

ARTICLE

Semantic integration declines independently of working memory in aging

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Abstract

Semantic integration and working memory both decline with age. However, it remains unclear whether the semantic integration decline is independent of working memory decline or whether it can be solely explained by the latter factor. In this event-related potentials experiment, 43 younger adults and 43 cognitively healthy older adults read semantically congruent and incongruent sentences. After controlling for working memory, behavioral accuracy was significantly lower in the older adults than in the younger adults. In addition, the semantic integration related N400 effect (incongruent vs. congruent) for correct trials was apparent in the whole brain in the younger adults but restricted to the posterior region in the older adults. The results clarify the relationship between working memory and semantic integration, and clearly demonstrate that semantic integration decline is independent of working memory decline during aging.

Keywords: aging; N400; semantic integration; working memory

Aging is no doubt one of the most significant demographic changes in the world today. The proportion of the world's population over 60 years will nearly double, from 12% to 22%, between 2015 and 2050 (<http://www.who.int>). Age-related decline across multiple domains severely reduces quality of life. Specifically, decline in language comprehension, as one of humans' core competencies, can have a pronounced impact.

Beyond single word recognition, language comprehension relies on the integration of small semantic blocks into larger coherent representations (Hagoort, Baggio, & Willems, 2009). Although older adults accumulate larger vocabulary and more language expertise than younger adults (Park & Reuter-Lorenz, 2009), it remains unclear whether semantic integration declines in aging. On the one hand, older adults have an advantage over younger adults in building discourse-level mental

representations, a skill that relies on semantic integration (Madden & Dijkstra, 2010), and they show preserved semantic integration during spoken language comprehension at normal speech rates (reviewed in Diaz, Rizio, & Zhuang, 2016). On the other hand, cumulative evidence has also shown that semantic integration performance declines with age (reviewed in Wlotko, Lee, & Federmeier, 2010).

Behavioral studies have shown that older adults have lower accuracy and longer response times than younger adults on sentence comprehension tasks (Federmeier, Kutas, & Schul, 2010; Wlotko *et al.*, 2010). Event-related potentials (ERPs) have also been used to capture the rapid process of semantic integration. When the semantic integration demand increases, a larger negative deflection appears and peaks at about 400 ms (N400) after the critical word onset (Hagoort, Hald, Bastiaansen, & Petersson, 2004; Kutas & Hillyard, 1980). In addition, the N400 effect is largely reduced in older adults compared to younger adults (Federmeier *et al.*, 2010; Wlotko & Federmeier, 2012; Xu, Hou, Zhao, Zhu, & Yang, 2017), and the reduced N400 effect has been shown to be correlated with age among older adults (Faustmann, Murdoch, Finnigan, & Copland, 2007). With age, the increasing difficulty of semantic integration also often induces a late positive component (LPC) that is observed after the N400, starting at about 550 ms (Federmeier *et al.*, 2010). The N400-LPC effect in aging has been found not only in Indo-European languages but also during Chinese sentence reading (Xu *et al.*, 2017). Moreover, Peelle, Troiani, Wingfield, and Grossman (2010) showed that when working memory demand increased, the task performance declined more than among those in the less demanding condition in aging.

The studies have raised the question of whether the age-related decline was due to diminished semantic processing *per se* or due to confounding factors such as working memory, one of the most prominent functions that declines in aging (Bopp & Verhaeghen, 2005; Park & Reuter-Lorenz, 2009). Previous comprehension studies have employed sentences heavily dependent on semantic memory (Federmeier *et al.*, 2010), or have commonly compared complex sentences versus simple sentences to reveal the semantic integration process, especially in functional magnetic resonance imaging studies (Grossman *et al.*, 2002; Peelle *et al.*, 2010, 2013). Given that the comprehension of complex sentences relies on working memory more than does the comprehension of simple sentences, the results of earlier studies must be interpreted in light of the possibility that there was a confounding effect of working memory. Critically, previous studies have confirmed that individual differences in working memory are closely associated with the N400 effect (Federmeier *et al.*, 2010; Federmeier, McLennan, De Ochoa, & Kutas, 2002; Gunter, Jackson, & Mulder, 1995; Salisbury, 2004) in older adults. In addition, complex sentences usually are syntactically complex sentences that require more syntactic processing than simple sentences do. Thus, studying this type of contrast cannot answer the question of whether semantic integration decline can be separated from working memory decline in aging.

