Aging, context processing, and comprehension

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Abstract

Context processing in language comprehension is multifaceted and dynamic, influencing multiple stages of sensory, perceptual, and higher-order cognitive processing. A wealth of evidence supports the idea that context information is rapidly utilized to influence ongoing language processing. At the same time, our understanding of how normative aging influences context processing is a topic of considerable debate across multiple literatures. Here, we provide a detailed overview across three distinct literatures—psycholinguistics, audiology, and cognitive electrophysiology—that have examined overlapping questions surrounding how the aging process impacts the use of context information during language processing. Following, we provide an initial

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framework for integrating these oft-conflicting literatures and conclude with a call for interdisciplinary and multi-modal research to bridge the gap between these literatures and move toward a more complete and generalized understanding of the dynamics of context processing across the lifespan.

1. Introduction

Within less than a second after encountering a written or spoken word, the literate adult brain not only rapidly decodes and categorizes this (oft-ambiguous) sensory input, but also links that input with long-term semantic and episodic memories that comprise a part of our lifespan accumulation of knowledge. More impressively, the comprehension of multiple words in texts or utterances involves the continuous processing, updating, and mapping of these incoming sensory stimuli onto an incrementally accumulating context representation. This cascade of complex and highly interdependent processes also occurs seemingly automatically, giving rise to what we experience as the meaning of that sentence or utterance. The question of how context representations shape bottom-up processing is a topic that has been at the forefront of psycholinguistics, speech and communication research, and cognitive science more broadly for at least the past 65 years (e.g., Howes & Osgood, 1954; Miller, 1951; Taylor, 1953). Since this time, work across multiple parallel but somewhat distinct research disciplines (psycholinguistics, audiology, cognitive neuroscience, reading research, neuropsychology), each using different paradigms and measurement outcomes, have converged on the finding that sensory and perceptual processes, word recognition, and higher-level language processes are facilitated when input is congruent with, and predictable from, prior context.

Despite these highly reliable findings, there exists considerable disagreement across these literatures about how context processing develops across the adult lifespan. As we detail below, several literatures have grown over the decades that have systematically studied age-related changes in context use in language processing. Unfortunately, however, many of these literatures have carried on largely independently of one another, despite their highly overlapping conceptual interests. As such, these literatures have developed separate and often contrasting findings, theories, and open questions. The goal of this review, therefore, is to critically review each of these literatures alone and attempt to integrate across their disparate and sometimes conflicting findings. In what follows, we first present a thorough overview of literatures

examining age-related changes in aspects of context processing across three literatures: (1) *behavioral psycholinguistics*, (2) *cognitive audiology*, and (3) *cognitive electrophysiology*. Following this, we present an initial framework for understanding what (at the surface-level) appear to be conflicting and inconsistent results across these disciplines. We close with a call for answers to what we view as the most critical open questions that are necessary to bridge the gap across these literatures and delineate the common mechanisms underlying context use and its development across the adult lifespan.

2. Findings from behavioral psycholinguistics

There is a rich literature in behavioral psycholinguistics examining age-related changes in context use in language processing. In the following section, we focus on studies examining age differences in context use utilizing behavioral measures of real-time online language processing (e.g., reaction time, eye-fixation durations) and subsequent off-line representations (e.g., comprehension accuracy, memory). Our review will primarily focus on context use at the sentence level. Note that there is a substantial literature exploring aging and context constraints in discourse processing (see Stine-Morrow & Radvansky, 2017 for a recent review). Although a full overview of this literature is beyond the scope of the current review, some findings from the discourse processing literature will be discussed where applicable. To preview the outcome of the below review, behavioral psycholinguistic studies of aging and context use in language processing have yielded considerably conflicting results. As we review below, findings across multiple behavioral paradigms and measures and focusing on different aspects of context processing have produced evidence for nearly every possible outcome of age-related change. Therefore, we outline the review below into findings from behavioral studies showing evidence for age-related *preservation* of context processing (i.e., age-invariance in context effects), evidence for age-related *deficits* in aspects of context processing (i.e., *smaller* context effects in older adulthood), and evidence for *compensatory* utilization of context in aging (i.e., *larger* effects of context in older adulthood). We conclude our discussion with a summary of the small but growing literature examining age-related changes in the effects of context on eye-movement control during reading.

2.1 Preservation of context use in aging

Several studies have produced findings showing evidence for age equivalence in context use in word recognition, sentence processing, and text

understanding (Balota & Duchek, 1991; Burke & Harrold, 1988; Daneman, Hannon, & Burton, 2006; Hopkins, Kellas, & Paul, 1995; Light, Valencia-Laver, & Zavis, 1991; Price & Sanford, 2012; Roe et al., 2000; Valencia-Laver & Light, 2000). In early work addressing context use in younger and older adulthood, Light et al. (1991) presented three experiments testing for age-related differences in the use of contextual constraints to draw appropriate inferences from text. Younger and older participants read sentences and either made explicit judgments of context relevancy or completed a cued recall task. Light et al. (1991) found no evidence for age-related differences in the ability to draw context-appropriate inferences from text, despite global age-related deficits in overall memory performance. Similarly, Valencia-Laver and Light (2000) reported findings from four experiments showing age-related preservation in the ability to draw causal bridges and make context-appropriate predictive inferences off-line (see also Light, LaVoie, Valencia-Laver, Albertson Owens, & Mead, 1992). These findings strongly indicate that older adults can encode context information in memory and use this context to reason and make off-line judgments and appropriate decisions about text.

Other work concerns the degree to which context can impact real-time word recognition processes in aging. Stine-Morrow, Miller, and Nevin (1999) presented young and older participants with auditory target words embedded in sentence contexts of varying constraint. At the target word, participants performed a lexical decision task. Stine-Morrow et al. (1999) found that contextual constraint had similar facilitative effects on auditory lexical decisions for both older and younger adults, and moreover, that older adults were able to incorporate real-time accuracy feedback to a greater degree to facilitate performance compared to the young. Hopkins et al. (1995) presented similar evidence for age-equivalence in lexical ambiguity resolution in sentence comprehension when younger and older adults were matched for overall differences in processing speed. Similar findings of age-related preservation of context-based lexical ambiguity resolution have been observed in more simplified word-word contexts as well. Balota and Duchek (1991) presented evidence that healthy older adults showed preservation in the ability to select contextually appropriate meanings from lexical contexts (e.g., music-organ-*piano* versus kidney-organ-*piano*), whereas adults with Alzheimer's dementia showed a pattern suggesting non-context-selective meaning access. Related to ambiguity resolution, another question is whether older adults have greater difficulty in suppressing contextually irrelevant meanings of ambiguous words based on context constraints.

Newsome and Glucksberg (2002) examined this question directly in a study where young and older adults were presented with either metaphor-relevant or metaphor-irrelevant prime contexts. Importantly, both younger and older adults showed the same pattern of facilitation to metaphor-relevant primes and slowing to irrelevant primes, suggesting that older adults can appropriately filter competing irrelevant information (see also Stine & Wingfield, 1994).

Many studies utilize stimuli based on cloze procedures for quantifying contextual constraint and lexical expectancy (Taylor, 1953). In a typical cloze task, a large number of participants are administered sentence frames in which a particular word (typically the last word of the sentence) is left blank, and participants are tasked with completing the sentence with the most probable word given the context. Cloze probability is then defined for each sentence-target word pair as the probability (computed across many participants) of producing that particular word as the completion of that particular sentence frame. One potential limitation of this method is that many studies typically create cloze norms from a small sample of young adults. This raises the concern that observed differences between age groups could reflect qualitative cohort-related differences in the predictions that younger and older adults make rather than quantitative differences in being able to use context to make appropriate predictions per se. Similar concerns have been raised in studies of free association norms for lexical processing and studies of age-related changes in categorical structure or category priming (see, e.g., Federmeier, Kutas, & Schul, 2010). However, prior work suggests that young and older adults show a very high degree of similarity in responses for both free association (Burke & Peters, 1986), and categorical structure (Howard, 1980) tasks. These findings suggest that the structure and organization of long-term semantic memory are more similar than different across age and cohort groups in literate adults, at least for common and canonical associations and categories. Nevertheless, there may be systematic differences in the types of predictions that young and older adults make to similar contexts, leading to qualitative effects that may be judged as quantitative differences of context use more generally. Two studies have directly addressed this question. Lahar, Tun, and Wingfield (2004) administered a cloze task to a large sample of adults ranging from 17 to 91 years of age. Importantly, they showed a high degree of consistency across age groups in cloze norms. Similarly, Little, Prentice, and Wingfield (2004) report very similar judgments of semantic fit and plausibility among younger and older adults. These findings suggest a high degree of consistency in the structure of semantic memory and

the selection of semantic information from local sentence contexts in younger and older adults, further supporting the claim that the fundamental ability to use contexts to form offline and conscious predictions is qualitatively similar in older and younger adults.

More recent work from McKoon and Ratcliff (2018, Experiment 2) further support the claim that older adults encode contextually relevant meanings from discourse to support off-line language processing in a manner that is similar to young adults. In their work, participants read short discourses that were followed by true/false sentences that probed either a matching or mismatching meaning from the discourse. Speed-accuracy tradeoff analyses and results from the diffusion decision model (Ratcliff & McKoon, 2008), a model of two-choice speeded decision making were examined. They found evidence that older adults encoded contextually relevant meanings to a similar degree to young adults (and adults with lower literacy), despite overall differences in speed-accuracy tradeoff (i.e., older adults prioritized accuracy over speed; see also Starns & Ratcliff, 2010).

