewed a scene of four objects, while listening to sentences such as "She will see a/an cherry/apple". On the Experimental trials, the indefinite articles "a" or "an" unambiguously cued the target, because the other three objects all had names that started with a phoneme that was incompatible with that article (e.g., for "an" the target would be "apple", and the three distractors would be "baby", "piano", and "duck"). On Control trials, participants heard similar sentences but with the definite article "the", which provides weaker cues to the target identity. If listeners use indefinite articles as cues, they should be able to fixate the target faster on the Experimental, compared to the Control, trials.

Importantly, "a" and "an" are semantically identical, and the disambiguating information they carry is phonological. Past research has suggested that younger adults use phonological cues to anticipate potential targets (e.g., Allopenna, Magnuson, & Tanenhaus, 1998; Zwitserlood & Schriefers, 1995). For example, upon hearing the onset /b/ listeners consider all the words that start with /b/ as possible referents (the *cohort effect*; Allopenna et al., 1998). Are phonological cues in the articles also used as cues? Interestingly, articles may not be fully processed in sentence comprehension. Readers often skip over articles in reading (O'Regan, 1979) and children older than age 4 show no disruption in sentence comprehension when an inappropriate article is used (Zangl & Fernald, 2007; McNamara, Carter, McIntosh, & Gerken, 1998). Thus articles, while potentially valuable phonological cues, may be skipped without causing much harm to comprehension. Thus, if older adults are less likely to process contextual cues, articles would be an excellent test bed.

The current experiment investigated whether indefinite articles are used as phonological cues to locate the referent during auditory sentence comprehension in younger and older adults, and whether the two groups process such cues differently.

Methods

Participants

Twelve younger adults (six females, mean age = 19.5, SE = 0.4 years), and twelve older adults (five females, mean age = 63.7, SE = 2.3 years) participated in the study in exchange for course credit or payment. All participants were native speakers of English. Older adults were tested on the Mini-Mental State Exam (Folstein, Folstein, & McHugh, 1975) and all scored within normal range.

Materials

Visual stimuli were presented as 300×300 pixel pictures of black and white line-drawings taken from either the IPNP corpus (Szekely et al., 2004), or from Snodgrass & Vanderwart (1980). Targets were 60 common nouns, half beginning with a vowel, and half with a consonant. There were no significant differences between the items in the two groups in frequency ($t(57) = 1.22$, $p = .23$; reported as frequency per million words, from SUBTLEX (Brysbaert & New, 2009)), number of syllables ($t(58) = -1.37$, $p = .18$), and number of phonemes ($t(58) = .27$, $p = .79$). Each item appeared once as the target in the Experimental condition ("an apple"), once as the target in the Control condition ("the apple"), and six more times as distractor in trials with other target nouns. One hundred and twenty sentences with the structure "She will see [article][target]." were recorded by a native English speaker at 44.1 kHz. All sentences were recorded naturally, without word splicing. This was necessary because the pronunciation of "the" could change depending on whether the following noun starts with a vowel or a consonant. Therefore, "a" and "an" should each have their own proper baseline of "the"; splicing would have removed this natural variability in "the" pronunciation and provided a biased baseline. In the recorded materials, there was no significant difference between the duration of the determiners and their paired "the" controls ($t(29) = .58$, $p = .56$ for "a" vs. "the"; $t(29) = 1.15$, $p = .23$ for "an" vs. "the").

Apparatus

Participants were seated approximately 25 inches away from a 17-inch monitor with the resolution set to 1024×768 dpi. Stimuli were presented using E-Prime Professional, Version 2.0 software (Psychology Software Tools, Inc., www.pstnet.com). A remote Eyelink 1000 eye-tracker recorded participants' monocular gaze position at 250 Hz.

Procedure

Participants were instructed to "listen and look at the pictures" (no response was required). Each trial began with a 1375 ms preview. In the first 1000 ms, the four line-

drawings were presented in the four corners, and in the last 375 ms a shrinking red dot appeared at the center to draw the gaze back to the central location. After the preview, the sentence was presented through speakers at a comfortable listening volume. The position of the four pictures was randomized on every trial. Participants first completed six practice trials, and then moved on to the experiment. Two blocks, each containing 60 intermixed "a", "an" and "the" trials were administered, with a break in between. No picture was repeated as the target within the same block.