Therefore, an important question is whether the semantic integration decline in aging can solely be explained by working memory. Theoretically, semantic integration and working memory are strongly related but also separable. On the one hand, the processing and storage in working memory varies among individuals, which in turn can account for qualitative and quantitative differences among younger and

older adults in language comprehension (Just & Carpenter, 1992). The ambiguous nature of language comprehension also requires the reader to select appropriate and inhibit inappropriate candidates, constraining comprehension (Hasher & Zacks, 1988). On the other hand, although the selection and inhibition involved in semantic integration are key components of the executive control part of working memory (Baddeley, 1992), semantic integration is thought to be different from executive control processes (Hagoort et al., 2009). Research has shown isolated activation for semantic integration, independent of executive control processes in younger adults (Zhu et al., 2013). In addition, it has been found that working memory impacts the use of animacy but not of semantic integration related to world knowledge (Nakano, Saron, & Swaab, 2010).

One way to determine the separation of semantic integration and working memory in aging would be to control for working memory, but most studies have not done this. One exception showed that the effect of chronological age on offline behavioral measurement of sentence comprehension was not significant after controlling for working memory decline (DeCaro, Peelle, Grossman, & Wingfield, 2016). However, it remains an open question whether there is age-related decline during online reading after controlling for working memory.

The aim of the present study was to isolate age-related decline in semantic integration from decline in working memory. We recruited 43 younger and 43 older adults, constituting a much larger sample than in previous studies (typically <20 in each group). This is a key strength, as a larger sample size can raise the reproducibility (Hu et al., 2016). The semantic integration task required participants to read congruent (“Honey is sweet”) and incongruent (“Honey is dusky”) sentences. Simple sentences do not involve complex syntactic structure and do not require the reader to maintain the semantic information in working memory, thus minimizing demands on working memory resources.

Furthermore, to clarify the working memory contribution in semantic integration decline during aging, the group comparison of the semantic integration effect was performed with and without controlling for working memory. Specifically, we planned to statistically control for any group differences in demographics or related cognitive functions. Then, in order to address the research question, working memory was added as an additional control variable. If there was evidence of age-related decline in semantic integration after controlling for working memory, then we could conclude that semantic integration decline is independent of working memory. By contrast, if there was no evidence of age-related decline in semantic integration after controlling for working memory, then we would conclude that declines in working memory explain declines in semantic integration.

Method

Participants

The present study recruited 86 Chinese speakers, of whom 43 were younger adults (14 male, 27 female, mean \pm SD, 22.2 \pm 3.6 years) and 43 were older adults (19 male, 24 female, 66.5 \pm 5.5 years). The two groups had comparable gender ratios ($\chi^2 = 0.43$, $p = .51$). Younger adults had more years of education (14.5 \pm 2.1 years)

Table 1. Demographic characteristics and neuropsychological functioning of the younger and older adults

| | Younger adults | Older adults |
|--------------------|----------------|--------------|
| <i>N</i> | 43 | 43 |
| Age | 22.2 (3.6) | 66.5 (5.5) |
| Gender | 27f/16m | 24f/19m |
| Years of education | 14.5 (2.1) | 11.7 (2.9) |
| Raven's score | 100.9 (19.0) | 101.8 (11.9) |
| VIQ | 116.7 (10.0) | 114.9 (10.4) |
| Verbal fluency | 46.1 (11) | 39.7 (7.2) |
| Working memory | 21.0 (4.6) | 14.8 (3.4) |

Note: Standard deviation in parenthesis. VIQ, verbal intelligence quotient.

than older adults (11.7 ± 2.9 years), $t(84) = 5.16$, $p < .001$. Written informed consent was obtained from each participant. By self-report, participants had normal or corrected-to-normal visual acuity and no history of psychiatric problems. Table 1 presents the demographic characteristics of participants.

Neuropsychological tests

To confirm the cognitive health status of the older participants, we administered the Beijing version of the Montreal Cognitive Assessment to the older adults to test short-term memory recall, visuospatial skill, executive functioning, language, orientation, attention, concentration, and working memory. The older participants in this study were cognitively healthy, as indicated by a mean score on the Montreal Cognitive Assessment of 26.9 ($SD = 2.7$, range = 25–30). Raven's Standard Progressive Matrices (Zhang & Wang, 1985) also revealed no significant difference in basic cognitive ability between the younger adults (101.8 ± 11.9) and older adults (100.9 ± 19), $t(84) = 0.27$, $p = .79$.