Overall, the above findings suggest that normal cognitive aging does not impair the ability to use accumulating contextual constraints to guide off-line comprehension and memory. One important caveat to the above-reported findings, however, should be discussed. Nearly all of the findings presenting evidence for age-invariance of context processing report null findings as evidence for a lack of age differences in context use. Importantly, because many of these studies were conducted on relatively small sample sizes (typical *Ns* in the range of 24 per age group), it is difficult to judge evidence for a lack of effects given the low power to detect modest effect sizes of between-subject differences at these typical sample sizes. One recent study from Cahana-Amitay et al. (2016) examined context processing in a larger sample of nearly 175 older adults. They used generalized linear mixed-effects models to examine the contribution of individual difference factors such as hearing acuity and cognitive control to sentence-final word recognition in constraining sentences (i.e., the SPIN task, see Section 3 for more detail). Importantly, although the effects of age alone were small (and likely constrained due to an age-range restricted sample), this study showed that over and above sensory deficits, age-related declines in inhibitory control predicted context use in sentence-final word recognition (see also Sommers & Danielson, 1999). Such larger-scale individual difference studies, paired with appropriate test statistics (e.g., Bayes Factor analysis, see Aczel, Palfi, & Szaszi, 2017), will be necessary for future work to draw conclusive findings regarding context use in aging, particularly if studies are aiming to show conclusive evidence for a lack of age-related differences.

2.2 Age-related deficits in context processing

Other work suggests evidence for selective age-related deficits in the ability to rapidly use accumulating contextual information to aid in comprehension, at least under certain circumstances (Dagerman, MacDonald, & Harm, 2006; Light & Capps, 1986; Morrow, Leirer, & Altieri, 1992; Noh & Stine-Morrow, 2009). For example, Light and Capps (1986) reported evidence for age-related differences in the use of context for resolving pronominal relationships (i.e., anaphor resolution). Young and older adults read short two-sentence passages, such as "*Henry spoke at a meeting while John drove to the beach. He brought along a surfboard.*" and were required to select the appropriate pronominal antecedent. When sentence pairs were presented back to back, young and older adults performed similarly. However, when an intervening "filler" sentence was inserted between the sentence pair, older adults were negatively impacted to a greater degree than the young. These findings suggest that the increased working memory load induced by the long-distance dependency had a selectively negative effect on older adults, presumably due to reduced working memory resources to maintain this contextual representation over the intervening material (see also Federmeier, Van Petten, Schwartz, & Kutas, 2003; Payne et al., 2014 for similar findings).

Similar findings were reported by Morrow et al. (1992), who examined the effects of aging and expertise on anaphor resolution in narrative comprehension when pilots (experts) and non-pilots (novices) read aviation narratives. They showed that older adults, regardless of expertise, had lower accuracy for more distal and minor characters. Noh and Stine-Morrow (2009) presented findings consistent with results above and also indicated that such age-related effects may not reflect declines in anaphoric processing per se, but rather with difficulty in encoding and tracking character representations when multiple discourse entities are introduced in close succession. They showed that older readers have particular difficulty both in accessing a previously presented character in a discourse after a new character is introduced and in thoroughly encoding a new character while other characters are present. Collectively, these findings suggest that working memory capacity limitations may negatively impact the ability to rapidly utilize context information in older adulthood (see Section 3.2 for a further discussion on how age-related differences in working memory may affect context use). Similar age-related costs have been reported in informationally dense sentences as well (Hartley, Stojack, Mushaney, Annon, & Let, 1994; Stine & Hindman, 1994).

McGinnis and Zelinski (2000, 2003) have reported age-related deficits in the ability to use contextual constraints for novel incidental word learning. Older adults were less able to derive the correct meanings of unknown words from context (McGinnis & Zelinski, 2000), and follow-up work (2003) using think-aloud protocols suggest that one source of this deficit may be related to older adults having over-generalized inferential processing. Under this idea, older adults do use context to generate predictions of likely upcoming input, but those representations have lower fidelity than those of the young. Findings such as these suggest that the question of context-use deficit in aging is likely to not be *binary,* but rather, aging may impact the time-course and representational nature of context representations, and how routinely such representations are constructed and activated in older adulthood. One study (Dagerman et al., 2006) presents behavioral data directly touching on such a conclusion.

In two cross-modal naming experiments, Dagerman et al. (2006) had younger and older adults listen to sentence contexts up to a penultimate ambiguous word that was subsequently disambiguated on the final word. The sentence-final word was presented visually, and the participants' task was to name the word as quickly as possible. The sentence-final word always disambiguated toward a verb meaning. In the ambiguous conditions, supportive contexts were either biased toward a verb-supportive (helpful) or noun-supportive (misleading) context, based on semantic constraint (e.g., verb supportive: *The union told the reporters that the corporation fires* **us**. Noun supportive: *The union told the reporters that the warehouse fires* **us**). In addition, syntactic constraints were added to create unambiguous contexts as well (e.g., verb-supporting: *The union told the reporters that the corporation could fire* ***us***. Noun supporting: *The union told the reporters that the warehouse could* fire **us**.).

Young adults showed consistent facilitative effects of prior context, such that when the target word disambiguated toward the appropriate context, they showed naming facilitation relative to when the word mismatched with the prior context. However, older adults showed no evidence for facilitation in on-line naming. Nevertheless, in an off-line compatibility judgment task, both younger and older adults judged targets to be compatible with the preceding noun-supporting context less often in the ambiguous condition than in the unambiguous condition, suggesting similar offline use of context among younger and older adults. Dagerman et al. (2006) interpreted their findings of reduced online context effects but equivalent offline effects in aging as reflecting an age-related reduction in the time-course of the availability of context representations. They supported this

claim via computational modeling, showing that manipulating a single propagation speed parameter in a simple localizationist model (see also McRae, Spivey-Knowlton, & Tanenhaus, 1998) could simulate the pattern of results observed in older adults. They concluded that the magnitude of age differences in context use was dependent upon a combination of the strength of the prior context, individual differences in the processing efficiency of the language system, and the amount of available time to process context. However, as we will discuss below in more detail, there is conflicting evidence from other methodologies (e.g., event-related brain potentials) regarding whether generalized slowing alone can account for online differences in context processing in aging.

2.3 Differential reliance on context in aging

In addition to the studies reviewed above showing both age-invariance and age-related deficits in context processing, there is also a considerable behavioral literature showing evidence that older adults differentially rely on context representations. Note that the preponderance of evidence consistent with these findings occurs primarily in audiology studies, under specific conditions of increased perceptual stress and/or among adults with hearing impairment (reviewed in more detail below). Similar evidence for age-related benefits from local context use (i.e., use of new and recently encountered information) have been found in cases under increased visual perceptual load as well, such as reading visually degraded text (Madden, 1988; Speranza, Daneman, & Schneider, 2000). Whereas this work has suggested companion effects under visual perceptual load, other studies suggest that older adults may be selectively impaired in higher-level conceptual processing under cases of increased visual noise (Gao, Levinthal, & Stine-Morrow, 2012). Similar robust behavioral evidence favoring age-related over-reliance on local context in sentence processing in the absence of increased perceptual load demand is less well supported by the literature. In this section, we review the few findings in the literature showing evidence for increased context use in cases without auditory or visual perceptual stressors.

Most evidence consistent with an age-related increased reliance on context (in the absence of perceptual load) comes from studies examining the use of discourse constraints and the construction of situation model representations from text and from studies examining the effects of prior knowledge and expertise on discourse processing. Stine-Morrow and colleagues

(Stine, 1990; Stine-Morrow, Loveless, & Soederberg, 1996; Stine-Morrow, Milinder, Pullara, & Herman, 2001; Stine-Morrow, Shake, Miles, & Noh, 2006; Stine-Morrow, Soederberg Miller, Gagne, & Hertzog, 2008) have consistently shown evidence that older adults differentially rely on discourse context in text processing. For example, Stine-Morrow et al. (1996) compared self-paced reading in younger and older adults as they read expository texts. Word reading times have been shown to speed up over successively constraining discourses, reflecting a serial-position effect that has been linked to facilitation from accumulating contextual constraints. They showed that this serial position effect was more pronounced in older adults (see also Stine-Morrow et al., 2008), and individual differences in the magnitude of the serial position effect predicted better text memory in older adults.

Miller and colleagues have examined whether older and younger readers vary in their use of prior contextual knowledge and domain-specific expertise in reading (Miller, 2009; Miller, Cohen, & Wingfield, 2006; Miller & Stine-Morrow, 1998; Miller, Stine-Morrow, Kirkorian, & Conroy, 2004). Miller et al. (2006) report an experiment in which younger, middle-aged, and older adults who varied in verbal working memory capacity read ambiguous texts either with or without a supportive title as a context manipulation (as a classic example, see, e.g., Bransford & Johnson, 1972). For example, participants read passages including sentences such as: "*It is important not to overdo any particular endeavor. That is, it is better to do too few things at once than too many*." Participants either read this passage in isolation or were shown a context title "*Washing Clothes*." Those who received passage titles prior to reading had access to a context representation allowing them to more easily understand the text and draw coherent links between sentences in the text. They found that the addition of the context title lead to faster and more efficient reading overall, but that these facilitative effects were greater among older adults compared to the young. Moreover, the addition of the context title attenuated the effects of individual differences in working memory capacity on reading time, suggesting that the contextual knowledge induced by the context title reduced demands on working memory capacity in discourse processing. Finally, Stine and Wingfield (1994) also showed evidence that local sentence context effects (cloze probability) differentially impacted word recognition performance for older adults in the absence of any perceptual load. Using a word-onset gating paradigm, they showed that although older adults required more word onset information overall for correct recognition compared to the young, their responses were more strongly related to the target word cloze probability than those in young adults.

2.4 Context processing and eye-movement control in reading

Very recently, the question of age-related changes in context use has re-arisen in a largely separate literature on how lexical predictability impacts eye movement control in reading (Choi, Lowder, Ferreira, Swaab, & Henderson, 2017; Kliegl, Grabner, Rolfs, & Engbert, 2004; Rayner, Reichle, Stroud, Williams, & Pollatsek, 2006; Steen-Baker et al., 2017; Stites, Federmeier, & Stine-Morrow, 2013). There are a number of important considerations to understanding this developing literature. As such, these studies are covered separately from our above review considering other behavioral methods.

The strongest predictors of eye movements in reading are the features of the individual words, primarily their length and written frequency. However, another strong predictor of eye movements in sentence reading is the predictability of the word given the prior context (often measured via cloze probability), such that fixation durations are faster for words that are more expected from the prior context (see Clifton et al., 2016; Rayner, 1999, 2009, for reviews). These effects of predictability are robust and highly replicable (see Staub, 2015 for a recent review) and have come to be incorporated into computational instantiations of several models of eye movement control in reading, most notably the EZ-Reader model (Reichle, Rayner, & Pollatsek, 2003; Reichle & Sheridan, 2015).

