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Thinking ahead or not? Natural aging and anticipation during reading

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ABSTRACT

Despite growing evidence of young adults neurally pre-activating word features during sentence comprehension, less clear is the degree to which this generalizes to older adults. Using ERPs, we tested for linguistic prediction in younger and older readers by means of indefinite articles (*a*'s and *an*'s) preceding more and less probable noun continuations. Although both groups exhibited cloze probability-graded noun N400s, only the young showed significant article effects, indicating probabilistic sensitivity to the phonology of anticipated upcoming nouns. Additionally, both age groups exhibited prolonged increased frontal positivities to less probable nouns, although in older adults this effect was prominent only in a subset with high verbal fluency (VF). This ERP positivity to contextual constraint violations offers additional support for prediction in the young. For high VF older adults, the positivity may indicate they, too, engage in some form of linguistic pre-processing when implicitly cued, as may have occurred via the articles.

1. Introduction

The anonymously-authored quote, "I still have a full deck; I just shuffle slower now," not only captures what some have described as the feeling of aging, but also reflects a commonly observed change in cognitive functioning during the later years of life; that is, while older adults have certain knowledge stores that appear to be relatively immune to age-related deterioration and while they are generally considered to comprehend well, there is often a decline in their ability to operate in a timely manner on such structures (e.g., Myerson, Hale, Poon, Wagstaff, & Smith, 1990; Salthouse, 1996). Language comprehension is one domain that reflects this "mixed bag" of preservation and decrement. Despite the age constancy of various comprehension-related processes (e.g., vocabulary size, Verhaeghen, 2003; contextual facilitation in sentence interpretation, Madden, 1988; organization of knowledge stores, Burke & Peters, 1986, etc.), older adults appear less likely than their younger counterparts to engage in pre-activating information (unconsciously anticipating upcoming input) during sentence processing (e.g., Federmeier, Kutas, & Schul, 2010; Federmeier, Mclennan, De Ochoa, & Kutas, 2002; Wlotko, Federmeier, & Kutas, 2008) as well as during more general cognitive processing (Bar, 2007) .

Historically, psycholinguists have found predictive language comprehension contentious. While incremental language processing has been well established, with sentential inputs processed as they are encountered without delay, distinguishing evidence for neural pre-activation from integration has proven challenging. Pre-activation entails unconsciously building representations for upcoming concepts, features or forms that may never be encountered in the input. In contrast, integration entails activating and processing representations as they are triggered by physical input. Primarily through on-line studies conducted over the past decade, evidence has accrued showing that young, healthy adults' receptive language – like other perceptual and cognitive brain functions – operates proactively (DeLong, Urbach, & Kutas, 2005; Federmeier, Wlotko, De Ochoa-Dewald, & Kutas, 2007; Kamide, Altmann, & Haywood, 2003; van Berkum, Brown, Zwitserlood, Kooijman, & Hagoort, 2005; Wicha, Moreno, & Kutas, 2004).

With evidence for routine context-based pre-activation of syntactic, semantic, and phonological features in younger adults, a natural question is what the consequences of normal aging are on the availability and use of anticipatory processes. At a performance-based level, there has been some debate in the literature regarding the top-down use of language context by older adults. In particular, some behavioral studies (e.g., Stine-Morrow, Miller, & Nevin, 1999; Wingfield, Alexander, & Cavigelli, 1994) have found that older adults – perhaps even more so than younger adults – take advantage of contextual constraint to facilitate lexical decision and

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word identification. Self-paced reading comprehension studies, too – which minimize possibilities of inducing strategic approaches related to overt task goals – have shown that with increased age, contextual knowledge facilitates discourse-embedded word processing (e.g., Stine-Morrow, Miller, Gagne & Hertzog, 2008) and reduces working memory load, leading to increased reading efficiency (Miller, Cohen, & Wingfield, 2006). On the other hand, ERP work (with its high temporal resolution and sensitivity to qualitative processing differences) has indicated that older adults are less able than younger adults to make use of highly constraining sentence context to rapidly facilitate semantic processing (e.g., Federmeier & Kutas, 2005). So when relatively age-preserved vocabulary and semantic knowledge interacts with processing speed and/or working memory or other more general processes – which are in decline from early adulthood onward (Craik, 1994; Park, Smith, Lautenschlager, Earles, Frieske, & Zwahr, 1996) – online context-building, integration and comprehension may not occur dynamically enough for upcoming input to be (effectively) pre-activated prior to its anticipated occurrence. In order to accommodate their decreasing processing abilities, older adults may rely more on external cues to support behaviors such as language comprehension (Craik, 1983) and thus may be biased toward top-down sentence comprehension only when task demands require it or when the input cues them to do so. Stine-Morrow et al. (2008) propose a self-regulated language processing model by which older readers, particularly those with high verbal ability, may allocate additional resources for semantic analysis during reading to offset some of their processing deficiencies. One such deficit that could potentially interact with language comprehension is older adults' decreased inhibitory control (e.g., Hasher & Zacks, 1988) – an issue relevant for linguistic prediction in light of what may be happening during the course of lexical access/activation. Still other less generalized accounts have proposed certain asymmetries in effects of aging on language processing, with production being more negatively impacted than comprehension (e.g., Burke & MacKay, 1997), and relatively stronger reliance by older individuals on semantic rather than phonological information (e.g., Cortese, Balota, Sergent-Marshall, & Buckner, 2003; Taylor & Burke, 2002).

