HHS Public Access
Author manuscript
Exp Aging Res. Author manuscript; available in PMC 2016 February 11.

Published in final edited form as:
Exp Aging Res. 2015 ; 41(3): 272–302. doi:10.1080/0361073X.2015.1021646.

THE EFFECT OF PLAUSIBILITY ON SENTENCE COMPREHENSION AMONG OLDER ADULTS AND ITS RELATION TO COGNITIVE FUNCTIONS

Jungmee Yoon,
Speech-Language-Hearing Sciences, The Graduate School and University Center of the City University of New York, New York, New York, USA

Luca Campanelli,
Speech-Language-Hearing Sciences, The Graduate School and University Center of the City University of New York, New York, New York, USA

Mira Goral,
Speech-Language-Hearing Sciences, The Graduate School and University Center of the City University of New York, New York, New York, USA; and Speech-Language-Hearing Sciences, Lehman College, Bronx, New York, USA

Klara Marton,
Speech-Language-Hearing Sciences, The Graduate School and University Center of the City University of New York, New York, New York, USA; and Faculty of Special Education, Eötvös Loránd University, Budapest, Hungary

Naomi Eichorn, and **Loraine K. Obler**
Speech-Language-Hearing Sciences, The Graduate School and University Center of the City University of New York, New York, New York, USA

Abstract

Background/Study Context—Older adults show age-related decline in complex-sentence comprehension. This has been attributed to a decrease in cognitive abilities that may support language processing, such as working memory (e.g., Caplan, DeDe, Waters, & Michaud, 2011,Psychology and Aging, 26, 439–450). The authors examined whether older adults have difficulty comprehending semantically implausible sentences and whether specific executive functions contribute to their comprehension performance.

Methods—Forty-two younger adults (aged 18–35) and 42 older adults (aged 55–75) were tested on two experimental tasks: a multiple negative comprehension task and an information processing battery.

Results—Both groups, older and younger adults, showed poorer performance for implausible sentences than for plausible sentences; however, no interaction was found between plausibility and age group. A regression analysis revealed that inhibition efficiency, as measured by a task that

Address correspondence to Jungmee Yoon, Speech-Language-Hearing Sciences, The Graduate Center of the City University of New York, 365 Fifth Avenue, New York, NY 10016, USA. jyoon2@gc.cuny.edu.

required resistance to proactive interference, predicted comprehension of implausible sentences in older adults only. Consistent with the compensation hypothesis, the older adults with better inhibition skills showed better comprehension than those with poor inhibition skills.

Conclusion—The findings suggest that semantic implausibility, along with syntactic complexity, increases linguistic and cognitive processing loads on auditory sentence comprehension. Moreover, the contribution of inhibitory control to the processing of semantic plausibility, particularly among older adults, suggests that the relationship between cognitive ability and language comprehension is strongly influenced by age.

Language comprehension is a complex skill that draws upon cognitive abilities as well as linguistic knowledge. Comprehension performance may vary based on the context of language use, task complexity (e.g., linguistic and cognitive demands), or modality (e.g., oral or written linguistic input). Moreover, individual differences in general cognitive ability, education level, and vocabulary size may also contribute to performance on language tasks. Age is another variable that contributes to language processing. Earlier research has demonstrated that older adults show preserved language abilities in some areas (e.g., increased vocabulary skills) but decreased performance in other areas (e.g., language comprehension and perception) (see, e.g., Goral, Spiro, Albert, Obler, & Connor, 2007; Schneider, Daneman, & Pichora-Fuller, 2002; Tun & Wingfield, 1999; Wingfield & Tun, 2001).

Research over the past decade suggests a link between language comprehension and underlying cognitive abilities. Older adults show poorer spoken sentence comprehension especially when tasks involve greater processing demands, such as in syntactically complex sentences (e.g., Wingfield & Stine-Morrow, 2000; Sommers, 1996). Many researchers attribute this decline specifically to deficits in working memory and attention control (e.g., Goral et al., 2011; Wingfield & Grossman, 2006). Slower processing speed and limited attention capacity have often been observed among older adults, possibly accounting for difficulties comprehending sentences with complex syntactic structures (e.g., Tun, Benichov, & Wingfield, 2010).

Studies examining sentence comprehension in healthy aging have utilized on-line processing and off-line performance measures, sometimes with inconsistent results. For example, age-related differences that have been reported with off-line measures, such as postsentential comprehension probes (e.g., DeDe, Caplan, Kemtes, & Waters, 2004; Stine-Morrow, Ryan, & Leonard, 2000), sometimes disappear in online processing measures, such as self-paced listening paradigms. This apparent discrepancy has been explained by Caplan and Waters (1999), who suggest that online processing measures do not require the same amount of working memory resources as offline measures and therefore do not always show age-related differences in performance. Below, we review results of both online and offline measures of sentence comprehension to provide evidence for the considerable contributions of cognitive abilities to comprehension performance.

Older adults with better cognitive abilities may demonstrate comparable comprehension performance to younger adults, especially in online processing (e.g., Wingfield & Grossman, 2006). Wingfield and Grossman (2006) found that older adults who perform as

well as younger adults during sentence comprehension recruit additional brain areas in doing so (i.e., increased brain activity in the dorsal area of the left inferior frontal cortex, considered crucial for maintaining and rehearsing stored verbal information in working memory). In the same study, older adults showed contralateral neural activation in the right posterolateral temporal-parietal region to compensate for the reduced activation in core language areas of the brain (i.e., left temporal-parietal region). Fiber tracts connecting frontal regions to posterior ones bilaterally have also been linked to better comprehension among older adults (Hyun et al., in revision). As a compensatory strategy for declines in comprehension, Wingfield and Grossman (2006) posit that older adults are likely to employ higher level activation or supplementary cognitive resources (e.g., by recruiting the frontal area of the brain associated with executive functions to compensate for decline in sensory functioning).

It has been proposed that age-related shifts in strategy are used to compensate for difficulties in sentence comprehension. Obler, Fein, Nicholas, and Albert (1991) reported that older adults showed greater reliance on semantic context than young adults. That is, older adults showed better comprehension for semantically plausible sentences than for semantically implausible ones. In contrast, Federmeier, Kutas, and Schul (2010) found that younger adults, but not older adults, showed a stronger N400 response for predictable sentence final words compared to unpredictable words in an event-related potential (ERP) study. This finding suggests that older adults are less likely than younger adults to use word predictability as a comprehension strategy. Although the two studies present contrasting findings, both findings suggest that older adults' performance is linked to semantic or contextual information during comprehension. It remains unclear, however, whether older adults overuse or underuse this information relative to younger adults. In the current study, we investigated the effects of aging based on off-line performance measures to determine whether older adults strategically utilize semantic context to support sentence comprehension. We also asked whether sentence processing performance may be related to cognitive processes other than working memory capacity, which has previously been linked to sentence comprehension (e.g., Christianson, Williams, Zacks, & Ferreira, 2006).