The first study to our knowledge to report a test of age differences in predictability effects on eye movements in reading came from work by Kliegl et al. (2004). Younger and older adults read a large number of sentences from the Potsdam sentence corpus, and analyses were conducted testing for age differences in global eye movement measures, as well as for effects of word frequency, word length, and predictability. Overall, age groups were more similar than they were different. Both younger and older adults showed evidence for increased facilitation with increasing predictability, effects that were stronger on second-pass measures (e.g., total reading time, regressions) than first-pass measures (e.g., first fixation duration), which the authors argued reflected the costs of encountering lower probability words, triggering increased regressions and re-inspection time. Aside from general age-related slowing, there were few age-related differences in the effects of context. One qualitative difference that did emerge, however, was that older adults showed a reduced probability of re-fixating on a word as it became more predictable from context, whereas young adults were more likely to skip a target word with increasing constraint. This finding may reflect age-related differences in the utilization of context to support parafoveal processing.

Indeed, this idea that contextual constraints may interact with the processing of words across the perceptual span during reading has been forwarded in several theories of reading among older adults. Most influential of these comes from Rayner et al. (2006), Rayner, Castelhano, and Yang (2009), and Rayner, Yang, Schuett, and Slattery (2013) who have argued that older adults adopt a series of strategies to compensate for age-related slowing of lexical processing, resulting in what has been termed a *risky reading* strategy. According to the risky reader theory, to maintain a fluent reading rate in the face of age-related declines in processing speed, older adults differentially rely on noisy and incomplete parafoveal visual information to "guess" the identity of upcoming words, leading to increased word skipping rates overall. However, because of age-related declines in parafoveal visual acuity (Payne & Stine-Morrow, 2012; Rayner et al., 2009), parafoveal words are often incorrectly identified, resulting in a greater rate of disruption to normal reading. Most importantly, for the current review, Rayner et al. (2006) argued that older readers differentially rely on contextual constraints in order to make these risky guesses about upcoming lexical items to overcome reductions in parafoveal acuity. Thus, this finding suggests that older adults should be more sensitive to manipulations of constraint during reading, particularly in the effects of cloze probability on skipping rates and in facilitation of processing when words are correctly predicted.

Although this theory has been widely cited in the reading literature (see recent review by McGowan & Reichle, 2017), direct evidence that older adults' eye movements are more sensitive to contextual constraint is lacking. In their original study, Rayner et al. (2006) present results from an eye tracking experiment in which younger and older readers' eye movements were recorded as they read sentences containing target words that varied in frequency or predictability. In addition to these experimental results, simulation results from the EZ-Reader model are presented that suggest that older adults' slowed lexical processing may lead to riskier reading behaviors. Although Rayner and colleagues claim that older adults show larger predictability effects than younger readers in fixation time data (supporting one key prediction from the risky reader theory), they did not find any direct evidence for statistically significant interactions between age and contextual constraint, suggesting that the effects of context were quite similar in younger and older adults (as in Kliegl et al., 2004).

Other recent tests of age differences in context use in reading have produced conflicting results. Using a gaze-contingent display change paradigm, Choi et al. (2017) examined the effects of preview lexicality (whether the target was presented as a word or not in parafoveal vision) and predictability

on eye movements in younger and older readers. All critical sentences were highly constraining (e.g., "*The doctor told Fred that his drinking would damage his …*") and the target word was either highly predictable (e.g., *liver*) or unpredictable but plausible (e.g., heart). Overall, in contrast with the arguments made by Rayner and colleagues, they found no age differences in skipping rates, saccade length, or the proportion of regressions (see also Wang et al., 2016; Zang et al., 2016 for similar evidence in Chinese). However, Choi and colleagues did find evidence that predictability effects were larger for two fixation measures, gaze duration and regression path duration. The authors interpreted this finding as consistent with the idea that older adults rely more heavily on sentence context, consistent with one dimension of the risky reading theory. Thus, the results from Choi et al. (2017) are almost a mirror inverse of those from Rayner et al. (2006) and Kliegl et al. (2004). However, a number of differences across the studies are worth mentioning. In both Kliegl et al. (2004) and Rayner et al. (2006), neutral contexts were used, whereas in Choi et al. unexpected target words in constraining contexts would lead to potentially more salient prediction violations. In addition, task goals may have differed across studies as Choi et al. (2017) presented comprehension questions frequently after each sentence, whereas prior studies typically only rarely cued off-line comprehension. Indeed, changing the type and frequency of comprehension questions has been shown to impact on-line language processing in prior work (e.g., Payne, Stites, & Federmeier, 2019; Swets, Desmet, Clifton, & Ferreira, 2008). Finally, Choi and colleagues included a parafoveal non-word mask in a boundary change paradigm, whereas the other prior studies examined natural reading without changes to parafoveal targets.

Two other studies have examined age differences in eye movements, with a focus on special populations. Whitford and Titone (2017) examined the effects of predictability in first- and second-language paragraph reading in bilingual adults. Younger and older French-English bilingual adults read four paragraphs, in which each word was coded for length, frequency, and predictability (similar to other corpus approaches, e.g., Kliegl et al., 2004). Critically for the current discussion, effects of word predictability were similar in both languages. L2 proficiency moderated context use in younger, but not older adults. Importantly, the effects of context were highly similar between younger and older adults on nearly every eye movement measure, the only exception being a small interaction between age and context on total-reading time, which the authors argue were driven by older adults showing inflated fixation durations on a subset of words with very low predictability.

Finally, Steen-Baker et al. (2017) examined the effects of lexical expectancy and constraint on eye-movements in a large community-based sample ($n = 80$) of younger to mid-life adults (16–64 years old) who varied substantially in literacy skill (e.g., reading grade level via the Slosson Oral Reading Test ranged from 2.5 to 12.5). They found evidence that age was positively associated with stronger facilitative effects of cloze probability on regression path durations (a late-pass fixation measure), independent of literacy ability. In particular, age effects were largest for the higher-cloze words, but effects were similar in magnitude for unexpected but plausible words. These findings suggest that older middle-aged adults were differentially utilizing context to facilitate words when they were consistent with expectations, rather than reflecting age-related costs to unexpected words (see Choi et al., 2017; Whitford & Titone, 2017). These findings reflect the only study of a mid-life non-convenience sample of community-dwelling adults. This mid-life sample may be particularly interesting to study, as this is a time in life where knowledge and experience are well-developed, but declines in working memory and attentional control may not be as well established. It may be in this mid-life period where adults have the best balance of experience and capacity to be successful in consistently relying on high-level contextual constraints to guide word processing. Indeed, other work has shown evidence consistent with the claim that working memory capacity and language experience effects dissociate in the utilization of syntactic contexts across the lifespan from young to middle to older adulthood (Payne et al., 2014). More work is needed studying context use across a full developmental spectrum to confirm the developmental trajectories of context processing.

2.5 Interim summary

As reviewed above, it is clear that the behavioral psycholinguistics literature has yielded highly conflicting results on the question of whether there are systematic differences in context use in aging. Nevertheless, some consistent patterns were observed. Overall, findings across multiple methods and paradigms reveal a pattern whereby older adults seem more similar than different than the young, both in some of the most immediate measures of processing (e.g., durations of eye fixations during reading) as well as in off-line measures of language performance, where temporal pressures are reduced (e.g., using context to draw appropriate inferences). Interestingly, selective age-related deficits in context processing seemed to emerge when local context-related demands resulted in increased working memory

demands (e.g., tracking multiple novel discourse entities or resolving anaphoric relationships over long distances), but, in general, the ability to maintain high-level discourse-relevant context (i.e., a situation model) appeared largely intact in older adults. Whether and how the above reported cross-paradigm differences result in changes in task demands, comprehension goals, or motivation and effort allocation that may account for some of the considerable variability in this literature requires further systematic experimentation. For example, studies directly comparing on-line effects of context on fixation durations during reading in younger and older adults when reading passively versus reading to make explicit predictive inferences may highlight age differences in effortful and strategic (goal-oriented) processing versus the propensity to habitually use context in the absence of explicit tasks.

3. Findings from cognitive audiology

Of the three literatures reviewed in this chapter, the cognitive audiology literature is perhaps the oldest and most substantial. In this section, we will selectively review many of the critical findings in cognitive audiology concerning age differences in the use of context in auditory word recognition and speech comprehension. Importantly, however, a comprehensive review of this entire literature is beyond the scope of the current review. As will be shown below, the field of cognitive audiology has a massive and rapidly growing body of evidence consistently showing that context is used regularly to support auditory word recognition and speech comprehension, and that older listeners may benefit more from context under conditions of increased listening effort. Indeed, an audiologist or speech pathologist reading this chapter may be surprised that other fields are still debating the degree to which older adults rely on context in language comprehension. Below, we will see that the most recent research in this domain has begun to assume that both young and older listeners beneficially use context, and current questions are concerned with the mechanisms underlying differences in context use in across age groups.

3.1 Context use in auditory word recognition

The benefits of context for speech perception, specifically auditory word recognition, have been known for nearly 70 years (Black, 1952; Pollack & Pickett, 1963). Several studies have highlighted that perceptual stressors and auditory factors play a substantial role in accounting for age

differences in context effects on word perception (Humes, 1996; Humes et al., 1994; for a review on how age-related perceptual deterioration may impact cognitive research see Schneider & Pichora-Fuller, 2000). Moreover, the prevalence of hearing loss increases with age, beginning in the fourth decade (Nash et al., 2011), with the incidence of presbycusis in older adults only being exceeded by arthritis and hypertension (e.g., Binnie, 1994; Haber, 1994). Therefore, one could argue that the reliance upon context seen in older listeners may serve a compensatory function. Older adults may differentially rely on top-down cues from context in cases where degradation of the bottom-up signal is substantial, due either to exogenous degradation of the perceptual input (e.g., increased background noise, or energetic masking) or due to endogenous declines in perceptual decoding that come with normal age-related hearing loss (i.e., informational masking) (see Pollack, 1975).