Furthermore, we evaluated all participants' language competence, assessed in terms of verbal intelligence (Gong, 1992) and verbal fluency. The Wechsler verbal intelligence quotient was comparable between the younger (116.7 ± 10.0) and older (114.9 ± 10.4) adults, $t(84) = 0.84$, $p = .41$. Verbal fluency was assessed by asking the participants to generate the names of as many animals or tools as possible in 1 min. The total number of animals and tools generated by the younger adults (46.1 ± 11.0) was significantly higher than the number generated by the older adults (39.7 ± 7.2), $t(84) = 3.2$, $p = .002$.

Finally, during the working memory test, participants were requested to recall the last word of each sentence of a sentence block. Following the digit span test in the Wechsler verbal intelligence scale, the number of sentences in each block varied from 3 to 8, and each sentence had 5–13 Chinese characters. To aid the detection of individual differences and to better interpret correlations between the score and the ERP effect, the individual's working memory span was defined as the total

number of remembered vocabulary words (Friedman & Miyake, 2005; Zhu, Hou, & Yang, 2018). The result showed that the average score of the younger adults (21.0 ± 4.6) was significantly higher than that of the older adults (14.8 ± 3.4), $t(84) = 7.03$, $p < .001$.

Stimuli

Congruent (CON) and incongruent (INCON) sentences were constructed. To shorten the sentence presentation, each sentence was three words long. For the CON condition, we constructed 160 congruent short sentences, with the critical word (CW) appearing at the end of each sentence (e.g., 蜂蜜很甘甜/Honey is sweet). For the INCON condition, the CW from the congruent sentence was replaced with a word (e.g., 昏暗/dusky) that semantically violated the context. The word frequency (Cai & Brysbaert, 2010; 1.85 ± 0.66 and 1.72 ± 0.68 for CON and INCON, respectively), $t(159) = 1.51$, $p = .13$, and number of strokes (18.1 ± 4.30 and 18.4 ± 4.60 for CON and INCON, respectively), $t(159) = 0.56$, $p = .58$, of the CW were matched between the CON and INCON conditions. The stimuli were equally distributed in different conditions, and counterbalanced across conditions and participants. The familiarity of the CON sentences was rated by another 16 younger adults, using a scale from 1 (*fully unfamiliar*) to 5 (*fully familiar*). The mean rating was 4.33 ($SD = 0.40$). To make sure the older adults were also familiar with the sentences, they were asked to rate the sentences using a scale from 1 (*fully unfamiliar*) to 5 (*fully familiar*) after the EEG recording. The mean rating was 4.23 ($SD = 0.24$).

Procedure

All stimuli were presented using E-Prime software (2.0). For each trial, after a 300-ms cross fixation, the sentence was presented word by word. Each word was presented at the center of the screen for 500 ms followed by a 100-ms blank screen. Then a question mark was presented for a period of 3000 ms, during which the participants were asked to judge if the sentence was semantically acceptable or not. A 1000-ms intertrial interval was used. The participants were asked to blink as little as possible during the reading.

EEG recording and preprocessing

EEG data were collected from a standard 64-channelcap (10/20 system; Neuroscan, the United States). The EEG was recorded continuously with a 70 Hz low-pass filter sampled at 500 Hz, with a 10 s constant time. All electrode impedances were kept below 5 k Ω before recording. The EEG data were rereferenced offline to the average of the two mastoids, and then filtered with a 0.1–30 Hz bandpass filter. Critical epochs ranged from –200 ms to 1000 ms relative to the onset of the target word, with –200 ms to 0 ms serving as the baseline. The artifact rejection criterion was $\pm 90 \mu\text{V}$, with fewer than 5% of trials being rejected. Then, the ERP data were averaged for each participant and each condition for correct trials only.