There is little discussion in the literature about the interaction between sentence structure and semantic information or about the specific cognitive mechanism(s) underlying semantic integration during auditory sentence comprehension in older adults (but see Fallon, Peelle, & Wingfield, 2006). The purpose of this study was to examine the association between specific executive functions, such as inhibitory control, and auditory comprehension of implausible sentences to further our understanding of the relationship between executive functions and sentence comprehension.

Contribution of Cognitive Abilities to Sentence Comprehension in Aging

Although previous studies have identified a number of cognitive mechanisms that may underlie sentence comprehension in older adults, such as general processing speed (Salthouse, 1996; Caplan, DeDe, Waters, & Michaud, 2011) and attention control (e.g., Salthouse, Fristoe, Lineweaver, & Coon, 1995), the majority of the studies examined the relationship between working memory and language comprehension, suggesting that better

comprehension is associated with lower working memory demands (e.g., Caplan et al., 2011; Grossman, Cooke, De Vita, Alsop, Detre, Chen, & Gee, 2002; Margolin & Abrams, 2009) and with better working memory spans. The notion that working memory deficits underlie comprehension changes in older adults has been based on studies examining the relation between working memory and syntactic complexity. For example, individuals with more limited working memory capacity may not be able to process information in an efficient manner, and their slow encoding of information or delayed processing may lead to rapid decay (e.g., Caplan et al., 2011). Few studies have considered the role of semantic complexity in sentence comprehension changes in older adults. It is conceivable that the processing load of semantically demanding sentences places as significant a burden on cognitive resources as syntactic complexity. Furthermore, the cognitive demands of semantically complex sentences may not be limited to working memory but may involve additional cognitive mechanisms, such as inhibition and attention control.

There are several executive functions that play an important role in language processing, as well as in age-related changes (Cahana-Amitay et al., in revision; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000; Rhodes, 2004; Zachs et al., 1996). Working memory, inhibition, and attention switching have been found to decrease with advancing age. Of particular interest in the current study is age-related change in the efficiency of inhibition, which has received considerable attention in the cognitive aging literature (e.g., Hasher, Quig, & May, 1997; Zacks & Hasher, 1988; Schilling, Chetwynd, & Rabbitt, 2002). Hasher and colleagues report that inhibition is directly linked to the processing of semantic ambiguity because the irrelevant information has to be suppressed. According to the inhibitory deficit hypothesis (Zacks & Hasher, 1988; May, Zacks, Hasher, & Multhaup, 1999; Lustig, Hasher, & Zacks, 2007), older adults are likely to have difficulty processing semantically and/or syntactically ambiguous sentences due to (1) increased susceptibility to interference or distraction; and (2) weaker memory representations of relevant information. It is also likely that older adults demonstrate inefficient inhibition due to difficulties attending to incoming information or switching attention back and forth during information processing. Recent evidence suggests that changes in attention control may contribute to age-related decline in comprehension (Goral et al., 2011). Aging may weaken attention-control mechanisms (e.g., Sommer, 1996), such that older adults are less likely to attend selectively to relevant information or switch between tasks or mental sets. This decreased mental flexibility may result in subtle changes in language comprehension as well as cognitive processing (Goral et al., 2011; Cahana-Amitay et al., submitted).

Although previous work has examined the relationship between language comprehension and cognitive function in older adults, findings are difficult to interpret because different studies (e.g., MacDonald et al., 1994; Miller et al., 2006; Pichora-Fuller, 2003; Titone et al., 2000; Waters & Caplan, 2005) have focused on different factors influencing sentence comprehension (e.g., syntactic complexity or semantic ambiguity) and different executive functions, such as working memory, processing speed, attention, or inhibition. Moreover, individual cognitive abilities (e.g., resistance to interference vs. attention) have proved difficult to dissociate with the tests (e.g., the Wisconsin Card Sorting test, the Trails test) that have been used in previous studies (e.g., Marton, Campanelli, Eichorn, Scheuer, &

Yoon, 2014; Miyake et al., 2000). To compare the extent to which specific executive functions predict comprehension of semantically complex sentences in young and older adults, we selected three target executive functions that have been linked to comprehension in aging that are separable and that may contribute differently to language comprehension: (1) updating and monitoring working memory representations; (2) shifting between tasks or mental sets; and (3) inhibition, more specifically resistance to proactive interference (Friedman & Miyake, 2004; Miyake et al., 2000).

Age-Related Differences in Reliance on Contextual Information

Language processing consists of distinct routes to interpretation: (a) processing of syntactic structure according to the morphosyntactic rules of a given language; and (b) semantic integration of lexical items (mapping them onto semantic roles such as agent and patient) based on listeners' experience with those lexical items (Christianson, Luke, & Ferreira, 2010). In electrophysiological studies of typical listeners, morphosyntactic and semantic processing are reflected in the P600 and N400 components, respectively, providing evidence supporting these distinct routes to comprehension (e.g., Kuperberg, Caplan, Sitnikova, Eddy, & Holcomb, 2006; Van Herten et al., 2006). Ferreira (2003) further reported an interaction between syntactic and semantic processing routes, described as the effect of "plausibility." In Ferreira's study, this effect was reflected in higher accuracy for plausible passives compared with implausible passives; however, no plausibility effect emerged with active sentences. To date, few behavioral studies have examined plausibility effects and these studies focus only on young adults.

The semantic contribution to language processing has been reported in the aging literature, with most studies focusing on its facilitative role in sentence comprehension (e.g., Cohen & Faulkner, 1983; Sommers & Danielson, 1999). Contextual information can facilitate sentence comprehension (e.g., Carpenter & Miyake, 1995) and serve as a means of compensating for underlying cognitive weaknesses. The extent to which older adults rely on contextual information to support comprehension has been examined in two types of studies: (1) studies comparing sentences with high and low levels of predictability; and (2) studies comparing plausible and implausible sentences. Kalikow, Stevens, and Elliot (1977) compared high-predictability and low-predictability sentences from the Speech Perception in Noise Task (SPIN) to examine the role of semantic support during spoken word recognition. The results demonstrated an age-related strategy shift such that older adults relied more on contextual information and benefited from the presence of added linguistic information (i.e., predictability) to a greater extent than young adults. One possible explanation for this finding is that such linguistic information may serve as a means of compensating for less efficient spoken language processing and reduced cognitive resources.

Another line of evidence for the role of contextual information in language comprehension comes from studies on semantic plausibility. Plausible information represents a type of contextual support, as such information can be automatically and easily processed on the basis of general world knowledge. In contrast, implausible information interferes with general knowledge and thus increases processing demands during sentence comprehension. Obler and her colleagues (1991) studied the role of plausibility in sentence processing and

found a performance discrepancy in older adults associated with implausibility, with poorer performance on implausible sentences compared to plausible ones. This discrepancy was not observed in younger adults, who performed similarly on both plausibility conditions. Older adults thus appeared to rely on real-world knowledge to compensate for cognitive-linguistic weakness (Obler et al., 1991).