Indeed, one of the most widely used speech audiology tests, both clinically and in basic research, is the Speech Perception in Noise test (Revised) (SPIN-R; Bilger, Nuetzel, Rabinowitz, & Rzeczkowski, 1984; Kalikow, Stevens, & Elliott, 1977). The SPIN-R task is frequently used to assess age differences in the use of context under various conditions of perceptual effort. The SPIN-R tasks patients or participants with identifying the final word in a sentence. These sentences are divided into different lists that are either presented in quiet or in background masking noise (e.g., multi-talker babble). Half of the sentences have highly constraining contexts such as "*Put the soup in your* bowl" and half are low in their contextual constraint, such as "*Susan often thought about* spring."). In a classic and widely-cited study, Pichora-Fuller, Schneider, and Daneman (1995) used the SPIN-R test to assess differences in word identification by younger adults with normal hearing, older adults with normal hearing, and older adults with presbycusis. As one would expect, they found that all groups did better as the signal-to-noise ratio increased (i.e., background noise decreased) and that all groups received a benefit from context, in that their word recognition performance was better in the highly constraining context. However, the context benefit was greater for older adults than younger adults and was the greatest for older adults with hearing impairment.

Another method for manipulating speech intelligibility and listening effort is the use of noise-vocoded speech. Noise-vocoded speech is produced by breaking the speech signal up into a number of frequency bands, modulating the noise within each of those bands, and then recombining those bands together (see Shannon, Zeng, Kamath, Wygonski, & Ekelid, 1995).

The more bands used in the vocoding, the more intelligible the speech, with 1 band being completely unintelligible and 16 or more bands usually being very intelligible (Faulkner, Rosen, & Wilkinson, 2001; Friesen, Shannon, Baskent, & Wang, 2001; Loizou, Dorman, & Tu, 1999; Ward, Rogers, Van Engen, & Peelle, 2016). Noise-vocoded speech preserves much of the temporal information but minimizes the contribution of fine structure cues and simulates the experience of hearing speech with a cochlear implant. Sheldon, Pichora-Fuller, and Schneider (2008) ran two experiments in younger and older listeners using the SPIN-R paradigm with a noise-vocoded speech signal (16, 8, 4, or 2 bands) rather than the typically used speech-to-noise ratio manipulation. In Experiment 1, both the sentences and the target words were presented with the noise-vocoded signal, with one-quarter of the stimuli being presented in each level of noise. In Experiment 2, the participants were first primed by hearing the sentence in quiet with a blast of white noise being presented where the target word would normally be. After the prime, the participants would hear the sentence again but in noise with the target word being presented at the same level of noise. They found that both older and younger listeners received a benefit from the priming, with older adults gaining more of a benefit. They also found that the number of bands needed to correctly identify 50% of the target words was lower in high-constraint than low-constraint sentences, an effect that was larger for older adults than for the young. In other words, Sheldon et al. (2008) replicated the findings from Pichora-Fuller et al. (1995) in showing that older adults received more of a benefit from context than younger adults. This pattern of results using the SPIN-R paradigm and showing that older adults gain more benefit from context has been replicated numerous times (Brown, 2000; Dubno, Ahlstrom, & Horwitz, 2000; Gordon-Salant & Fitzgibbons, 1997; Goy, Pichora-Fuller, Lieshout, Singh, & Schneider, 2007; Humes et al., 1994; Hutchinson, 1989; Murphy, Craik, Li, & Schneider, 2000; Pichora-Fuller, Schneider, MacDonald, Pass, & Brown, 2007; Schneider, Daneman, & Murphy, 2005; Sommers & Danielson, 1999; see also Benichov, Cox, Tun, & Wingfield, 2012 and Nittrouer & Boothroyd, 1990 for paradigms similar to the SPIN-R showing similar results).

Although the most common manipulations of perceptual effort in cognitive audiology involve masking the speech signal by manipulating the SNR of speech relative to background noise or (more recently) distorting the auditory signal via noise vocoding, other manipulations of perceptual effort have also revealed similar effects of context use on word processing. For example, one way to increase perceptual demands in word recognition

experiments is to experimentally manipulate the rate at which the stimuli are presented through time compression of speech. One way this compression is done is by dividing the speech signal up into equally small intervals and removing a fixed interval (e.g., every third interval). It is argued that this method of time compression increases the demands on speech processing without degrading the signal (Foulke & Sticht, 1969; Wingfield, 1996; Wingfield, Poon, Lombardi, & Lowe, 1985; see also, Gordon-Salant & Fitzgibbons, 1999; Fitzgibbons & Gordon-Salant, 2001; Schneider et al., 2005). Therefore, an experimenter could use this technique to increase the perceptual effort required without confounding task difficulty with age-related hearing impairments that might occur if the experimenter varies the level of background noise.

Wingfield et al. (1985) used this speech speeding technique to present older and younger listeners with three different types of sentences in clear speech while varying the speed at which the sentences were presented. The first type of "sentences" were ones that were simply random strings of words that bore no sentential meaning. The second type of sentences were semantically anomalous but maintained syntactic structure (e.g., "Friskey water drank clear dogs"). The final type were normal, meaningful sentences. Participants were tasked with recalling the sentences to the best of their ability. Wingfield et al. (1985) found that both age groups performed worse in recalling random strings, with performance decreasing as the speed of the speech increased. Moreover, older adults were more negatively affected by the increase in speed for random word strings. In contrast, in sentences with preserved syntactic and semantic context, younger adults performed at almost perfect accuracy at all speeds. Older listeners also had increased accuracy for the syntactically intact but meaningless sentences but their accuracy decreased slightly with increases in the speed of speech. For normal, meaningful sentences and at the slowest speech rate, the older listeners had almost identical recall accuracy as the younger listeners. Most critically, the increase in recall accuracy from the random strings to the normal sentences was much greater for the older adults than the young. These results suggest that both young and older listeners do not perform as well in word recognition when perceptual effort increases due to increased demands on speech processing speeds, but that both groups can successfully use context to compensate for increases in perceptual effort, a benefit that was larger for the old (see Wingfield, 1996 for additional discussion on the results of this study).

Another paradigm commonly used in cognitive audiology to investigate the use of context in speech perception is the word-onset gating paradigm

(Cotton & Grosjean, 1984; Grosjean, 1980, 1985). In a typical word-onset gating task, participants are asked to identify a word with only the first 50 ms of the word initially presented to them. The word is then repeatedly presented, with incrementally more onset time introduced with each iteration, until the word can be correctly identified. A participant typically needs as little as about 200 ms to correctly identify a word in context, with listeners needing about 130 ms more time on average to identify words without context (Grosjean, 1980; Wingfield, 1996). When heard without any supportive context, older adults typically need more of the word presented before identification (Craig, 1992; Elliott, Hammer, & Evan, 1987). Lash, Rogers, Zoller, and Wingfield (2013) recently replicated this finding, showing that younger normally-hearing adults needed less of the word presented to them compared to older adults, in neutral contexts. Further, they additionally found that older adults with poorer hearing required significantly more of the word presented compared to older adults with good hearing. Importantly, however, they found that, as incrementally more sentential context was provided, the gap in performance between these groups slowly closed such that, in the condition with the highest contextual constraint the three groups performed equivalently. These results are similar to previous findings showing a considerable contextual benefit for older adults in the word-onset gating paradigm (Craig, Kim, Rhyner, & Chirillo, 1993; Perry & Wingfield, 1994; Stine & Wingfield, 1994; Wingfield, Aberdeen, & Stine, 1991).

3.2 Effects of context use on speech comprehension and memory

Most audiological research in the use of context in speech perception has focused on the immediate effects on word recognition. However, language understanding extends far beyond recognition of a single target word. The listener needs to integrate the recognized word into the broader context of the discourse or sentence in which it is heard and encode the general and specific details of what was said into a persisting memory representation. Thus, age differences may extend well beyond word perception. Therefore, in this section, we review several of the studies examining context effects on subsequent speech comprehension and speech recall in younger and older adults.

In a classic study, Rabbitt (1968) studied the effects of increased perceptual effort during listening on the recollection of word lists. Young adults with normal hearing were presented with audio of lists of eight digits. These lists were split in two and the first half was either heard in noise or in quiet and the second half was heard in either noise or quiet. Importantly, participants were able to shadow the lists accurately, indicating they were correctly

hearing the lists even if they were presented in noise. Rabbitt (1968) found that if the second half of the list was heard in noise, the participants did a poorer job at recalling the first half of the list, *regardless* of whether the first half was heard in noise or not, as compared to when they heard the second half of the list without noise. Rabbitt (1991) extended these findings to show that older adults with hearing impairments performed poorer than older adults with normal hearing on this same task (see also Murphy et al., 2000). The results from these two findings led Rabbitt (1968, 1991) to argue that the increases in perceptual effort that result from either a hearing impairment or listening to speech in noise pull resources away from memory encoding.

In an effort to test the validity of this effortfulness hypothesis, McCoy et al. (2005) reported results from a running memory span task in which a group of older adults with normal hearing and a group of older adults with poor hearing heard a continuous list of words and were periodically interrupted and asked to repeat back the last three words that they heard. Thus, this task required participants to maintain and continuously update words in working memory. Importantly, both groups were at or near ceiling in their recollection of the most recent word, indicating that both groups were correctly perceiving each word in the list. However, they found that the older adults with normal hearing performed significantly better than those with hearing impairment at correctly identifying the first two words that they were required to name. McCoy et al. (2005) concluded that this gives support for the hypothesis that older adults with poorer hearing are putting more effort into the actual perception of the words. This additional perceptual effort pulls resources away from other higher-level cognitive processes, such as encoding and maintaining these lexical items in working memory. Thus, the older adults with poorer hearing were accurately perceiving the words but not encoding them into memory as efficiently (see also Pichora-Fuller et al., 1995; Tun & Wingfield, 1999). More central to the current discussion, McCoy et al. (2005) also manipulated the contextual constraint of each word list. The degree of the contextual constraint of each list was constructed by manipulating local co-occurrence probabilities between adjacent words in each list (for details on how these type of word lists are constructed see Miller & Selfridge, 1950). McCoy et al. (2005) found that the addition of contextual constraint in the word lists eliminated any between-group differences in effortfulness effects on memory. In other words, regardless of hearing acuity, older adults, performed at or near ceiling in the recall task when context was provided.