Results

Figure 1 shows the proportion of fixation (±SE) on the target for the Experimental (a/an) and Control (the) conditions, separated by article type and age group. Statistical analyses were performed using the Growth Curve Analysis method (GCA; Mirman, 2014), a variant of multilevel regression (or hierarchical linear modeling) that uses orthogonal polynomials to capture the curvilinear pattern of fixation proportions over time. Effects of the variables of interest on the polynomial terms provide a way to quantify and evaluate those effects on statistically independent (i.e., orthogonal) aspects of the fixation proportions trajectory. Data were contrast coded and centered, and unless otherwise specified, the overall target fixation trajectory was modeled with a cubic polynomial. Dependent variables included Age (young vs. old), Condition (definite article "the" vs. indefinite articles "a"/"an") and ArtType (Article Type; type of the indefinite article: "a" vs. "an"). The interaction between these variables and polynomial terms were explored over the intercept, linear and quadratic terms, as higher order interactions are difficult to interpret (see Mirman et al., 2014 for a full discussion). The cubic term was, however, entered in both the fixed the random effect structures to obtain the best fit to the data.

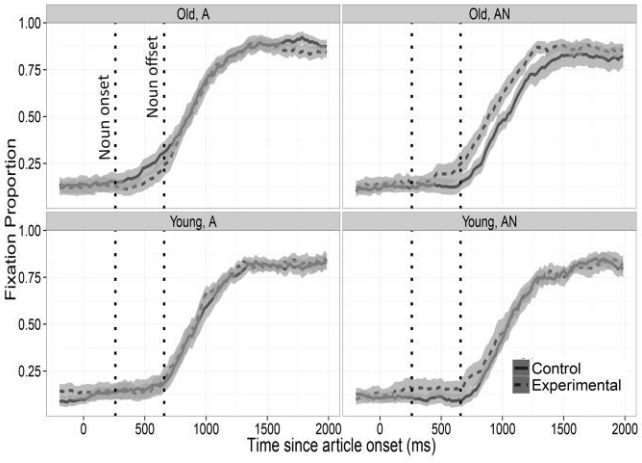

Figure 1: Proportion of fixations (±SE) to the target in Experimental (a/an) vs. control (the) conditions, separately for each article and each age group.

The first analysis addressed four questions: (a) Do phonological cues facilitate target localization? (b) Do both younger and older adults both use these cues? (c) Are there differences in using "a" and "an" cues? And (d) Do the two age groups both show these differences? Table 1 shows the full model results.

Table 1- Results of the GCA first analysis.

Fixed effect structure	Coefficient	SE	t	p-value
Intercept	0.403	0.025	16.012	<0.001
Linear	1.907	0.082	23.264	<0.001
Quadratic	0.405	0.059	6.872	<0.001
Cubic	-0.301	0.032	-9.341	<0.001
Intercept*Age	0.024	0.024	1.018	0.320
linear*Age	0.065	0.066	0.984	0.336
Quadratic*Age	-0.069	0.058	-1.187	0.248
Intercept*Condition	0.031	0.006	5.29	<0.001
Linear*Condition	0.073	0.025	2.878	0.005
Quadratic*Condition	-0.107	0.023	-4.69	<0.001
Intercept*ArtType	-0.013	0.006	-2.265	0.027
Linear*ArtType	-0.023	0.025	-0.909	0.367
Quadratic*ArtType	0.027	0.023	1.188	0.239
Intercept*Condition*Age	-0.002	0.006	-0.309	0.758
Linear*Condition*Age	<0.001	0.025	-0.019	0.985
Quadratic*Condition*Age	0.002	0.023	0.084	0.933
Intercept*Condition*ArtType	0.021	0.006	3.451	0.001
Linear*Condition*ArtType	-0.005	0.025	-0.212	0.832
Quadratic*Condition*ArtType	-0.05	0.023	-2.19	0.032
Intercept*ArtType*Age	-0.001	0.006	-0.091	0.928
Linear*ArtType*Age	-0.051	0.025	-2.024	0.047
Quadratic*ArtType*Age	-0.008	0.023	-0.332	0.740
Intercept*Condition* ArtType*Age	0.011	0.006	1.847	0.069
Linear*Condition*ArtType*Age	0.033	0.025	1.311	0.194
Quadratic*Condition*ArtType*Age	-0.024	0.023	-1.068	0.289
Random effect structure	**Variance**	**Correlation**		
Subject				
Intercept	0.012			
Linear	0.124	-0.17		
Quadratic	0.061	-0.7	0.4	
Cubic	0.013	-0.35	-0.67	0.2
Condition*ArtType|Subject				
Intercept	0.003			
Linear	0.063	0.38		
Quadratic	0.044	-0.43	0.01	
Cubic	0.030	-0.24	-0.47	0.26
Residual	0.002			