Statistics

Based on methods used in previous studies (Hagoort, 2008; Kutas & Federmeier, 2011) as well as visual inspection, we calculated peak latency and amplitude for the N400 and LPC time windows, as well as onset latency for N400 effect. The time windows for examining the N400 effect in the younger and the older adults were 300–500 ms and 350–550 ms, respectively (Federmeier *et al.*, 2010). The time window for the LPC was 700–900 ms. Onset latency for the N400 effect was assessed by determining the point in time at which 50% of the peak amplitude was exceeded by a difference wave between conditions (INCON–CON), using Jackknife correction (Miller, Patterson, & Ulrich, 1998). The electrodes were grouped as left and right hemisphere and anterior and posterior regions (F1, F3, F5, FC1, FC3, FC5, for left anterior; F2, F4, F6, FC2, FC4, FC6 for right anterior; P1, P3, P5, CP1, CP3, CP5 for left posterior; and P2, P4, P6, CP2, CP4, CP6 for right posterior).

Four analyses of covariance (ANCOVAs) were conducted. First, a 2 (Condition: CON, INCON) \times 2 (Group: Younger, Older) \times 2 (Hemisphere: Left, Right) \times 2 (Region: Anterior, Posterior) ANCOVA was used to predict average amplitude, with years of education and verbal fluency as control variables. Second, this ANCOVA was repeated, adding working memory as an additional covariate. Third, a 2 (Hemisphere: Left, Right) \times 2 (Region: Anterior, Posterior) ANCOVA was used to predict peak latency, with years of education and verbal fluency as control variables. Fourth, this ANCOVA was repeated, adding working memory as an additional control variable. We planned to conduct simple main effect tests with the Bonferroni correction for multiple comparisons if we found any significant Group \times Condition interactions. The Greenhouse–Geisser correction was applied when evaluating effects with more than one degree of freedom to protect against Type I errors due to sphericity violations. Finally, we evaluated the correlations between N400 amplitude and accuracy, and between P600 amplitude and accuracy, to test the significance of ERP effects.

Results

Behavioral results

Table 2 presents the response accuracy in the two conditions for both groups. After controlling for years of education and verbal fluency, there was no significant Condition effect, $F(1, 82) = 0.71$, $p = .40$, Group effect, $F(1, 82) = 2.51$, $p = .12$, or Condition \times Group interaction, $F(1, 82) = 2.72$, $p = .10$, on accuracy. However, after controlling for working memory, a significant Condition \times Group interaction emerged, $F(1, 81) = 3.90$, $p = .05$, $\eta_p^2 = .05$, but there was still no Condition, $F(1, 81) = 1.39$, $p = .24$, or Group effect, $F(1, 81) = 1.04$, $p = .31$. Simple main effects tests revealed that the younger adults were more accurate than the older adults in the INCON condition ($p = .04$, $\eta_p^2 = .05$) but not the CON condition ($p = .85$). Within each group, the condition effect was significant in younger adults ($p < .001$, $\eta_p^2 = .21$) but not in older adults ($p = .15$).

Latency

Figure 1 presents the time course of each condition of the two groups in representative electrodes. For the N400 effect, a trend of earlier peak latency in the younger

Table 2. Younger adults' and older adults' mean percent accuracy in semantic integration of congruent (CON) and incongruent (INCON) sentences

| | Younger adults | Older adults |
|-------|----------------|--------------|
| CON | 90.7 (6.9) | 85.3 (13.3) |
| INCON | 98.4 (3.6) | 88.7 (12.9) |

Note: Standard deviation in parenthesis.