Wingfield, Alexander, and Cavigelli (1994) incrementally increased the amount of context available for the identification of a target word for both young and older listeners. Participants were initially presented with the entire target word in isolation and asked to identify the word. Each time the word was incorrectly identified, one additional word was added either before or after the target word depending on the condition. For example, if the participant was listening to a target word that was in the *preceding context* condition they would first hear "WARM" and then "him WARM" and then "keep him WARM" and so on until they were able to correctly identify the word. In the *following context* condition, they would hear "WARM" and then "WARM and" and then "WARM and dry" and so forth. Elderly listeners performed worse than young listeners when the words were presented in isolation. As more words were added preceding the target word, identification increased for both age groups as a function of the number of words. This increase was similar between the groups. However, when the target word was followed, rather than preceded, by incrementally more context words, identification rates increased for both groups, but the effect was much smaller for the older listeners. Wingfield et al. (1994) argued that a "memory trace" of the ambiguous target word must be kept in working memory to utilize the following context and that older adults were less effective at this maintenance. This suggests that the differences seen were not just due to perceptual decline, but also due to age-related differences in working memory (for additional discussion of these findings see Wingfield, 1996).

The above studies suggest that increasing perceptual effort by degrading the speech signal, or by increasing demands on working memory may drive the differential use of context in speech comprehension seen in older adults. To assess the interaction between these two sources of increases in listening effort, Gordon-Salant and Fitzgibbons (1997) conducted a study in which they experimentally manipulated demands on memory while presenting speech in background noise to older and young listeners with and without impaired hearing. The SPIN-R high constraint and low constraint stimuli were used and all sentences were presented in background noise. On half of the trials, the participants were tasked with identifying the final word of the sentence, as is typical of the SPIN-R task. However, to increase the demands on working memory, on the other half of the trials, the participants were instructed to recall the whole sentence. They found that young and older listeners performed equivalently in the final-word recall task, such that all groups recalled the final word better in the high constraint condition. The most important finding for the current discussion was that, in the

sentence recall task, older listeners with hearing impairment performed the poorest in recalling the sentences with low contextual constraint when compared to the other groups. However, in the high constraint sentence recall condition, older adults with hearing impairment performed comparably to the other groups, exhibiting near ceiling performance. These results suggest that, especially in cases where the speech signal is degraded by the presence of background noise and hearing deficits, and when there is an increased demand on working memory, older adults gain a more substantial benefit from using context in speech recall.

In 2016, the *Fifth Eriksholm Workshop on Hearing Impairment and Cognitive Energy* proposed a Framework for Understanding Effortful Listening (FUEL; Pichora-Fuller et al., 2016), based on a large consensus among experts in the speech and hearing sciences. This framework relies on many of the principles common among models of cognitive resources and working memory (for a review see Wingfield, 2016). These principles include the assumptions that there is a limited capacity of cognitive resources available for completing a task, that there are individual differences in those capacities, and that the amount of resources allocated to completing a task depends on the demand of the task. Moreover, the FUEL suggests that there is a limited capacity of cognitive resources available at any given point and that this capacity is modulated by arousal and motivational states of the listener. Importantly, the framework argues that the amount of effort required for successful speech comprehension is a product of the demand of the listening task and the motivation of the listener to successfully accomplish this task. Thus, listening effort entails "the deliberate allocation of mental resources to overcome obstacles … in carrying out listening tasks" (Pichora-Fuller et al., 2016, p. 10S). Sources of cognitive demand may come from degradation of the speech signal, challenging syntax, or the cognitive and language abilities of the listener (for a review on how acoustic challenge specifically may affect listening effort, see Eckert, Teubner-Rhodes, & Vaden, 2016; Hornsby, Naylor, & Bess, 2016; Peelle, 2018; Richter, 2016). The effort required by older listeners would thus be expected to be comparably higher than in younger listeners in the same listening scenario, due to age-related changes in hearing acuity and memory capacity. It may be these differences in listening effort that account for age differences seen in the low contextual constraint listening situations reviewed above. However, the studies reviewed above suggest that older adults may rely on context in a compensatory manner to reduce the amount of effort required in speech comprehension such that they are able to perform as well as their younger counterparts.

3.3 Older adults may over-rely on context when listening in noise

The work discussed above has primarily focused on situations in which supportive context is beneficial to the comprehension of the listener. Less well studied are listening scenarios where "supportive" context can actually hinder comprehension. The phenomenon of false hearing occurs when a person incorrectly perceives a speech signal and is confident that they heard a certain word even though the actual word is different (e.g., thinking someone said "fun" when they really said "run"; see Sommers & Lewis, 1999). This phenomenon of false hearing has been found to occur more frequently in older listeners than in young listeners (Rogers, 2017; Rogers, Jacoby, & Sommers, 2012; Rogers & Wingfield, 2015; Sommers, Morton, & Rogers, 2014; see also Sommers & Huff, 2003). The general idea is that false hearing occurs in cases where the speech signal is degraded and, as a result, there is an increased top-down reliance on the context of the sentence or discourse in order to attempt recognition in the face of perceptual uncertainty. This increased reliance on context can lead to a misperception of the spoken word if the actual word is not predictable based on the prior context.

To test whether or not there are age differences in over-reliance on context in speech comprehension, even when it could be a hindrance, Rogers et al. (2012) gave older and young listeners a task in which they were presented with semantically-related word pairs that they had been previously trained on. Their task was to try to correctly identify the second word in the pair and then give their associated confidence level with each choice. The second word was presented with background noise and was either semantically congruent (e.g., BARN-HAY) or incongruent with the first word pair (e.g., BARN-PAY). There were two findings from this study that are important for the current discussion. First, when compared to young adults, older adults performed better when the second word was congruent, and significantly worse when the target was incongruent. Second, older adults' confidence was identical in both the congruent and incongruent conditions, with older adults showing higher levels of confidence in their answers than young adults in both conditions. In a follow-up study, where the number of times the pairs were shown to the participant was manipulated, Rogers (2017) showed that these effects are primarily due to semantic priming, rather than repetition priming. In other words, the effect of context on false hearing was larger than the effect of associative memory. Taken together, these results suggest that older listeners rely heavily upon context when listening to speech in noise. This compensatory strategy may serve a beneficial role to older adults when

words are predictable from sentence context (but see Luke & Christianson, 2016). However, this same strategy can become a hindrance to an older listener when the spoken word is not highly predictable based on the context (see also Payne et al., 2014 for a similar argument in relative-clause attachment).

3.4 Interim summary

In summary, there is little debate in the field of Cognitive Audiology as to whether older adults utilize context, or perhaps even over-rely on context in speech processing. Indeed, as reviewed above, many studies showed that older adults performed worse on tasks in lower constraint conditions but performed equivalently to younger adults in conditions of higher constraint in word recognition and memory for speech, particularly in cases where perceptual processing is taxed. These findings suggest that, compared to younger adults, older adults gain more of a benefit from context, in part because they show poorer performance in more cognitively and perceptually taxing conditions. In fact, as discussed above, the growing literature on aging and context-driven false hearing suggests that older adults may over-rely on context in cases of increased perceptual demands. Importantly, while this over-reliance on context may be compensatory to the older listener in situations where context yields correct predictions, it can be detrimental when input is inconsistent with context-based predictions. Open questions currently being debated in cognitive audiology are whether this reliance on context in older adults is driven by declines in perceptual ability, or are reflective of more complex interactions between perceptual and cognitive change in aging. Nevertheless, there is a clear consensus that both cognitive and perceptual changes in aging can negatively impact speech comprehension, particularly in cases of increased perceptual demand (i.e., listening to an unfamiliar, fast, or accented speaker, or listening to speech in considerable background noise), but that relying on context can help to reduce the influence of these stressors, particularly in older adults with lower hearing acuity.

4. Findings from cognitive electrophysiology

Event-related potential (ERP) methods offer a non-invasive and direct measurement of brain activity, providing a unique window into understanding the cognitive and neural mechanisms underlying real-time language processing. In this section, we discuss the rapidly growing literature on aging and context processing in cognitive electrophysiology, including

the use of unique ERP components as neural indices of specific stages of language processing, as well as the utility of ERPs for exploring mechanisms of real-time context use in both visual and auditory language processing. Indeed, a considerable number of ERP studies have directly examined age-related changes in real-time context processing. Before considering this literature in detail, we first provide a brief interlude into the use of ERPs in language research.

4.1 ERP studies of language processing

ERPs are derived from the ongoing EEG by time-aligning segments of the EEG signal relative to an event of interest, such as a stimulus onset or a participant's response, and averaging many of these similar EEG segments to reveal activity that is time and phase locked to the event. The resulting ERP is depicted as a waveform at a given (set of) electrode location(s), typically accompanied by topographic maps detailing the distribution of voltages over the entire head. One of the major strengths of ERPs in cognitive neuroscience is the concept of a *component*—a stereotyped feature of the ERP with specific eliciting conditions. ERP components are defined empirically by a combination of their polarity, timing, scalp distribution, and sensitivity to task manipulations. With extensive validation, ERP components come to be associated with particular cognitive and neural processes (see Fabiani, Gratton, & Federmeier, 2007; Kappenman & Luck, 2012 for introductory overviews). ERPs have proven to be critically important tools for the study of human language comprehension, acquisition, and learning. The fact that ERPs can be continuously monitored with high temporal resolution and even in the absence of explicit tasks or behaviors has allowed for an expanded empirical study of the often covert and temporally extended neurocognitive phenomena underlying language processing.