A comparison between plausible and implausible sentences can be used to examine possible effects of interference on sentence comprehension. We proposed that older adults may have a selective problem with syntactic decoding, a difficulty in inhibiting semantic interference with real-world knowledge, or a combination of both (Davis & Ball, 1989). According to Zacks and Hasher (1988), older adults may perform better on plausible sentences than on implausible sentences (the plausibility advantage) because the plausible ones can be processed with little interference from or conflict with previous knowledge. However, it is unclear whether older adults show a plausibility advantage only when sentence structures are more complex or demanding. That is, when syntactic demands are low, it is possible that older adults will perform like younger adults and show no discrepancy between plausibility conditions. The present study expands upon earlier findings by Obler et al. (1991) by examining the effect of plausibility on sentence comprehension in older adults using sentences that vary in structural complexity. These manipulations enable us to observe the contributions of inhibitory functions, as well as working memory and attention switching, during sentence comprehension. We chose to focus on negative sentences because, like embedded or passive sentences, this syntactic structure is associated with high processing demands and comprehension difficulties but has been less extensively studied (Carpenter, Just, Keller, Eddy, & Thulborn, 1999; Goral et al., 2011; Margolin & Abrams, 2009). Our primary aim was to investigate how sentence structures with one or two negatives affect comprehension abilities and how these structures may interact with semantic information in the aging population.

The Present Study

Although previous studies attribute the plausibility advantage in older adults to age-related changes in interference control (i.e., resisting semantic interference), this explanation is generally speculative. In the current study, we tested whether older adults demonstrate poor interference control in the processing of semantically implausible sentences when both semantic plausibility and sentence structure (i.e., number of negatives) are manipulated. We included manipulations of both plausibility and sentence structure in order to examine the independent effects and possible interaction of these variables. Moreover, we considered whether specific executive functions (i.e., inhibitory control and/or attention switching) contribute to sentence comprehension among older adults in addition to the well-known contribution of working memory abilities.

Of particular interest was whether inhibitory control plays a role in the processing of implausible complex sentences during comprehension. We predicted that older adults, whose inhibitory control might not be as efficient as that of younger adults, could benefit from plausible information during sentence processing to a greater extent than young adults. Our review of age-related comprehension difficulty led to three specific research questions:

(1) Are larger age differences in comprehension observed for the processing of implausible sentences compared to plausible ones? (2) Is a greater plausibility effect observed in structurally more complex sentence conditions compared to less complex ones? (3) Does inhibition efficiency contribute to older adults' comprehension of implausible sentences beyond the demonstrated contribution of working memory abilities?

The corresponding hypotheses were that (1) larger age differences in comprehension should be observed on implausible sentences compared to the plausible sentences and should be linked to poorer inhibitory control in older adults; (2) the number of negatives in a sentence would increase cognitive and linguistic processing loads during comprehension such that larger plausibility effects should be revealed in the more complex sentence conditions (i.e., single- and double-negative conditions compared with no-negative); and (3) inhibition efficiency would predict comprehension performance on implausible sentences in older adults. In other words, older adults with better inhibition control would outperform older adults with poorer abilities on implausible sentences but not necessarily on plausible sentences.

METHODS

Participants

Forty-two young adults (YA), ranging in age from 18 to 35 years, and 42 older adults (OA), ranging from 55 to 75 years, participated in the study. The average age of the YA group was 26.2 years (*SD* = 4.2) and that of the OA group was 64.6 years (*SD* = 6.1). All participants were monolingual native English speakers. Potential participants were screened via a telephone interview before scheduling the experiment to ensure that they had no history of neurological disabilities, learning or reading disabilities, emotional or psychiatric disorders, stroke, or any major health issues. All participants were right-handed except for three YAs and six OAs. Among the non-right-handers, one was ambidextrous in each age group and the rest were left-handed. All participants reported normal or corrected vision.

Additional inclusion criteria consisted of bilateral pure tone averages of at least 25 dB HL for YAs and 40 dB HL for OAs, based on mean thresholds obtained in both ears at octave frequencies of 500, 1000, 2000, and 4000 Hz (Lemkens et al., 2002). Although hearing thresholds between 25 and 40 dB HL is considered a mild hearing loss (Clark, 1981), this criterion has been used in research involving elderly adults, even when experimental procedures involve auditory stimuli (e.g., Cahana-Amitay et al., 2012; Goral et al., 2011). We further ensured that sentences were being presented at an adequate loudness level by encouraging participants to adjust the volume to a comfortable level during the practice trials before testing began. The Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) was administered to all participants to screen out mild cognitive impairments or dementia. From a subject pool of 84 participants, two OAs were excluded due to low MMSE scores (i.e., below 26). An additional YA was excluded due to failure to complete experimental procedures. In all, 41 YAs and 40 OAs were included for data analysis. Average years of education was matched across the two age groups at just over 16 years (see Table 1). All participants were recruited from the community and compensated for their participation. This project was approved by the institutional review board (IRB) at

The Graduate Center of the City University of New York. Informed consent was obtained from all participants prior to beginning any experimental procedures.

Procedure/Stimuli

Two experiments were drawn from a larger study: (1) a multiple negative sentence comprehension task developed by Goral and colleagues (Goral et al., 2011); and (2) an information processing battery developed by Marton (Marton et al., 2014). The sentence comprehension task was administered via E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA) and consisted of sentences presented auditorily via headphones. The spoken sentence stimuli (see details below) were recorded by a female native speaker of American English using a head-worn microphone in a double-walled, sound-attenuated booth. The language comprehension task consisted of two blocks of trials with a short break in between blocks. On each trial, a spoken sentence was presented. Participants were asked to listen to each recorded sentence and judge its plausibility by pressing either the rightmost or leftmost button on a response box, which were labeled "likely" or "unlikely" for plausible and implausible sentences, respectively. The assignment of left and right buttons was counterbalanced across participants. Participants were instructed to respond accurately and as quickly as possible. Three practice items were given at the beginning of testing.

The language comprehension task included a total of 50 sentences, with three types of experimental sentences and two types of control sentences. Within each condition, five sentences were plausible and the other five sentences were implausible. The same lexical items were used to generate the experimental sentences across each of the three negative conditions. For example, the experimental sentence stimuli included (1) 10 sentences with no negative (e.g., *Because the ceiling light is off, the room is dark. [plausible]; Because the ceiling light is on, the room is dark. [implausible]*); (2) 10 sentences with one negative located in either the first or second clause (e.g., *Because the ceiling light is* ***not*** *on, the room is dark. [plausible]; Because the ceiling light is* ***not*** *off, the room is dark.[implausible]*); and (3) 10 sentences with two negatives, one in each clause (e.g., *Because the ceiling light is* ***not*** *off, the room is* ***not*** *dark.[plausible]; Because the ceiling light is* ***not*** *on, the room is* ***not*** *dark. [implausible]*). Sentence length varied based on experimental condition, with 0-, 1-, and 2-negative sentences consisting of 10, 11, and 12 words, respectively. Control sentences included either 11 or 12 syllables and had no negatives (e.g., *Because the knife was sharp, it could cut the large turkey. [plausible]; Because the knife was dull, it could cut the large turkey. [implausible]*).There were two sets of 50 sentences (i.e., 10 sentences with no negative; 10 sentences with one negative; 10 sentences with two negatives; 10 affirmative sentences with 11 syllables; 10 affirmative sentences with 12 syllables), and the presentation of the two sets was counterbalanced. Each participant heard only one set of sentences, and we analyzed the two sets together.