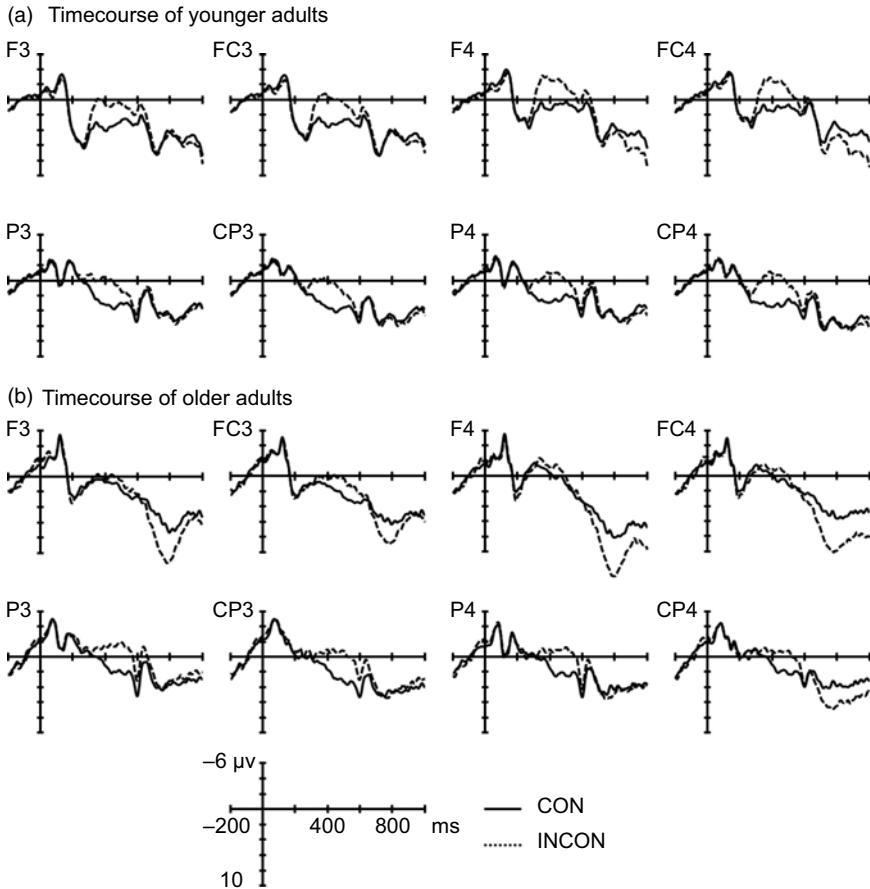


Figure 1. Grand averages for incongruent and congruent conditions in representative electrodes for (a) younger adults and (b) older adults.

adults (418 ± 47 ms) than the older adults (438 ± 45 ms), $F(1, 82) = 2.92, p = .09, \eta_p^2 = .03$, and a significant Region \times Hemisphere interaction, $F(1, 82) = 5.57, p = .02, \eta_p^2 = .06$, were found after controlling for years of education and verbal fluency. When working memory was controlled for, there was no main effect for

Group, $F(1, 81) = 2.42, p = .12$. For the peak latency of the LPC, there was no significant main effect of Group (younger adults 715 ± 47 ms, older adults 727 ± 45 ms) and no interactions ($ps > .12$).

The mean of the onset latency was 307.25 ($SD = 0.27$) and 405.30 ($SD = 0.27$) for younger and older adults, respectively. Repeated ANOVA revealed that there was a significant Group effect, $F(1, 84) = 63983, p < .001$, with slower onset latency in the older adults than in the younger adults. There was a significant Region \times Group interaction, $F(1, 84) = 3216, p < .001$; in both anterior and posterior regions, older adults showed slower onset latency than younger adults ($ps < .001$). When working memory was controlled for, the results showed significantly later onset latency in the older adults than in the younger, $F(1, 81) = 48329.01, p < .001$, in the anterior regions than in the posterior, $F(1, 81) = 71.69, p < .001$, and in the left hemisphere than in the right hemisphere, $F(1, 84) = 37.94, p < .001$. The Region \times Group interaction was significant, $F(1, 84) = 2514.46, p < .001$. Follow-up analyses showed that latency in the anterior region was significantly later than in the posterior region in both younger and older adults ($ps < .001$), and latency in the older adults occurred significantly later than in the younger adults in both anterior and posterior regions ($ps < .001$). A significant effect was also observed for the Hemisphere \times Group interaction, $F(1, 84) = 1482.79, p < .001$, the Hemisphere \times Region interaction, $F(1, 84) = 32.35, p < .001$, and the Region \times Group \times Hemisphere interaction, $F(1, 84) = 2241.18, p < .001$, showing significantly later onset in the older than in the younger adults in the left anterior, right anterior, left posterior, and right posterior regions ($ps < .001$).