4.2 The N400 and context use in aging

The N400 is the most widely studied of the "language-related" ERP components. The N400 is a prominent centro-posterior negative deflection in the ERP, peaking approximately 400 ms after stimulus onset (in young adults). Decades of research have shown that the N400 is part of the typical brain response elicited by all meaning-bearing stimuli (or potentially meaning-bearing stimuli), including not only spoken, written, or signed words, but also meaningful faces, objects, sounds, and even odors (see Kutas & Federmeier, 2000, 2011 for reviews). Collectively, this work has

strongly suggested that the N400 is a multi-modal and domain-general (i.e., not language specific) brain potential, reflecting activity within a widely distributed but left-hemisphere dominant fronto-temporal neural network (Lau, Phillips, & Poeppel, 2008; Van Petten & Luka, 2006). Collectively, the evidence strongly suggests that its amplitude reflects the amount of new semantic information becoming active in response to the current input (for reviews see Federmeier & Laszlo, 2009; Kutas & Federmeier, 2000, 2011). Most importantly, the N400 is highly sensitive to local and global context, such that its amplitude is reduced when a stimulus is congruent with its prior context across multiple levels of representation. For example, in sentence processing, N400 amplitudes are elicited as a monotonic inverse function of their cloze probability, such that more predictable words elicit smaller (more positive) N400 amplitudes (Kutas & Hillyard, 1984; Wlotko & Federmeier, 2012a, 2012b). Such sentence-level constraints are shaped further by discourse contexts as well (George, Mannes, & Hoffman, 1994; Nieuwland & van Berkum, 2006; van Berkum, Hagoort, & Brown, 1999).

Aging is associated with a reduced amplitude and an increased latency of the N400 (Federmeier et al., 2003; Gunter, Jackson, & Mulder, 1992; Kutas & Iragui, 1998; Woodward, Ford, & Hammett, 1993; see Wlotko, Lee, & Federmeier, 2010 for a review). In one of the earliest systematic studies of age-related change in the N400, Kutas and Iragui (1998) reported results from a study examining individual differences in N400 categorical congruity effects across adults ranging from 20 to 80 years of age. Although all age groups (up to 80 years of age) produced reliable N400 congruity effects (smaller N400s to congruent than incongruent category-target pairs), increased age was associated with a systematic linear decrease in N400 amplitude (0.05–0.09 μV/year, $r = 0.40$), as well as reliable linear slowing of peak N400 amplitude (1.5–2.1 ms/year, $r = 0.60$). Recent work combining ERFs (event-related fields, the magnetoencephalography (MEG) equivalent of ERPs) with MRI and diffusion tensor imaging suggests that age-related changes in the N400 are driven in part by diffuse structural changes in gray matter volume and white matter pathways, including cortical thinning in left temporal cortex and reductions in fractional anisotropy of white-matter pathways connecting left frontal and temporal cortex, suggesting reduced frontotemporal connectivity (Kemmotsu et al., 2012).

Over and above these "main effects" of aging on the N400, several studies have reliably shown evidence that aging has a selective influence on the sensitivity of the N400 to contextual constraint. Indeed, nearly every study that has directly tested age-related differences in the use of context on the

N400 reports either a reduced amplitude context effect, delayed latency of the context effect, or both, in older relative to younger adults (e.g., Dave et al., 2018; DeLong, Groppe, Urbach, & Kutas, 2012; Federmeier & Kutas, 2005; Federmeier et al., 2010, 2003; Federmeier, McLennan, De Ochoa, & Kutas, 2002; Ford et al., 1996; Gunter et al., 1992; Huang, Meyer, & Federmeier, 2012; Lee & Federmeier, 2012; Payne & Federmeier, 2017a, 2017c, 2018; Schwartz, Federmeier, Van Petten, Salmon, & Kutas, 2003; Wlotko & Federmeier, 2012a, 2012b; Woodward et al., 1993). For example, Federmeier and Kutas (2005) presented younger and older adults with the same target word (e.g., *beard*) preceded by either a strongly constraining context (i.e., *No one at the reunion recognized Dan because he had grown a* …) or a weakly constraining context (i.e., *At the children's park next to the beach she saw a man with a* …). Older adults showed both reduced and delayed constraint effects compared to younger adults, which were driven primarily by age-related decreases in using the richer information available from strongly constraining contexts to facilitate the N400. This effect was replicated by Wlotko, Federmeier, and Kutas (2012), who further dissociated effects of constraint from lexical expectancy by presenting younger and older adults with strongly and weakly constraining sentences completed by either their most expected target words or unexpected (but plausible words) (see also Federmeier, Wlotko, De Ochoa-Dewald, & Kutas, 2007, Section 4.3). Most notably, older adults showed a reduced effect of expectancy in weakly constraining contexts compared to strongly constraining contexts. That is, whereas older adults showed a significant N400 difference between expected and unexpected target words in strongly constraining contexts, they did not show a difference in weakly constraining contexts, unlike the young. These findings suggest that older adults needed overall stronger contextual constraints to facilitate semantic processing compared to the young, who could take advantage of even weakly constraining contexts.

One question raised here is whether the reduced sensitivity to context reflects generalized changes in the scaling properties of the N400 or generalized reductions in sensitivity of the N400 (and/other ERP components) in aging. Such scaling effects would muddy the interpretation of age-related effects on the N400 (see also Payne & Federmeier, 2018; Wlotko et al., 2010 for a detailed discussion). Mounting evidence suggests that the observed context effects on the N400 reflect functional changes in early neural semantic processing, rather than generalized age-related changes in measurement properties of the ERP component. For example, in the study

reviewed above by Federmeier and Kutas (2005), no age effects were observed on either the timing or the magnitude of the N400 response to weakly-constraining but expected target words. Moreover, Federmeier et al. (2003) directly compared age-related differences in lexical associative priming and sentence context effects on the N400 in the same experiment. Older adults showed N400 facilitation from the presence of lexically associated words, effects that were similar to that measured for younger adults, despite overall age-related delays in sensory components. At the same time, however, effects of sentence-level congruity on the N400 were reduced in amplitude and delayed by over 200 ms in older adults compared to the young.

Similar findings showing preserved (and even greater) age-related sensitivity to lexical features despite age-related reductions in context use have recently been reported by Payne and Federmeier (2018). In addition to sensitivity to constraint and expectancy, the N400 shows graded and incremental sensitivity to the accrual of contextual constraints as a sentence unfolds from word to word (Dambacher, Kliegl, Hofmann, & Jacobs, 2006; Payne & Federmeier, 2018; Payne, Lee, & Federmeier, 2015; Van Petten & Kutas, 1990, 1991). For example, an oft-replicated finding in younger adults is that the N400 to open-class words exhibits a clear inverse relationship with the words' ordinal position within a sentence (i.e., the *word position* effect), reflecting the incremental accrual of a message-level context representation as the sentence unfolds. Such effects arise in congruent sentences, but not in so-called syntactic prose sentences that provide only syntactic constraints (i.e., "*The infuriated water grabbed the justified dream.*") or in randomly shuffled words, suggesting that this effect is driven by the accumulation of message-level semantic context rather than a generalized habituation of the N400. If older adults do not gain the same degree of facilitation from context in part because they construct a message-level context representation with poorer fidelity (i.e., Wlotko et al., 2010), then older adults should show reduced word position effects in aging. Indeed, Payne and Federmeier (2018) showed that older adults show reliable but substantially reduced word position effects in congruent sentences compared to the young, suggesting that age-differences in context effects can be observed continuously throughout a sentence, as context accumulates.

A number of studies have presented evidence that, in young adults, lexical effects on the N400 can be overridden by message-level constraints as the context unfolds (Dambacher et al., 2006; Kretzschmar, Schlesewsky, & Staub, 2015; Payne & Federmeier, 2018; Payne et al., 2015;

Van Petten & Kutas, 1990, 1991). For example, Payne et al. (2015) reported a single-trial approach to modeling the effects of word position on the N400, and examined how accumulating context interacted with the sensitivity of the N400 to lexical properties of individual words. They showed that word frequency effects were reduced with increasing context, whereas effects of orthographic neighborhood were unaffected by accumulating context, with effects persisting throughout all word positions (see also, Laszlo & Federmeier, 2009). Payne and Federmeier (2018) extended this work by modeling single-word variability in N400 responses in older adults using the same materials as in Payne et al. (2015). They observed robust effects of orthographic neighborhood density on the N400, effects that were actually larger in older adults than the young, as well as preserved effects of word frequency in aging. Importantly, in older adults, frequency effects were not modulated by accumulating contextual constraints, whereas in young adults, word frequency effects are reduced with increasing constraint. Collectively, these findings indicate that older adults are less likely to rely on top-down contextual constraints in real time, and therefore rely more strongly on bottom-up lexical features to facilitate semantic access of individual words in sentence processing. Importantly, this observed pattern of findings, where older adults show robust sensitivity of the N400 to lexical features despite age-related reductions in context use, strongly argue against explanations of age-related reductions in the N400 in terms of domain-general changes in the measurement properties of the ERP component.

4.3 Aging and context-based prediction

Given the consistent age-related reductions in context use in aging reported above, a number of researchers have theorized as to the source of these deficits in context processing. For example, some have argued that these effects reflect quantitative age-related reductions in the capacity to integrate information with the accumulating context, while others have argued that such effects reflect, in part, qualitative changes in the propensity to use context predictively to anticipate upcoming input (see Federmeier, 2007; Huettig & Mani, 2016; Wlotko et al., 2010 for reviews). Such accounts are difficult to dissociate based on patterns of N400 facilitation alone. Indeed, facilitative effects of prior semantic context have been argued to arise from multiple different sources, including through bottom-up mechanisms such as passive priming (Traxler, Foss, Seely, Kaup, & Morris, 2000; but see Coulson, Federmeier, Van Petten, & Kutas, 2005) and post-lexical

integration (Hagoort, 2005; Huettig & Mani, 2016), as well as through anticipatory mechanisms, including the pre-activation of likely semantic features (Federmeier, 2007; Federmeier & Kutas, 1999; Kutas & Federmeier, 2000), and more direct prediction of specific upcoming lexical items and their associated features (i.e., orthographic and phonological representations; DeLong, Urbach, & Kutas, 2005; Federmeier & Laszlo, 2009; Kuperberg & Jaeger, 2016; Lau, Holcomb, & Kuperberg, 2013). Difficulty in dissociating such top-down predictive processing accounts from bottom-up accounts arises because both theories predict facilitation of semantic processing (and thus reduced N400s) in supportive contexts.