There may be good reasons to expect such performance-based differences given age-related anatomical changes. For instance, aging has been proposed to compromise several brain regions that may constitute a network of association-based prediction: e.g., the medial temporal lobe, the medial parietal cortex, and the medial prefrontal cortex (Bar, 2007). Additionally, age-related volumetric or neurotransmitter changes to the prefrontal cortex (PFC), linked to changes in PFC activity during executive processing tasks, could result in decreased performance under conditions, for instance, of high working memory load, when there is interference, or when task-switching is involved – some or all of which may be involved in the comprehension of more or less predictable input strings (e.g., Gunning-Dixon & Raz, 2003; Head, Raz, Gunning-Dixon, Williamson, & Acker, 2002). Still other studies have found that there tends to be less lateralization (more bilateral activity) for a variety of cognitive tasks in older, relative to younger, adults (e.g., Cabeza, Anderson, Locantore, & McIntosh, 2002; Reuter-Lorenz et al., 2000). This is a relevant point because some proposals for context-based linguistic prediction have suggested that pre-activation is a left hemisphere-biased process (e.g., Federmeier & Kutas, 1999b).

Other theories argue that shifts in cognitive processing strategies from younger to older adults may arise not necessarily as a consequence of age-related anatomical changes per se, but rather may develop through the nonuse of certain cognitive functions – with the flip side being that certain skills or activities may serve to buffer against decline (e.g., Hultsch, Hertzog, Small, & Dixon, 1999). For instance, Salthouse (1991) suggests that declines in activity patterns of older adults may lead to atrophy of various cognitive skills (the "use it or lose it" hypothesis). The extent to which older adults rely on alternative strategies to cope with such declines (e.g., Logan, Sanders, Snyder, Morris, & Buckner, 2002) is a potentially important area of investigation for the study of prediction in language processing.

Relatively few studies have attempted to directly test the nature of predictive language processing in older adults using on-line methods. Electrophysiological studies by Federmeier and colleagues (e.g., Federmeier et al., 2002; Federmeier et al., 2010; Wlotko, Federmeier, & Kutas, 2008) have found that as a generalized comprehension strategy, individuals over 60 years of age are less likely to pre-activate upcoming semantic information in a similar manner or to the same extent as younger adults. Their conclusions have primarily been based on findings relating to two ERP effects: the N400 and a late frontal positivity.

The N400 is a well-established negative-going ERP component prominent over posterior scalp sites, peaking around 400 ms post-item onset. Its amplitude correlates with degree of semantic activation and the fit of any potentially meaningful item with its preceding or surrounding context (Kutas & Hillyard, 1980; for a review, see Kutas & Federmeier, 2011). Notably, for young comprehenders N400 amplitude has been shown to be inversely correlated ($r \sim -.9$) with the offline cloze probability of an eliciting item (e.g., DeLong et al., 2005; Kutas & Hillyard, 1984), although it appears to be insensitive to the degree to which less expected items violate contextual constraint (defining "context" here as a preceding word, phrase, sentence, or discourse; or an environmental surrounding, internal state, etc.). Federmeier et al. (2002) demonstrated that while young comprehenders showed reduced amplitude N400s to implausible spoken sentence continuations categorically related to expected continuations (relative to categorically unrelated implausible continuations), older adults on the whole did not show this pattern. For younger adults, this pattern reliably emerged in highly constraining sentence contexts (e.g., to *baseball* in '*He caught the pass and scored another touchdown. There was nothing he enjoyed more than a good game of… football/baseball/monopoly.*'), but not weakly constraining ones. Since the categorically related violations (*baseball*) were rated as implausible as the unrelated ones (*monopoly*), it followed that the facilitation for the related items was due to the overlapping features with the expected item (*football*) already having been pre-activated. Although this "predictive" ERP pattern was not observed across all older adults in the study, a subset of them with relatively high offline verbal fluency scores *did* show the reduced within-category violation young adult N400 response pattern. From these findings, it was hypothesized that although older adults are generally less likely (or able) to use context predictively, certain resource availability may be important for preservation of predictive language comprehension abilities with aging.

Another relatively less explored ERP response – a late frontal positivity sensitive to contextual constraint violations – has also been linked to predictive language processing. It has been suggested that this effect may reflect a processing consequence for not receiving an item highly pre-activated by its preceding context – i.e., "mispredicting". In studies of young adults described by Federmeier et al. (2007) and DeLong, Urbach, Groppe, and Kutas (2011), anterior positivities following (and concurrent with) the N400 were observed to constraint violations. For instance, Federmeier et al. (2007) crossed high and low sentence constraint with more and less expected sentence endings and found that young adults showed increased ERP frontal positivity between 500 and 900 ms post-target onset to unexpected words continuing high constraint contexts. However, when Wlotko et al. (2008) presented older adults with these same types of materials, older adults, as a group, did not elicit the constraint violation-related