Amplitude change

Figures 2 and 3 present the condition difference in time course and distribution, respectively. For the N400, after controlling for years of education and verbal fluency, the results showed significantly larger amplitude in the INCON than CON condition, $F(1, 82) = 7.04, p = .01, \eta_p^2 = .08$, and more negative amplitude in the older adults than in the younger adults, $F(1, 82) = 3.99, p = .05, \eta_p^2 = .05$. A significant effect was also observed for the Group \times Condition interaction, $F(1, 82) = 5.74, p = .02, \eta_p^2 = .07$, and the Group \times Condition \times Region interaction, $F(1, 82) = 8.14, p = .005, \eta_p^2 = .09$. Simple main effect tests revealed a significant N400 effect in both the anterior ($p < .001, \eta_p^2 = .25$) and the posterior regions ($p < .001, \eta_p^2 = .40$) in younger adults, but only in the posterior region in older adults ($p < .001, \eta_p^2 = .29$).

When working memory was controlled for, the amplitude of N400 was larger in the INCON than in the CON condition, $F(1, 81) = 4.24, p = .04, \eta_p^2 = .05$. There was still a Group \times Condition \times Region interaction, $F(1, 81) = 6.27, p = .01, \eta_p^2 = .07$, showing a significant N400 effect in both the anterior ($p < .001, \eta_p^2 = .20$) and posterior regions ($p < .001, \eta_p^2 = .33$) in the younger adults, but only in the posterior region in the older adults ($p < .001, \eta_p^2 = .29$).

For the LPC, after controlling for years of education and verbal fluency, a marginally significant effect for the Condition \times Group interaction, $F(1, 82) = 3.61, p = .06, \eta_p^2 = .04$, a marginally significant Condition \times Group interaction, $F(1, 82) = 3.61, p = .06, \eta_p^2 = .04$, and a marginally significant Group \times Condition \times Region

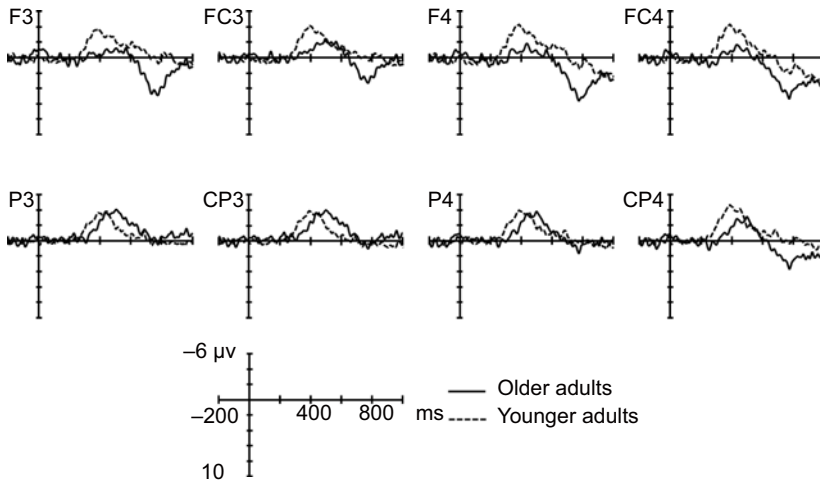


Figure 2. Different waves between conditions (incongruent vs. congruent) for younger and older adults. Younger adults presented significant N400 effects in both anterior and posterior electrodes. Older adults presented a delayed and significant N400 effect in the posterior electrodes and a significant P600 effect in the anterior electrodes.

interaction, $F(1, 82) = 3.64$, $p = .06$, $\eta_p^2 = .04$, were found. Simple effects tests revealed a significant LPC effect in the anterior region in the older adults ($p = .002$, $\eta_p^2 = .11$) but not the younger adults.

When working memory was controlled for, a significant Condition \times Region interaction, $F(1, 81) = 4.72$, $p = .03$, $\eta_p^2 = .06$, and a marginally significant Group \times Condition \times Region interaction, $F(1, 81) = 3.04$, $p = .08$, $\eta_p^2 = .04$, were found. Simple effects tests revealed a significant LPC effect in the anterior region in the older adults ($p = .004$, $\eta_p^2 = .10$), but not the younger adults.

It is interesting to note that the larger N400 effect was associated with higher accuracy in the INCON condition compared to the CON condition for the younger adults ($r = -.38$, $p = .01$) but not for the older adults ($r = .001$, $p = .99$). There was a trend toward a difference between the correlation coefficients (Fisher's $Z = 1.78$, $p = .08$). For the P600 effect in the anterior region, no correlation with accuracy was found in either group ($ps > .90$).