The stimuli and tasks for the second experiment were drawn from an original information processing battery developed by Marton (Marton et al., 2014). The three tasks included in the present study comprised manipulations to measure: (1) inhibitory control, (2) working memory, and (3) attention switching. Tasks were administered via computer, and responses were collected via three large colored buttons (one red button between two black ones)

positioned approximately one inch away from the edge of the desk. All tasks involved category judgments for simple high-frequency words. Task order was randomized across participants to control for practice or other task order effects. In each trial, participants were instructed to press and hold the red response button to start. They were instructed to release the red button as soon as a category name (e.g., "Family") appeared at the top of the screen, then wait for the appearance of a target word that belonged to the category (e.g., "Mother") or a distractor word that did not ("Ball"). The interval between the appearance of a category name and target or distractor word varied between 1000 and 2000 ms. For target words, participants were required to press the black button corresponding to the side on which the target word appeared. For distractor items, participants were required to press the red button in the center. Participants were instructed to respond as quickly as possible with either hand. Failure to respond within 5 s triggered automatic presentation of the subsequent trial.

The inhibitory control condition utilized previous target words as distractors. This manipulation was designed to create proactive interference, requiring participants to respond differently to the item, which was previously a target word but became a distractor for the current category. In the working memory condition, category names were presented once, followed by a series of target or distractor words that were not preceded by the category name. Increased working memory load was required to maintain category names in memory while making decisions for the series of items within each category. The attention switching condition involved more frequent category changes, which required more switching between categories than the baseline measure.

All experimental procedures were completed in a single testing session that took place in a quiet room and took approximately 3 hr, with breaks as needed. The order of the experimental tasks was counterbalanced across participants. Performance accuracy (ACC) and response time (RT) were automatically recorded for both language comprehension and information processing tasks.

Data Reduction and Analysis

For the language comprehension and the information processing tasks, dependent variables were response accuracy (%) and response time (ms). Additionally, to address patterns of trade-off between speed and accuracy observed in the data, we calculated overall performance efficiency (i.e., response time/response accuracy; see Townsend & Ashby, 1983).

Independent variables for the language comprehension task included semantic plausibility (plausible vs. implausible), negative condition (0-, 1-, or 2-negative), and group (young vs. older adults). The mean RT of each participant was calculated for each condition, using only correct responses. As we expected that mean and *SD* would vary from the easy to more difficult conditions, within-subject RT outlier data were identified separately for each negative condition. RT points 2 *SD* above or below the mean were considered outliers and were replaced by the upper ($M + 2$ *SD*) or lower ($M - 2$ *SD*) limit of the data distribution for each individual. Group mean RT and ACC were computed to identify between-subject outliers. Outliers were determined by considering box plots, normality checks, *z*-scores, distribution checks, and comparisons of raw data. Among the between-subject outliers, we

deleted outlier data of one older adult who performed less accurately and more slowly than the rest of the group across conditions of the language task, including the easiest condition. Additionally, as stated above, both RT and ACC outlier data from the implausible 2-negative condition were excluded for one young adult due to a missing RT data point resulting from zero accuracy in the condition. Remaining outlier RTs were replaced using the same procedure described for within-subject outliers, but for each group (i.e., the upper or lower limit of the data distribution of each group).

For the information processing tasks, independent variables were the specific cognitive functions measured by each condition, namely, working memory, inhibitory control, and attention switching. Mean RT for each participant and group was processed in each condition and a 3-*SD* criterion was employed to detect and replace within-subject and between-subject outliers.[1] Group mean RT and ACC were calculated. Outlier RTs were replaced using a procedure similar to that used with the language data. Two outlier participants, one YA and one OA, were removed due to extremely poor performance across conditions. Outlier scores replaced or deleted in each task were less than 3% of the data set. Effects are reported as significant for $p < .05$. Significance level for post hoc analyses was adjusted using Bonferroni's correction by multiplying the unadjusted *p* values by the number of comparisons.

RESULTS

First, we consider the overall performance of each group on the sentence comprehension task and analysis of variance (ANOVA) results to determine the effects of semantic plausibility, negatives, and interactions between the two variables. Then, we turn to the overall performance of each group on the information processing tasks. Finally, we report the regression results to examine the relation between cognitive functions and comprehension performance with respect to our third research question.

Language Comprehension Performance

To determine whether age-related differences of comprehension performance were observed and whether plausible sentences were more easily processed than implausible sentences, ACC, RT, and efficiency data were entered into an individual mixed-design ANOVA with a between-subjects factor (younger vs. older participants) and two within-subject factors: negative condition (0-, 1-, and 2-negative) and plausibility condition (plausible vs. implausible). Separate analyses were performed using participants as the random factor (*F1* analysis) and using items as the random factor (*F2* analysis). The results of the analyses by participant and by item were then combined in the $minF'$ statistic. The $minF'$ statistic allowed us to generalize our findings across participants and items at the same time (Clark, 1973).

Here we describe results mainly based on the efficiency data combined in $minF'$ calculations, in order to take both performance accuracy and speed into account, and to

[1]We used 3-*SD* criteria here because 2-*SD* criteria excluded too many data points and therefore made it difficult to distinguish extreme outliers from faster or slower responses.

combine results from *F1* and *F2* analyses. Descriptive statistics for comprehension by group and condition are summarized in Table 2.

For efficiency data, results of the *minF′* analysis revealed a main effect of plausibility, with poorer performance in the implausible condition, a main effect of number of negatives, and a Negatives × Plausibility interaction (Table 3).

Post hoc comparisons for the effect of number of negatives showed that the 2-negative condition was more difficult than both the 1- and the 0-negative conditions, *minF′* (1, 73) = 8.82, $p = .012$ and *minF′* (1, 62) = 15.2, $p = .001$, respectively. The difference between 0-negative and 1-negative was not statistically significant, *minF′* (1, 36) = 0.72, $p = 1$ (Bonferroni adjusted).

Post hoc analysis for the Negatives × Plausibility interaction indicated significant performance differences between plausible and implausible sentences in the 2-negative conditions only (see Table 4). For plausible sentences, no significant differences emerged in any of the negative conditions. In contrast, for implausible sentences, the 2-negative condition was significantly more difficult than both 0- and 1-negative conditions. No difference emerged between 0- and 1-negative implausible sentences (Table 4).

Although our findings focus on *minF′* results, we did find a main effect of group and a Group × Negatives interaction on efficiency performance in the *F1* analysis, that is, the by-subject analysis (see Table 3). The effect of group indicated that older adults performed worse than younger adults. The Group × Negatives interaction indicated that the effect of number of negatives was greater for older adults than younger adults, as illustrated in Figure 1 (see also Table 5).