Thus, one way that researchers have explored the extent to which language comprehenders predict upcoming information is by examining whether there are processing consequences when readers encounter information that is plausible but inconsistent with a potentially strongly-held prediction (assuming that a prediction was made; Federmeier et al., 2007; Thornhill & Van Petten, 2012). Indeed, the processing of plausible *prediction violations* (semantically congruent but unexpected words in strongly lexically constraining contexts) consistently elicit a frontally-distributed positivity following the N400 (Federmeier et al., 2010, 2007; Payne & Federmeier, 2017b; Thornhill & Van Petten, 2012; Van Petten & Luka, 2012 for a review). In one of the first studies to directly report this frontal positivity, Federmeier et al. (2007) examined lexical expectancy and sentential constraint effects on the ERP response to sentence-final words, in sentences such as (*a*)–(*d*):

(a) ***Strongly Constraining, Expected:*** *Sam could not believe her story was true.*
(b) ***Strongly Constraining, Unexpected:*** *Sam could not believe her story was published.*
(c) ***Weakly Constraining, Expected:*** *I was impressed by how much she knew.*
(d) ***Weakly Constraining, Unexpected:*** *I was impressed by how much she published.*

In the critical comparison, conditions (*b*) and (*d*) were lexically matched and equally unexpected (~0% cloze probability). Therefore, any additional processing in (*b*) that is not present in (*d*) is likely driven by the cost of encountering an unlikely but plausible word in a context that is strongly predictive of a different word. Only strongly constraining but unexpected items (*b*) were shown to elicit a late anterior positivity following the N400. Federmeier et al. (2007) argued that this component likely reflects the increased neural demands necessary to override or suppress the anticipated semantic representation, and perhaps to revise the message-level

representation following prediction violations. A number of other studies have reported a similar late anterior positivity (DeLong et al., 2011, 2012; Federmeier et al., 2010; Kuperberg & Wlotko, 2018; Payne & Federmeier, 2017b; Thornhill & Van Petten, 2012; Van Petten & Luka, 2012), and have shown that this anterior potential is dissociable from the posterior P600 (DeLong, Quante, & Kutas, 2014; Kuperberg, 2013; Van Petten & Luka, 2012). As discussed above, Wlotko et al. (2012) used the same materials to examine joint effects of constraint and expectancy in older adults. Importantly, older adults as a group did not elicit the frontal positivity, consistent with the claim that older adults are not engaging in predictive processing. As a group, similar findings noting the lack of a frontal positivity to prediction violations in older adults have been additionally reported in a number of other studies (DeLong et al., 2014; Federmeier et al., 2010; Payne & Federmeier, 2017c; but see Dave et al., 2018). Thus, older adults as a group appear not to benefit as much as the young from prediction-based facilitation on the N400, but also may not experience prediction related *costs* to the same degree when predictions are violated.

Further supporting this claim, Federmeier & Kutas, 1999; Federmeier et al. (2002) demonstrated that young adults, but not older adults show predictive patterns of semantic pre-activation. Participants read two-sentence constraining contexts like

> *"He caught the pass and scored another touchdown. There was nothing he enjoyed more than a good game of …* (a) *football,* (b) *baseball,* (c) *monopoly."*

Critically, although both (*b*) and (*c*) are equally implausible, young adults show reduced N400 effects to the implausible target that is semantically related to the expected item compared to the out-of-category target. This facilitation for the related but implausible ending has been argued to be due to overlapping semantic features with the expected item (*football*) that has presumably been already pre-activated by the prior context (Federmeier & Kutas, 1999). Importantly, older adults do not show this facilitation, instead showing similar magnitude N400 effects to both (*b*) and (*c*), consistent with the idea that, as a group, older adults may not pre-activating semantic features of likely upcoming input based on prior context.

Federmeier et al. (2010) examined age differences in context use and prediction in a task meant to substantially minimize task difficulty across multiple dimensions. Instead of using long and elaborative contexts (which may be taxing to working memory), they used simple category cues (e.g., *A type of tree*), which were completed with targets that were either expected high

typicality exemplars (e.g., oak), unexpected low typicality exemplars (e.g., ash) or incongruent targets (e.g., tin). Moreover, stimulus presentation was slowed to account for potential age-related differences in processing speed (category cues were presented for 2150 ms and with a cue-target interval of 750–1050 ms). Young adults showed a robust N400 effect that was largest for incongruent targets, reduced for unexpected but plausible completions, and smallest for expected targets. Moreover, they showed a large frontal positivity to unexpected exemplars. However, for older adults, even in a task that substantially reduced task demands, they showed reduced N400 effects and no evidence for a frontal positivity to the unexpected exemplars, similar to prior work in the sentence domain (Wlotko et al., 2012). These findings argue against recent arguments that task difficulty alone drives the observed differences in age effects reported across behavioral and electrophysiological studies of context processing (see, e.g., Choi et al., 2017).

DeLong et al. (2005) have shown similar evidence consistent with neural pre-activation of phonological features by taking advantage of phonological regularity of English indefinite articles—that "an" precedes nouns beginning with vowel sounds, whereas "a" precedes nouns beginning with consonant sounds. Participants read sentences that create constraints toward a particular article-noun combination. For example:

The day was breezy so the boy went outside to fly ***a*** *kite/****an*** *airplane ….*

In young adults, they reported that N400 effects were observable at the article (i.e., larger N400s to *an* than *a*), which they argued reflected phonological pre-activation of the predictable upcoming target word. Although the replicability of this effect and the conditions under which this effect can be elicited have been a recent topic of intense debate (see Nieuwland et al., 2018 and replies by Yan, Kuperberg, & Jaeger, 2017; DeLong, Urbach, & Kutas, 2017; Nicenboim, Vasishth, & Rösler, 2019), such findings are indeed broadly consistent with work in other languages (e.g., Dutch, Spanish) that exploit gender-marking of upcoming words (Van Berkum, Brown, Zwitserlood, Kooijman, & Hagoort, 2005; Wicha, Moreno, & Kutas, 2004). Importantly for the present discussion, DeLong et al. (2012) examined these effects in a sample of older adults using the same exact materials. In this study, older adults did not show evidence for N400 effects at the article, despite showing robust N400 effects at the noun.

Finally, further evidence bolstering the claim that older adults show prediction-specific deficits in context processing comes from studies showing that only older adults with high verbal fluency show young-like ERP patterns of predictive processing (Dave et al., 2018; DeLong et al., 2014;

Federmeier & Kutas, 2005; Federmeier et al., 2002, 2010; Lee & Federmeier, 2011; but see Wlotko et al., 2012). Verbal fluency is typically measured with one of several standardized rapid cued production tasks that require adults to produce as many words as possible within a short time window (e.g., 60 s) based on some kind of cue (e.g., animals, words that begin with F). Successful performance in this task requires intact top-down language production mechanisms that are critical for language prediction: the ability to rapidly and efficiently generate appropriate lexical items, monitor verbal output, and inhibit task-irrelevant semantic information (see also McDowd et al., 2011). Federmeier (2007) argued that individual differences in this task reflect the speed and efficacy of frontally-mediated top-down production mechanisms that are critical for language prediction. As such, older adults with intact production mechanisms can utilize context effectively to predict likely upcoming input (see also Federmeier, 2007; Wlotko et al., 2010 for an extended discussion).

4.4 Interim summary

The findings from the cognitive electrophysiology literature reviewed above have overall been quite consistent in indicating both quantitative and qualitative age-related differences in the real-time use of context on multiple neural indices of semantic processing. Overall, older adults show reduced and delayed effects on context on the N400 component of the event related potential, a finding that is highly consistent across studies, stimuli, task, and modality. These effects persist despite age-related preservation in lexical influences on the N400, suggesting that these context effects do not solely reflect age-related neuroanatomical or neurophysiological changes in the underlying generators of the N400. Despite reduced N400 context effects, older adults still show reliable N400 context effects, especially in highly constraining contexts, suggesting that, as a group, they can and do use contextual constraints to facilitate neural activity associated with semantic access. At the same time, mounting evidence suggests that older adults do not routinely utilize context in an anticipatory manner to predict likely upcoming input, instead relying on context in a more bottom-up stimulus-driven fashion.

5. The way forward: Bridging gaps and integrating literatures

A wealth of evidence supports the idea that context information can be rapidly used to influence ongoing language processing. Strongly supportive contexts influence preparatory activation of likely upcoming input,

facilitate bottom-up perceptual and lexical processing, and influence long-term memory representations. Despite these highly reliable and robust effects of context on nearly every aspect of comprehension, understanding exactly how aging impacts context processing is a topic of considerable debate across the above-reviewed literatures. Thus, our overarching goals of this review were to attempt to (a) provide a detailed overview of three disparate literatures that have examined overlapping questions surrounding how aging impacts the use of context during language processing, and (b) to move toward integrating these oft-conflicting literatures. Our motivation for the first goal was based on the consideration that reviewing any one of these literatures in isolation is likely to lead to very different conclusions about context processing in aging. For example, considering the electrophysiological data alone, one may come to the conclusion that aging is associated with a reduced predictive use of context as well as reduced effects of context on real-time neural semantic activation (e.g., Wlotko et al., 2010), whereas reviews of context processing in audiology come to quite opposing conclusions (e.g., Pichora-Fuller, 2008).

Several important principles emerge from this review, converging around the need for these fields to better integrate and focus future research on (a) the boundary conditions underlying optimal and sub-optimal context use in younger and older adults, (b) the strategic and compensatory nature of relying on supportive contexts at multiple levels of representation, and (c) the temporally-distributed nature of context processing mechanisms. Indeed, despite the seeming surface-level lack of consistency in findings, the picture that unfolds from this review is that absolute black-and-white questions of whether older adults use context or not are likely ill-posed. It is clear from the above review that older adults can and often do rely on context representations to guide various aspects of language processing. Instead, the literature needs to shift away from such "first-order" questions toward addressing the dynamics and flexibility of context processing in a manner that cuts across the long-held paradigmatic and measurement traditions within each literature.