The effect of Condition was significant on the intercept, linear and quadratic terms, showing that the phonological cues provided by the indefinite articles reliably facilitated localization of the target compared to the less phonologically-informative "the". This effect was not reliably different between older and younger adults, as evidenced by non-significant Condition*Age interactions on all three polynomial terms, implying that both age groups used these cues. We then asked if facilitation was more pronounced for one type of the definite article over the other. The interaction between Condition and ArtType was significant over two of the three polynomial terms (intercept and quadratic), indicating that the article "an" was more facilitatory than the article "a", when each article was compared to its own baseline "the". Finally, we asked

whether younger and older adults differed in their processing of "a" vs. "an" articles. We found a marginal effect of the three-way interaction (Condition by ArtType by Age) on the intercept, hinting at a possible difference.

In summary, the results of this analysis provided strong evidence that both younger and older adults used phonological cues associated with the definite articles to more efficiently locate the visual target, but also suggested that there might be differences in how the two age groups used such cues. These differences were explored in the next set of analyses.

The second set of analyses focused on separate exploration of facilitation in "an" and "a". The model structure was similar to that of the first analysis, except that ArtType was removed since only subsets of data containing either "an" or "a" were analyzed by each model. Table 2 presents the results of the analysis on the "a" dataset. Neither the effect of Condition, nor its interaction with age, was significant on any of the polynomial terms.

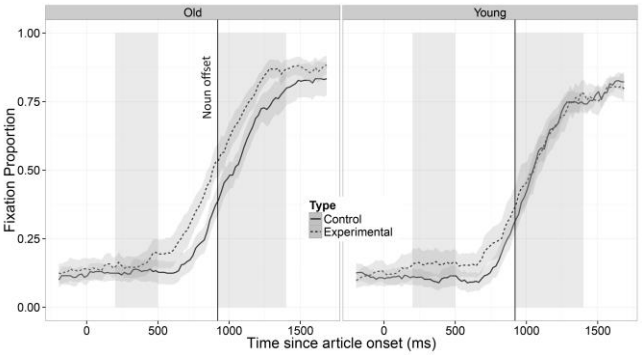

Figure 2: Proportion of fixations (±SE) on the target in Experimental (an) vs. control (the) conditions in each age group. Gray rectangles mark the two analysis time windows.

Table 3 shows the results of the analysis on the "an" subset. The effect of Condition was significant on the intercept and quadratic terms, showing that participants used "an" as a more reliable cue to locate the target compared to "the". Importantly, the interaction between Condition and age was also significant on the linear term. These results indicate that while, as a group, younger and older adults both use "an" as an informative cue for finding the referent, they do so differently. The next set of analyses further explored these differences by focusing on early and late time windows.

Early time window. This analysis focused on a narrow window of 300 ms, starting 200 ms after the presentation of the article (to allow for planning and execution of an eye movement), and ending 240 ms after the onset of the word. This window best captures early use of phonological cues for anticipatory target localization. We found a main effect of Condition on the intercept, such that "an" facilitated target fixation compared to "the" (coefficient = -0.022, SE = 0.009; t = -2.471; p = 0.022). Critically, we also found a reliable interaction between Condition and Age on the quadratic term (coefficient = -0.018; SE = 0.006; t = -3.260; p = 0.003). This interaction suggests that the anticipatory effect of phonological cue was reliably more pronounced in the younger, compared to the older, adults (See Fig. 2).