In order to evaluate the possible confounding effect of sentence length,[2] we performed an additional mixed-design ANOVA with a between-subject factor of age group and two within-subject factors: sentence length (10-word, 11-word, and 12-word sentences) and plausibility condition (plausible vs. implausible). Results revealed neither a main effect of sentence length, $F(2, 156) = 2.297$, $p = .104$, $\eta_p^2 = .461$, nor a sentence Length × Plausibility interaction, $F(2, 156) = 2.297$, $p = .104$, $\eta_p^2 = .539$; however, there was a main effect of plausibility, $F(1, 78) = 7.93$, $p = .006$, $\eta_p^2 = .794$. The main effect of group was not significant, $F(1, 78) = .911$, $p = .343$. The Group × Plausibility interaction, $F(1, 78) = .433$, $p = .512$, $\eta_p^2 = .1$, and the Group × Sentence Length interaction, $F(2, 156) = 2.764$, $p = .066$, $\eta_p^2 = .539$, were not significant.

Performance on the Information Processing Battery

Descriptive statistics for data by group and condition are summarized in Table 6. Accuracy, reaction time, and efficiency data were entered into an individual mixed-design ANOVA with a between-subjects factor of age group (younger vs. older participants) and a within-

[2]It was not possible to perform *F2* analysis and *minF′* calculation for the effect of sentence length because the lexical items of the control sentences were different from those of the experimental conditions.

subjects factor of task variables with four levels (baseline, working memory, attention switching, and inhibition).

For the efficiency data, ANOVA results showed significant main effects of group and task. The interaction between group and task was not significant (see Table 7). Post hoc comparisons for the task effect showed that there were no statistically significant differences between baseline, working memory, and attention switching tasks, and that all of them were significantly easier than the Inhibition task (see Table 8). Analysis of RT data revealed a significant Group × Task interaction (see Table 7); this interaction indicates that the effect of the inhibition condition was greater in older adults than in younger adults, as illustrated in Figure 2 (see also Table 9).

Relationships Between Sentence Comprehension and Cognitive Functioning

A hierarchical regression analysis[3] was conducted to investigate which specific cognitive function(s) predicted sentence comprehension (Tabachnick & Fidell, 2007). Consistent with previous analyses, we used the efficiency measure (which combined accuracy and performance speed) for the regression analysis. We were particularly interested in determining which cognitive functions predicted performance for implausible sentences in the most difficult condition. Therefore, the efficiency measure in the 2-negative *implausible* condition was entered as a dependent variable with the three cognitive functions and age group as predictors. Although we found moderate correlations among the predictor variables, the assumption of multicollinearity was not violated, based on the average variance inflation factor (VIF) of 2.6 (range: 1.15–4.32) for our independent variables, which falls well below 10, the accepted cutoff score for determining multicollinearity (Chatterjee & Hadi, 2006).

The independent variables were entered following a theoretically constrained order: we first entered (Model 1) the two covariates to control for processing efficiency for plausible sentences (only for the 2-negative *plausible* condition) and general efficiency of processing (baseline), which were kept in the models. Age group and inhibition performance were also entered in Model 1. The model showed that the efficiency measure in the 2-negative plausible condition best predicted implausible processing ($p < .001$).

In Model 2, we examined the Age Group × Inhibition interaction. As hypothesized, our data revealed that this interaction effect was significant, predicting the processing of implausible sentences ($p < .05$), indicating different patterns between the two age groups. That is, inhibition efficiency contributed to the comprehension of implausible 2-negative sentences in older adults. As older adults resist interference more efficiently (with better inhibitory control), they show better performance in the processing of implausible 2-negative sentences. Model 2 thus accounts for the data better than Model 1. Note that the estimated difference between age groups is larger for participants with poor inhibitory control than for participants with better control (based on efficiency scores ± 1 *SD* in each age group). That is, high-performing older adults are about 233 ms faster than younger adults; however, low-performing older adults are on average 991 ms slower than younger adults. In Model 3, two

[3]We also performed a stepwise regression and found results that were similar to those obtained in the hierarchical regression.

other measures of executive functions were entered: working memory and attention switching. Results indicated that these two variables accounted for a non-significant amount of variance (0.4%) and were not significant predictors of the outcome variable (for working memory, p = .474; for attention switching, p = .578). In Model 4, we entered the interactions between group and three measures (attention switching, working memory, and baseline performance). Model 4 did not explain a significant amount of variability above and beyond model 3 (R^2 change = 0.9%). Models 3 and 4, in summary, did not explain a significant amount of variability above and beyond the variability explained by Model 2 (see Table 10).

DISCUSSION

In the current study, we employed a multiple-negative sentence-comprehension task to examine age-related decline in comprehension and increased susceptibility to interference during processing of semantically implausible sentences. Goral et al. (2011) found that sentences with two negatives did not increase processing load selectively for older adults, aged 55 to 75, as all participants demonstrated performance accuracy decrease on the 2-negative condition, with no age effect. Our additional examination of the effect of semantic plausibility within the negative sentence constructions enabled us to find important interactions between syntactic structure, semantic integration, and age-related differences in language comprehension performance.

Our key finding with respect to the effect of negative processing was that an increasing number of negatives increased computational processing demands for all participants (as reflected in ACC, RT, and efficiency measures). This is consistent with previous studies for younger and older adults. For example, Christensen (2009) found that sentences with negatives were cognitively more demanding than affirmative sentences for young adult participants; however, his finding was restricted to RT differences, not ACC. Margolin and Abrams (2009) reported that both young and older adults performed more slowly and less accurately on single-negative sentences compared to sentences without negatives in a reading comprehension task. It is possible that increasing the number of negatives in a sentence affects performance due to the concurrent increase in sentence length; however, we did not see any confounded effect of sentence length on the negative processing.

Despite generally similar patterns of performance between the groups, certain subtle differences suggest that the older adults were more sensitive to the increasing demands required by additional negatives. The Group × Negatives interaction in the *F1* analysis (by-subject) indicates that the effect of negatives differed based on group. Although both groups had difficulty processing 2-negative sentences compared to baseline sentences (0-negative), older adults were also less efficient in the 2-negative compared to 1-negative condition. In contrast, young adults showed reduced efficiency for 2-negative sentences compared to 0-negative but showed no efficiency difference between 0- and 1-negative or 1- and 2-negative conditions. These findings suggest that sentence comprehension abilities of older adults deteriorate more rapidly than younger adults as linguistic stimuli grow increasingly complex.

A novel manipulation of sentence comprehension examined in this study was for semantic plausibility. We examined the interaction between semantic plausibility and age group (Research Question 1) and the interaction between semantic plausibility and complex structure (Research Question 2). Overall less efficient (less accurate and slower) performance was observed for implausible sentences than for plausible counterparts in the most difficult condition (i.e., 2-negative), together with no difference between implausible and plausible sentences in the 0- and 1-negative conditions in both groups. This finding suggests that the plausibility information, interacting with processing load by negatives, affects sentence comprehension performance in older adults as well as younger adults. Note that previous studies (e.g., Federmeier et al., 2002; Kalikow et al., 1977) reported age-related differences in the processing of semantic information. However, the current study differs from these studies in terms of the type of semantic, contextual information tested. That is, we examined whether older adults benefit from plausible information compared to younger adults, whereas the other studies focused on predictability.