Discussion

Previous studies found that age-related decline in semantic integration was closely associated with decline in working memory, but it was unclear whether these two types of decline were independent of one another. The present study addressed this question by examining age-related decline in semantic integration while controlling for decline in working memory, in a large sample of younger and older adults. Unlike earlier studies, we minimized the working memory demand by employing simple rather than semantically complex sentences to assess semantic integration. Behavioral and ERP data showed that age-related declines in semantic processing

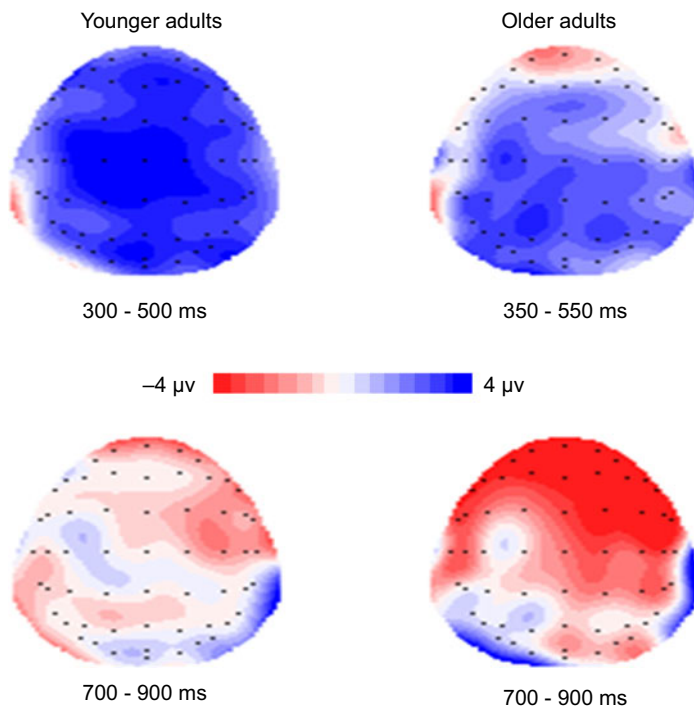


Figure 3. N400 effect and late positive component effect distribution in both younger and older adults. N400 effect was whole-brain distributed in the younger adults while restricted to the posterior regions in the older adults (top panel). P600 effect was significant in the anterior region in the older adults but not in the younger adults (bottom panel).

are independent of declines in working memory. These results shed light on understanding language comprehension decline during aging.

The most important findings were those that documented the independence of semantic integration and working memory. After controlling for working memory, two pieces of evidence documented a clear advantage for younger adults relative to older adults in terms of semantic integration.

First, the behavioral assessment of accuracy during the semantic integration task showed that for the younger adults, accuracy was higher when reading incongruent sentences than congruent sentences (Zhu *et al.*, 2009, 2012), but this difference was not found in older adults. One may argue that the older adults may intend to interpret the incongruent sentence in a different way so that the rejection rate (i.e., accuracy) was reduced. Such an explanation is in line with the inhibitory deficit account (Hasher & Zacks, 1988), which proposes that in advance of the aging breakdown the inhibitory function, and thus irrelevant information, was allowed to enter into working memory. If that is true for the older adults, then the interpretation effort during sentence reading should be reflected in the brain response, as typically such effort is associated with a larger brain response (Gazzaley, Cooney, Rissman, & D'Esposito, 2005). However, as shown in the ERP results, the INCON sentences

induced a smaller N400 effect and not a larger N400 amplitude in older adults compared to younger adults. Therefore, the decline of semantic integration could not be purely explained by different interpretations or inhibitory deficit.

Second, the amplitude difference of the N400 effect between the older and younger adults further confirmed the behavioral decline of semantic integration during aging. While a significant N400 effect was found in both the anterior and posterior regions in the younger adults, the N400 effect was restricted to the posterior region in the older adults. In contrast, the N400 effect difference is more likely capturing the intrinsic semantic integration ability decline in aging. The alteration of accuracy and the N400 effect suggests that the older adults showed reduced sensitivity in discriminating semantic congruency during sentence comprehension, consistent with recent findings (Faustmann et al., 2007; Wlotko et al., 2010; Xu et al., 2017). Moreover, a significant N400–accuracy correlation in the INCON condition was only found in the younger adults, not the older adults. Consistent with the amplitude change pattern, the N400 is sensitive to semantic congruency, and this sensitivity was declined in the older adults. Such a reduced semantic integration effect could be explained by reduced brain functional response or brain shrinkage as observed in previous studies (Diaz et al., 2016; Grossman et al., 2002; Peelle et al., 2010; Tremblay, Dick, & Small, 2013; Zhu et al., 2017), or inefficient information transmission across the language network (Diaz et al., 2016; Fedorenko & Thompson-Schill, 2014).