Late time window. This time window was chosen to reflect the opposite of an anticipatory process, namely to explore if phonological cues were still being used even when the target noun had been completely spoken and there was no longer any ambiguity about the referent. To this end, we chose a time window starting at the end of the noun (920 ms after the article onset) until the point where fixations plateaued (1400 ms after the article onset). This analysis revealed a marginal main effect of Condition on the intercept (coefficient = -0.033, SE = 0.016; t = -2.058; p = 0.052), as well as a significant interaction between Condition and Age on the quadratic term (coefficient = 0.028; SE = 0.011; t = 2.478; p = 0.018) and a marginal effect of this interaction on the intercept (coefficient = -0.028; SE = 0.016; t = -1.782; p = 0.089). Importantly, the direction of this interaction was the opposite of that found in the early time window analysis, showing that in this late time window, older adults continued to rely on the earlier phonological cues from the article to find the referent, considerably more than younger adults (see Fig. 2).

Table 2- Results of the GCA on the "a" subset.

Fixed effect structure	**Coefficient**	**SE**	**t**	**p-value**
Intercept	0.44	0.025	17.467	<0.001
Linear	2.026	0.076	26.493	<0.001
Quadratic	0.276	0.07	3.931	<0.001
Cubic	-0.376	0.035	-0.813	<0.001
Intercept*Age	0.025	0.025	1.021	0.319
Linear*Age	0.079	0.066	1.197	0.245
Quadratic*Age	-0.068	0.069	-0.983	0.337
Intercept*Condition	0.008	0.008	0.948	0.354
Linear*Condition	0.015	0.044	0.354	0.727
Quadratic*Condition	-0.022	0.028	-0.799	0.433
Intercept*Condition*Age	0.011	0.008	1.323	0.2
Linear*Condition*Age	-0.01	0.044	-0.222	0.826
Quadratic*Condition*Age	-0.032	0.028	-1.137	0.268
Random effect structure	**Variance**	**Correlation**		
Subject				
Intercept	0.012			
Linear	0.034	-0.97		
Quadratic	0.085	-0.7	0.7	
Cubic	0.005	-0.24	0.24	0.17
Condition|Subject				
Intercept	0.003			
Linear	0.175	0.4		
Quadratic	0.034	-0.55	-0.12	
Cubic	0.039	-0.32	-0.77	0.32
Residual	0.003			

In summary, the second set of analyses showed that (1) the effect of phonological cue was stronger in "an" than in "a", (2) both younger and older adults used "an" as a cue to localize the visual referent, and (3) the two age groups used

the cue with notably different timelines; early in younger and late in older adults.

Table 3- Results of the GCA on the "an" subset.

Fixed effect structure	Coefficient	SE	t	p-value
Intercept	0.367	0.026	14.299	<0.001
Linear	1.787	0.08	22.423	<0.001
Quadratic	0.534	0.056	9.613	<0.001
Cubic	-0.226	0.031	-7.26	<0.001
Intercept*Age	0.024	0.025	0.96	0.337
Linear*Age	0.072	0.075	0.957	0.338
Quadratic*Age	-0.066	0.053	-1.229	0.219
Intercept*Condition	-0.033	0.01	-3.299	0.001
Linear*Condition	-0.017	0.037	-0.45	0.653
Quadratic*Condition	0.076	0.036	2.095	0.036
Intercept*Condition*Age	-0.006	0.01	-0.608	0.543
Linear*Condition*Age	-0.079	0.037	-2.13	0.033
Quadratic*Condition*Age	0.01	0.036	0.278	0.781
Random effect structure	**Variance**	**Correlation**		
Subject				
Intercept	0.011			
Linear	0.097	-0.14		
Quadratic	0.034	-0.85	0.52	
Cubic	0.007	-0.21	-0.29	0.22
Condition|Subject				
Intercept	0.006			
Linear	0.071	0.62		
Quadratic	0.059	-0.31	0.05	
Cubic	0.024	-0.52	-0.5	0.34
Residual	0.002			