In terms of the plausibility effect on sentence comprehension, our results are consistent with those reported by Ferreira (2003), even though sentence structures differed between studies. Overall, our findings provide further evidence for distinct routes of processing during sentence comprehension. In our study, sentence comprehension was influenced by manipulations of sentence complexity using negatives, and semantic processing was influenced by sentence plausibility. Moreover, we found different degrees of sensitivity between age groups for each contributor to language comprehension. Our data indicated a hint of age-related differences in auditory processing of negatives (i.e., Group × Negative interaction based on *F1* analysis only, not in *F2* analysis and *minF′* results) but similar processing patterns for semantic integration (i.e., lack of Group × Plausibility interaction) in the two groups.

Also, we should note that, in contrast to the present study, an interaction effect between group and semantic plausibility was found in the study of Obler et al. (1991). They reported the effect of plausibility only among the elderly participants (in their 70s), but not among their young adults (in their 30s) who performed similarly—at ceiling—for both plausible and implausible sentences. The authors argued that older adults might use different types of comprehension strategies relative to young adults, based on their findings that reliance on semantic content (rather than on syntactic cues) was observed in their elderly participants. It is worth noting that the single- and double-negative sentences used in the study of Obler et al. (1991) were additionally syntactically complex in that they included embedded structures (e.g., “The tourist who was *not inexperienced* lost the passports”). It is possible, therefore, that the age-related differential effects of plausibility are only observed under certain circumstances where demands for syntactic decoding are increased, showing the association of plausibility with age-related syntactic processing difficulty.

In summary, to answer our first research question, the implausible conditions were more difficult for all participants to process and older adults performed both more slowly and less accurately than young adults. However, we did not find the interaction we predicted between plausibility and age group. In contrast, the answer to our second research question was positive, as we observed a significant interaction between the number of negatives and

plausibility, pointing to an added difficulty of judging implausible sentences in the 2-negative conditions for both age groups. We turn next to our third question, regarding the underlying cognitive skills that may be recruited for efficient processing of these types of complex sentences.

The relation between sentence comprehension and executive functions, especially the role of working memory, has been previously studied for complex syntactic processing in a number of studies (e.g., Caplan et al., 2011; Goral et al., 2011; Margolin & Abrams, 2010; Wingfield & Grossman, 2006). In the current study, however, our focus was not only on sentence structure but also on the role of semantic plausibility. Sommer (1996, 1999) argued that, compared with younger adults, older adults might be more likely to use semantic context differently during spoken word recognition due to limited inhibitory abilities. That is, older adults demonstrated greater difficulty identifying lexical items with many competitors (i.e., high neighborhood density) than words with fewer competitors (i.e., low neighborhood density). The author found that older adults benefited from the addition of contextual information (i.e., predictability information) during spoken word recognition, and, furthermore, individual differences in inhibition control accounted for older adults' recognition performance for the more challenging high neighborhood density words. Yet, this previous finding is based on word-level processing; therefore, it is hard to generalize to sentence-level processing as studied here.

The effect of contextual facilitation in aging adults was also studied by Cohen and Faulkner (1983). The authors found different contextual effects between age groups for low- but not high-predictability words, and stimuli were presented in a background of white noise, which may have served as a distraction and required some degree of inhibitory control. Janse (2012), for example, suggests that inhibitory abilities as measured by Stroop interference relate to speech processing in noise among older adults. However, based on previous evidence, it is not sufficient to evaluate the contribution of cognitive functions to language comprehension. It is possible that additional cognitive abilities are needed for the processing of semantically implausible sentences. We therefore set out to examine whether the ability to inhibit real-world knowledge contributes to accurate processing of semantically implausible sentences.

Our regression analyses confirmed an interaction effect between age group and inhibition efficiency, showing different patterns between the two groups with respect to the contribution of cognitive functions to sentence comprehension. Among the older adults, inhibition efficiency emerged as a strong predictor of the processing of implausible 2-negative sentences. That is, older adults with better inhibition control (i.e., 1 *SD* below the mean of efficiency) perform similarly to younger adults, whereas older adults with poor inhibition control (i.e., 1 *SD* above the mean of efficiency) perform worse than younger adults. As in Goral et al. (2011), our older participants with better cognitive control (in our study, inhibition efficiency; in theirs, working memory and attention switching) comprehended implausible 2-negative sentences more efficiently than comparable-aged participants with poorer inhibitory control.

Our finding that a significant Group × Inhibition interaction effect predicted comprehension of implausible sentences is consistent with the hypothesis that semantically implausible sentences increase the degree of interference from general knowledge that older comprehenders rely on. That is, older adults with better inhibition ability comprehended complex sentences, in particular implausible, 2-negative sentences, more efficiently and more accurately than older adults with poorer inhibition ability. It should be noted that some older adults with better inhibition skills performed more efficiently than our young adults, and that our efficiency data from the younger adults did not show a ceiling effect. This pattern supports the compensatory theory for performance in aging and is consistent with previous evidence showing that older adults with better cognitive skills or additional brain activation during cognitive activity can compensate for language processing decline associated with increasing age (e.g., Wingfield & Grossman, 2006). Our finding of individual differences among our older adults suggests that advanced age itself does not necessarily predict poor performance; rather, older adults who show decline in cognitive functioning (e.g., in inhibition) experience difficulties in sentence comprehension, consistent with the interpretations of Goral and colleagues (2011). We find it interesting that the performance on the sentence comprehension task itself did not differ in the two age groups (based on *minF′* result), but that an age-related difference was evident in the underlying cognitive skills supporting successful performance.

In the current study, we did not find that our working memory measures contributed to off-line sentence comprehension in either group, although previous studies have repeatedly reported a role of working memory in sentence comprehension. We can speculate that working memory may contribute to syntactic processing per se, whereas the processing of implausible complex sentences relies to a larger degree on inhibition abilities. An alternative explanation for the difference between our findings and other studies is that most studies measure working memory using variations of span tasks, which are linguistically complex, whereas our working memory task was deliberately not linguistically demanding. In a previous study (Marton et al., 2014) with a sample of 44 children, efficiency measures on this WM task were moderately correlated with a more traditional measure of WM ($r = -.59$, $p < .001$), suggesting that although less linguistically demanding, our task represented a valid measure of WM.