One major issue clouding the future cross-disciplinary study of context use in aging is that different researchers rely on one or a small set of measurements and experimental paradigms. Importantly, any one experimental paradigm is likely to carry with it specific task demands and to focus attention toward specific comprehension processes (e.g., relying heavily on word recognition, or relying on explicitly detecting an unexpected word). Future work will benefit from adopting a multimodal measurement approach, in

which multiple outcomes are simultaneously measured in the same experiment and participants. This approach is necessary to test the degree to which different measurement outcomes yield systematically different patterns of age-related change. Given the review above, it is likely that certain measures will be more or less sensitive to different stages of perceptual and cognitive processing (see, e.g., Schotter, 2018). Adopting a multi-paradigmatic approach, in which the same experiment and stimuli are replicated across multiple paradigms or modalities, is critical for future work. For example, Payne, Stites, and Federmeier (2016) adopted this approach to examine whether context-based plausibility and prediction violations induced foveal load during reading by conducting parallel eye tracking and event-related brain potential experiments. Synthesizing the approaches from multiple fields like this would allow a researcher to test the robustness and replicability of a phenomenon across different paradigms and could help delineate which effects may be modulated by paradigmatic differences in factors such as task demands, modality, presentation rate, perceptual effort, and control over input.

Future work should consider explicitly manipulating comprehension goals, motivational states, and content relevancy in order to better understand the flexibility of context processing mechanisms in goal-directed comprehension. These manipulations will help elucidate the conditions under which older and younger readers may differentially rely on supportive contexts. For instance, across many of the experiments reported above, some tasked participants to passively comprehend text or speech, while others instead tasked participants with completing some explicit comprehension, memory, or judgment task. Growing evidence suggests that language processing systems generate representations that are underspecified and often incomplete during everyday comprehension (Ferreira, Bailey, & Ferraro, 2002). Importantly, however, subtle changes to communicative goals and environments can substantially alter real-time language processing. Eye tracking experiments tend to include intermittent comprehension questions on a subset of items. In contrast, many ERP language studies impose no external task, though there is considerable variability within this field as well (see Payne et al., 2019 for a review). A growing literature has begun to highlight how explicit changes to comprehension goals can modulate real-time language processing in many circumstances (e.g., Fallon, Peelle, & Wingfield, 2006; Payne et al., 2019; Swets et al., 2008).

For example, Dave et al. (2018) reported a recent study using an explicit predictability judgment task to examine age differences in predictive processing. Older and younger adults read moderately constraining two-

sentence contexts that were completed with either the most expected target word or an unexpected word. Importantly, participants were tasked with explicitly predicting each passage-final word and reporting the accuracy of these predictions after each target word (see also Brothers, Swaab, & Traxler, 2015). The authors argued that comparisons of self-reported prediction success and cloze probability allowed them to separate effects of contextual support from effects of prediction accuracy. The authors reported reduced effects of prediction in older adults on both the N250 and N400, as well as reduced N400 effects of contextual support. Importantly, however, they showed that N400 prediction effects (not predicted versus predicted) occurred earlier in time compared to effects of contextual support (low cloze versus predicted), a finding they previously reported in young adults (e.g., Brothers et al., 2015). Moreover, they showed evidence that older adults showed a larger frontal positivity to low cloze words and non-predicted words, suggesting preservation of prediction in aging when older adults were explicitly cued to predict upcoming words. At the same time, it is likely that the explicit task of being asked to predict upcoming words modulates neural indices of semantic processing. For example, Payne et al. (2019) showed that the LPC to context incongruent words was substantially increased when reading under an explicit plausibility judgment task compared to reading passively for comprehension.

There are several other examples of work attempting to resolve cross-paradigm questions by modifying existing paradigms to more naturally bridge the gap across literatures. For example, single-word RSVP reading studies preclude the ability to examine parafoveal processing. Given the discrepant findings in context use and the important role of parafoveal processing in theories of aging and reading (e.g., Payne & Stine-Morrow, 2012; Rayner et al., 2006), an open question concerns whether older adults may benefit from the availability of parafoveal previews in reading in ERP paradigms. Barber, Ben-Zvi, Bentin, and Kutas (2011) introduced a visual hemi-field flanker RSVP paradigm for studying parafoveal processing during reading (see also Payne et al., 2016; Stites, Payne, & Federmeier, 2017). Payne and Federmeier (2017a) reported the first study to examine age differences in parafoveal and foveal N400 effects of context use in this paradigm. Like younger adults (e.g., Stites et al., 2017), older adults showed a robust N400 effect to parafoveally presented words that were unexpected or anomalous compared to expected based on the prior context. In fact, the magnitude of this effect was nearly as large and similar in latency in older adults as in the young, perhaps consistent with one tenet of the risky reader

theory that older adults may over-rely on (incomplete) parafoveal semantic information to guide lexical processing in a compensatory manner (Rayner et al., 2006). However, younger adults showed parafoveal-to-foveal priming of the N400 (i.e., reduced N400 amplitudes once the word is subsequently viewed foveally) whereas older adults did not. These findings suggested that, although parafoveal semantic processing per se was preserved in aging, older adults showed a selective deficit in rapidly carrying forward this parafoveal information to integrate it with subsequent foveal visual semantic representations. Given recent developments in the co-registration of eye movements and EEG during reading and the calculation of *fixation-related potentials* (see, e.g., Dimigen, Sommer, Hohlfeld, Jacobs, & Kliegl, 2011; Schotter, 2018 for recent reviews), future work directly linking ERP and eye-movement studies of aging and context processing reviewed above would strongly benefit from such co-registration studies.

In addition to control of attention across the visual field, experimenter-controlled RSVP studies common in cognitive electrophysiology and psycholinguistics more generally do not allow readers volitional control over timing and rate of input. Indeed, older readers are not only slower on average, but are much more variable readers, showing broader and more skewed RT distributions during word reading (Payne and Stine-Morrow, 2014). Recent work combining self-paced reading paradigms with the ERP RSVP paradigm (Ng, Payne, Steen, Stine-Morrow, & Federmeier, 2017; Payne & Federmeier, 2017b; Tanner, 2019) have allowed for a direct examination of the role of control and intra-individual variability in word processing on neural indices of context use. Moreover, this approach allows for analyzing relationships between behavioral and neural measures of context processing. For example, Payne and Federmeier (2017b) conducted a replication of Federmeier et al. (2007) (see above for a review), but allowed readers to self-pace their reading instead of the typical experimenter controlled presentation. They showed that behavioral responses to prediction violations were highly variable and that the speed of behavioral responses to prediction violations were associated with dissociable neural responses. Fast trials were associated with the more common frontal positivity, whereas extremely slow trials (in the tail of the RT distribution) were associated with an earlier anterior N2 effect, typically associated with increased cognitive control (Folstein & Van Petten, 2008). Payne and Federmeier (2017c) recently expanded on this work by conducting the same experiment in older adults. Older adults overall were slower and more variable readers. Prior work using these same sentences in (experimenter controlled) RSVP reported no

evidence of a frontal positivity in older adults, suggesting reduced anticipatory processing in older adults (Wlotko et al., 2012). However, Payne and Federmeier (2017c) found that a frontal positivity was elicited but only in the subset of trials that generated the slowest behavioral responses to prediction violations. Thus, these findings highlight that questions of context use in older adults can vary even within the same participant from trial-to-trial. Moreover, changing the paradigm to allow for volitional control over the rate of input can result in young-like predictive processing, at least on a subset of trials (see also Piquado, Benichov, Brownell, & Wingfield, 2012 for similar compensatory effects of self-paced listening in speech comprehension).

One final area for further study centers on furthering our understanding of the cognitive consequences of perceptual challenge to context use in aging. The most reliable evidence for an increased compensatory reliance on context in older adulthood comes from studies where perceptual effort is experimentally manipulated, for example, by listening to degraded or masked speech or by reading text presented in visual noise. An open question concerns how increasing listening or viewing effort through such perceptual demands may also result in changes to comprehension goals, motivation, and (perceived) cognitive demand in older relative to younger comprehenders. Indeed, this idea that small changes in task demands result in differentially greater compensatory changes in functioning in older compared to younger adults permeates theories of cognitive and brain aging (Fabiani, 2012; Reuter-Lorenz & Cappell, 2008; Schneider-Garces et al., 2010). With advancing age, executive control and working memory resources are differentially recruited at progressively lower levels of difficulty in order to maintain similar levels of performance. For example, older adults rely more heavily on executive control processes even in simple short-term verbal memory storage tasks (Park & Reuter-Lorenz, 2009; Reuter-Lorenz & Jonides, 2007). Wingfield and Grossman (2006) showed similar findings in syntactic processing, whereby older adults show increased compensatory recruitment of working memory-dependent neural networks during comprehension of simple subject-relative clauses, whereas younger adults only show this increased activation in the more complex object-relative clauses. The extent to which perceptual manipulations differentially increase effort in older compared to younger adults, and thus result in compensatory shifts in neural activation is an open question. Some studies have begun to examine electrophysiological indices of perceptual and semantic processing under differences in listening effort in young normal hearing adults (Obleser & Kotz, 2011). Such manipulations may also lead to changes

in compensatory activation to overcome these changes in task difficulty, including relying more on top-down context representations when bottom-up input is degraded. Whether this increased reliance on context is systematically reduced in cases where context use is not critical for performance in the task, such as in experiments that do not explicitly cue off-line comprehension, is an important open question for future research.

6. Conclusion

Because the normal aging process influences nearly all stages of sensory and cognitive processing that support effective language comprehension, it is not surprising that aging influences how top-down context is used to bias ongoing language processing. Thus, current questions in the literature about whether older adults under-utilize or over-utilize context, as a rule, are necessarily incomplete as they miss the dynamic nature of context use in language comprehension. Indeed, younger and older adults appear to rely on context in very different ways across diverse communicative environments. Across the above reviewed literatures, it is clear that older adults will rely on supportive (or non-supportive) contexts depending on the current demands of the comprehension environment. At the same time, temporal, attentional, and memorial constraints with aging lead to increased effort to utilize context in the same way as the young. Future work is needed to understand the factors that promote or hinder effective context use in aging and to further elucidate the cognitive and neural mechanisms by which older and younger adults rely on different contextual cues across a diverse range of comprehension environments. Toward this goal, our call is for researchers in each of these domains to increase efforts to integrate findings, theories, measurement approaches, and paradigms across these literatures in an effort to actively draw bridges between literatures. Only in this way will we move toward a more complete and generalized understanding of the dynamics of context processing across the lifespan, and many other phenomena for that matter.

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