General Discussion

Our results suggest that articles were indeed used as informative contextual cues for localizing the referent during online sentence comprehension regardless of age. This finding suggests that while comprehension does not critically depend on articles, listeners do use these function words as cues. However, this benefit was limited to the less frequent article "an". Note that each article was compared to its corresponding control condition (e.g., "a cherry" is compared to "the cherry" and "an apple" to "the apple"), thus subtle differences in the pronunciation of "the" when followed by a consonant or a vowel were controlled for. The most likely reason for "an" being used as a more prominent cue than "a", is that the subset of words that "an" cues (i.e., words that start with a vowel) is much smaller than the subset of words that are cued by "a". Also in modern American English, the use of "a" along with a noun that starts with a vowel, though infelicitous, is not uncommon, especially in disfluent speech (e.g., "He's a um… artist!"), decreasing the validity of "a" as a unique cue.

Critical for our investigation was that older adults too showed evidence of employing these article cues for locating the referent. This finding complements the literature on contextual cue processing in older adults, which has almost entirely focused on the processing of semantic context. Note that studies that investigate ERP responses on the article (e.g., Delong et al., 2005, 2012), investigate retrieval of the phonological form in response to semantic cues in the sentence, e.g., retrieving the word "kite" or "airplane" (and subsequently the appropriate article a/an), given the context "The day was breezy so the boy went outside to fly ...". Thus these studies follow a different goal from the present study, which tested whether phonological cues associated with the articles themselves are used by listeners. Our results suggest that older adults do use such phonological cues, even on function words that past research suggests are not critical for sentence comprehension (e.g., McNamara et al., 1998; Zangl & Fernald, 2007).

However, our analyses of early and late time windows revealed intriguing differences in the timeline of cue processing between younger and older adults. While younger participants used phonological article cues in an anticipatory fashion, i.e., to locate the target *before* the target name was spoken, older adults showed no evidence of anticipatory cue use. On the other hand, older adults showed continued advantage for the target when it followed "an", compared to "the", in the late time window, *after* the noun had been spoken. In this late time window, younger adults showed no difference in fixating targets that were preceded by either article type, presumably because the noun information was enough for unequivocally localizing the referent in both conditions.

The delay in the processing of phonological article cues in older adults mirrors the reports of delayed N400 effect during semantic context processing (e.g., Delong et al., 2012; Federmeier et al., 2003; 2010; Wlotko & Federmeier, 2012; Wlotko et al., 2012). Moreover, older adults' continued processing of such cues in a late time window is compatible with Delong et al.'s (2012) report of prolonged N400 in this population (see also Wlotko et al., 2012). Our results add to these findings in three ways. First, the delay in processing contextual cues in older adults is not limited to semantic cues. This shows that the issue does not stem from specific dynamics within the lexical-semantic system, and is instead be better explained by models of general slowing in cognitive processing with aging (e.g., Myerson et al., 1990). Importantly, this slowing does not encompass automatic aspects of processing, such as activation of lexical representations through related representations (e.g., Federmeier et al., 2003; see Burk & Shafto, 2008, for a review), but seems to be specific to operations that require active processing and control.

The second way that the current results add to the findings of ERP studies is that it corroborates those findings using a measure that is sensitive enough to capture subtle differences in the timeline of cognitive processing, while still capturing overt behavior. We intentionally used articles which, according to past research, were dispensable to comprehension to show that even such subtle cues can be used in older adults and have measurable behavioral consequences. Finally, the sentences used in the current experiment entailed no anomaly or syntactic complexity, thus providing a straight-forward test of contextual cue use in sentence comprehension.

In summary, these results, together with those of past studies, support a model of sentence comprehension in which the use of semantic and phonological contextual cues to process upcoming words continues in old age, but the efficiency of using such cues for anticipatory word retrieval decreases considerably with aging.

Acknowledgments

The authors to thank Allison Britt and Kristen Graziano for their help with recordings and data collection. This research was funded in part by NIH grant R01DC010805 to DM and by the Moss Rehabilitation Research Institute.

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