Our finding extends previous evidence for the relation between cognitive abilities and sentence processing, demonstrating that inhibition efficiency could be linked to the processing of implausible sentences, but only in older adults. This is a novel finding showing that some older adults seem to employ the ability to resist interference when processing implausible sentences. We hypothesized that implausible sentences conflict with general knowledge in older adults; we found that both younger and older adults had more difficulty processing implausible sentences but that inhibition efficiency predicted performance only for older adults. Further, we expected that individuals might encounter a different degree of interference in the processing of implausible sentences and that some older adults could perform as well as young adults; indeed, that is what we found. Further study of multiple measures of cognitive abilities and their contribution to the processing of a

variety of language tasks would enhance our understanding of the relationship between language processing and age-related cognitive changes.

One limitation of the present study concerns the potential confound of hearing ability. Although older participants all passed hearing screenings at 40 dB, it is possible that some older adults may have had a mild hearing loss (thresholds between 25 and 40 dB) and that this could have influenced their performance. Our finding that the performance of older adults was slightly faster and more accurate than that of young adults at baseline (plausible sentences, 0 negatives) suggests that our pattern of results was not due to group differences in hearing, however.

Second, it should be noted that each negative condition in our comprehension task consisted of five semantically plausible and five implausible sentences. Given the relatively small number of observations, our findings should be considered with caution.

Finally, although we have some evidence for the validity of our working memory measure, as described above, we do not presently have similar data for the inhibition and attention switching tasks. However, our findings across studies show very consistent performance patterns with theoretically predicted outcomes; clinical groups (children with autism, attention-deficit hyperactivity disorder [ADHD], and specific language impairment [SLI]) perform more poorly than the control groups on these tasks and multilingual individuals show superior performance to monolingual participants (e.g., Marton, 2014; Yoon et al., 2013).

CONCLUSIONS

We conclude that, along with sentence structure, semantic implausibility increases linguistic and cognitive processing loads on an auditory sentence comprehension task. Moreover, our findings demonstrated a relation between inhibition control and sentence comprehension performance, specifically among older adults. We observed evidence of within-group differences such that older adults with better inhibitory control performed more efficiently than those with poorer inhibitory control during comprehension of implausible sentences. Although we suggest that processing of both semantically and syntactically complex sentences differs from processing of semantically simple but syntactically complex sentences, future studies will be required to further disentangle this issue. The compensation hypothesis (Cabeza et al., 2002; Wingfield & Grossman, 2006) predicts the additional neural activation of prefrontal cortical areas of the brain among better-performing older adults. Our results are consistent with the compensation hypothesis in that older adults with more efficient inhibition relative to those with less efficient inhibition performed better during comprehension of semantically implausible sentences. As we employed performance efficiency measures for sentence comprehension and executive functions, the nature of a possible speed-accuracy tradeoff in information processing would be another question to investigate in future studies of language processing among older adults. Finally, future developmental studies considering effects of semantic implausibility and its relation to inhibition efficiency across adulthood, rather than only in two discrete age groups, would

enhance our understanding of the precise trajectory of the interaction between cognitive and linguistic abilities across the adult life span.

Acknowledgments

This project is part of a larger study, Executive Functions Predict Sentence Comprehension Across the Lifespan, headed by Klara Marton, Mira Goral, and Loraine Obler. The negation task was developed by Mira Goral, Manuela Rossie Clark-Cotton, and Jay Fournier in the Language in the Aging Brain Laboratory (Goral et al., 2011), funded by NIH grant 5R01AG14345, (M. L. Albert and L. K. Obler, co-Principal Investigators). The executive function tasks were developed by Klara Marton as part of the study The Impact of Inhibition Control on Working Memory in Children with SLI (Marton et al., 2014), funded by the National Institute of Health (NIH/NIDCD; 1R15DC009040-01). Thanks to two anonymous reviewers for their helpful suggestions.

FUNDING

This project is part of a larger study, Executive Functions Predict Sentence Comprehension Across the Lifespan. The negation task was developed in the Language in the Aging Brain Laboratory, funded by NIH grant 5R01AG14345. The executive function tasks were developed as part of the study The Impact of Inhibition Control on Working Memory in Children with SLI, funded by the National Institutes of Health (National Institute on Deafness and Other Communication Disorders grant 1R15DC009040-01).

References

Burke, DM.; Shafto, MA. Language and aging. In: Craik, FIM.; Salthouse, TA., editors. The handbook of aging and cognition. New York: Psychology Press; 2008. p. 373-443.

Cabeza R, Anderson ND, Locantore JK, McIntosh AR. Aging gracefully: Compensatory brain activity in high-performing older adults. NeuroImage. 2002; 17:1394–1402. [PubMed: 12414279]

Cahana-Amitay D, Ojo E, Sayers J, Oveis A, Duncan S, Spiro A, … Obler L. Executive functions and sentence-final word processing in aging. in revision.

Caplan D, DeDe G, Waters G, Michaud J. Effects of age, speed of processing, and working memory on comprehension of sentences with relative clauses. Psychology and Aging. 2011; 26:439–450. [PubMed: 21480714]

Caplan D, Waters G. Verbal working memory capacity and language comprehension. Behavioral and Brain Science. 1999; 22:114–126.

Carpenter PA, Just MA, Keller TA, Eddy WF, Thulborn KR. Time course of fMRI-activation in language and spatial networks during sentence comprehension. Neuroimage. 1999; 10:216–224. [PubMed: 10417254]

Carpenter PA, Miyake A. Language comprehension: Sentence and discourse processing. Annual Review of Psychology. 1995; 46:91–120.

Chatterjee, S.; Hadi, AS. Regression analysis by example. 4. Hoboken, NJ: Wiley-Interscience; 2006.

Christensen KR. Negative and affirmative sentences increase activation in different areas in the brain. Journal of Neurolinguistics. 2009; 22:1–17.

Christianson K, Luke SG, Ferreira F. Effects of plausibility on structural priming. Journal of Experimental Psychology: Learning, Memory, and Cognition. 2010; 36:538–544.

Christianson K, Williams CC, Zacks RT, Ferreira F. Misinterpretations of garden-path sentences by older and younger adults. Discourse Processes. 2006; 42:205–238. [PubMed: 17203135]

Clark JG. Uses and abuses of hearing loss classification. The American Speech-Language-Hearing Association (ASHA). 1981; 23:493–500.

Cohen G, Faulkner D. Word recognition: Age differences in contextual facilitation effects. British Journal of Psychology. 1983; 74:239–251. [PubMed: 6883014]

Davis GA, Ball HE. Effects of age on comprehension of complex sentences in adulthood. Journal of Speech and Hearing Research. 1989; 32:143–150. [PubMed: 2704189]

DeDe G, Caplan D, Kemtes KA, Waters G. The relationship between age, verbal working memory, and language comprehension. Psychology and Aging. 2004; 19:601–616. [PubMed: 15584786]

Fallon M, Peelle J, Wingfield A. Spoken sentence processing in young and older adults modulated by task demands: Evidence from self-paced listening. Journal of Gerontology. 2006; 61:10–17.