Taken together, the results suggest that age-related semantic integration decline co-occurs with working memory decline, but functions independently of working memory. The isolated semantic integration decline in the present results fit well with theoretical assumptions (Hagoort et al., 2009) and empirical evidence of isolated activation for semantic integration in a previous functional magnetic resonance imaging study (Zhu et al., 2013) and an ERP study (Nakano et al., 2010). Alternatively, evidence of different connection patterns across a set of brain regions shared by semantic integration and working memory could also support the independence of the two processes (Fedorenko & Thompson-Schill, 2014). The inconsistency between the present study and the extant literature may be due to the difference in stimuli. Because the comprehension of complex sentences relies on working memory more than simple sentences do, it is easier to find a working memory effect on comprehension decline in studies that used complex sentences (DeCaro et al., 2016; James, Krishnan, & Aydelott, 2014). Therefore, the results of other studies may be confounded by working memory.

Controlling for working memory provides evidence that informs current controversies regarding the peak latency of the N400 effect. While some studies have found delayed peak latency of the N400 effect (Federmeier, Van Petten, Schwartz, & Kutas, 2003; Gunter et al., 1995; Wlotko & Federmeier, 2012; Xu et al., 2017), other studies have not (Faustmann et al., 2007; Federmeier et al., 2002). The inconsistency may be due to the confounding effect of working memory decline. In the current study the marginal delay in peak latency was no longer apparent when working memory was taken into account. Critically, the present study found delayed onset latency for older adults. Given that onset latency reflects processing speed, the result further suggests that slowing in general processing speed (Salthouse, 1996) may contribute to declines in semantic integration.

Previous studies have suggested that the LPC reflects the cost of predictive error in older adults and is also correlated with verbal fluency (Federmeier *et al.*, 2002, 2010). Inconsistent with these claims, there was no such correlation in the present study ($r = -.18$, $p = .26$). Alternatively, the significant LPC effect found exclusively in anterior regions in the older adults may suggest they tried to compensate for the N400 effect decline (Peelle *et al.*, 2010; Xu *et al.*, 2017). However, the nonsignificant correlation between LPC effect and accuracy ($r = -.04$, $p = .81$) suggests that the older adults did not successfully compensate for the declines in semantic integration, if there was a compensation effort (Cabeza & Dennis, 2012). Finally, it might be possible that the older adults were trying to build up a compensatory scaffold, but this did not significantly help their performance, consistent with the scaffolding theory of aging and cognition (Park & Reuter-Lorenz, 2009). Future studies are required to test whether there were brain regions that can successfully compensate for the declines in semantic integration.

Finally, isolation of semantic integration from working memory and other neuropsychological functions may be helpful in future research on language and degenerative diseases. For instance, in assessment of aphasia, working memory deficits would be detrimental to comprehension especially in complex sentences. The independence of semantic integration during reading and working memory would help to detangle language and general disorder in aphasia. Moreover, recent studies have shown that there are significant semantic processing deficits in Alzheimer disease (Kemper, Marquis, & Thompson, 2001; Sugarman *et al.*, 2012), and semantic performance can be used to discriminate Alzheimer patients from cognitively healthy elderly adults (Clark *et al.*, 2016; Szatloczki, Hoffmann, Vincze, Kalman, & Pakaski, 2015). However, such semantic decline also accompanies declines in general cognitive processes. Isolating semantic process effects from other factors may help researchers to better understand the semantic deficits in degenerative diseases.

Conclusions

The present study found that although age-related declines in semantic integration and working memory co-occur, the two processes appear to be independent. After controlling for working memory, there was still significant age-related decline in semantic integration in a relatively large sample. The results demonstrate a distinction between semantic integration and working memory during aging.

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