Federmeier KD, Kutas M, Schul R. Age-related and individual differences in the use of prediction during language comprehension. Brain and Language. 2010; 115:149–161. [PubMed: 20728207]

Ferreira F. The misinterpretation of noncanonical sentences. Cognitive Psychology. 2003; 47:164–203. [PubMed: 12948517]

Folstein MF, Folstein SE, McHugh PR. Mini-Mental State: A practical method for grading the cognitive state of patients for the clinician. Journal of Psychiatric Research. 1975; 12:189–198. [PubMed: 1202204]

Goral M, Clark-Cotton MR, Spiro A III, Obler LK, Verkuilen J, Albert ML. The contribution of set shifting and working memory to sentence processing in older adults. Experimental Aging Research. 2011; 37:516–538. [PubMed: 22091580]

Goral M, Spiro A, Albert ML, Obler LK, Connor LT. Change in lexical retrieval skills in adulthood. The Mental Lexicon. 2007; 2:215–240.

Grossman M, Cooke A, De Vita C, Alsop D, Detre J, Chen W, Gee J. Age-related changes in working memory during sentence comprehension: An FMRI study. NeuroImage. 2002; 15:302–317. [PubMed: 11798267]

Hasher L, Quig MB, May CP. Inhibitory control over no-longer-relevant information: Adult age differences. Memory and Cognition. 1997; 25:286–295. [PubMed: 9184480]

Hyun J, Dobromyslin V, Goral M, Cahana-Amitay D, Spiro A, Albert M, Obler L. White matter integrity associated with negative and affirmative sentence processing in cognitively normal older adults. in revision.

Janse E. A non-auditory measure of interference predicts distraction by competing speech in older adults. Aging, Neuropsychology, and Cognition. 2012; 19:741–758.

Just MA, Carpenter PA. A capacity theory of comprehension: Individual differences in working memory. Psychological Review. 1992; 99:122–149. [PubMed: 1546114]

Kalikow DN, Stevens KN, Elliott LL. Development of a test of speech intelligibility in noise using sentence materials with controlled word predictability. Journal of the Acoustical Society of America. 1977; 61:1337–1351. [PubMed: 881487]

Kuperberg GR, Holcomb PJ, Sitnikova T, Greve D, Dale AM, Caplan D. Distinct patterns of neural modulation during the processing of conceptual and syntactic anomalies. Journal of Cognitive Neuroscience. 2003; 15:272–293. [PubMed: 12676064]

Lemkens N, Vermeire K, Brokx JPL, Fransen E, Van Camp G, Van De Heyning P. Interpretation of pure-tone thresholds in sensorineural hearing loss (SNHL): A review of measurement variability and age-specific references. Acta Oto-Rhino-Laryngologica Belgica. 2002; 56:341–352. [PubMed: 12528251]

Lustig, C.; Hasher, L.; Zacks, RT. Inhibitory deficit theory: Recent developments in a “new view”. In: Gorfein, DS.; MacLeod, CM., editors. Inhibition and Cognition. 2007. p. 145-162.

MacDonald MC, Pearlmutter NJ, Seidenberg MS. The lexical nature of syntactic ambiguity resolution. Psychological Review. 1994; 101:676–703. [PubMed: 7984711]

Margolin SJ, Abrams L. Not may not be too difficult: The effects of negation on older adults’ sentence comprehension. Educational Gerontology. 2009; 35:308–322.

Marton, K. Cognitive profiles of children with different neurocognitive disorders. Invited talk at the IV. Meixner Conference on Dyslexia; October 11–12, 2013; Budapest. 2014.

Marton K, Campanelli L, Eichorn N, Scheuer J, Yoon J. Information processing and proactive interference in children with and without specific language impairment (SLI). Journal of Speech, Language, and Hearing Research. 2014; 57:106–119.

May CP, Zacks RT, Hasher L, Multhaup KS. Inhibition in the processing of garden-path sentences. Psychology and Aging. 1999; 14:304–313. [PubMed: 10403717]

Miller L, Cohen J, Wingfield A. Contextual knowledge reduces demands on working memory during reading. Memory & Cognition. 2006; 34:1355–1367. [PubMed: 17225514]

Miyake A, Friedman NP, Emerson MJ, Witzki AH, Howerter A, Wager TD. The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. Cognitive Psychology. 2000; 41:49–100. [PubMed: 10945922]

Obler LK, Fein D, Nicholas M, Albert ML. Auditory comprehension and aging: Decline in syntactic processing. Applied Psycholinguistics. 1991; 12:433–452.

Pichora-Fuller M. Cognitive aging and auditory information processing. International Journal of Audiology. 2003; 42:26–32.

Psychology Software Tools, Inc. E-Prime 2.0. 2012. Retrieved from http://www.pstnet.com

Rhodes GM. Age-related differences in performance on the Wisconsin Card Sorting Test: A meta-analytic review. Psychology and Aging. 2004; 19:482–494. [PubMed: 15382998]

Salthouse TA. The processing-speed theory of adult age differences in cognition. Psychological Review. 1996; 103:403–428. [PubMed: 8759042]

Salthouse TA, Fristoe NM, Lineweaver TT, Coon VE. Aging of attention: Does the ability to divide decline? Memory & Cognition. 1995; 23:59–71. [PubMed: 7885266]

Schneider BA, Daneman M, Pichora-Fuller MK. Listening in aging adults: From discourse comprehension to psychoacoustics. Canadian Journal of Experimental Psychology. 2002; 56:139–152. [PubMed: 12271745]

Schilling VM, Chetwynd A, Rabbitt PMA. Individual inconsistency across measures of inhibition: An investigation of the construct validity of inhibition in older adults. Neuropsychologica. 2002; 40:605–619.

Sommers MS. The structural organization of the mental lexicon and its contribution to age-related declines in spoken-word recognition. Psychology and Aging. 1996; 11:333–341. [PubMed: 8795062]

Sommers MS, Danielson SM. Inhibitory processes and spoken word recognition in young and older adults: The interaction of lexical competition and semantic context. Psychology and Aging. 1999; 14:458–472. [PubMed: 10509700]

Tabachnick, BG.; Fidell, LS. Using multivariate statistics. 5. Boston: Pearson; 2007.

Titone D, Prentice KJ, Wingfield A. Resource allocation during spoken discourse processing: Effects of age and passage difficulty as revealed by self-paced listening. Memory and Cognition. 2000; 28:1029–1040. [PubMed: 11105529]

Townsend, JT.; Ashby, FG. The stochastic modeling of elementary psychological processes. Cambridge, UK: Cambridge University Press; 1983.

Tun PA, Benichov J, Wingfield A. Response latencies in auditory sentence comprehension: Effects of linguistic versus perceptual challenge. Psychology and Aging. 2010; 25:730–735. [PubMed: 20853977]

Tun PA, Wingfield A. One voice too many: Adult age differences in language processing with different types of distracting sounds. The Journals of Gerontology. 1999; 54B:317–329.

Waters G, Caplan D. The relationship between age, processing speed, working memory capacity, and language comprehension. Memory. 2005; 13:403–413. [PubMed: 15952262]

Wingfield A, Grossman M. Language and the aging brain: Patterns of neural compensation revealed by functional brain imaging. Journal of Neurophysiology. 2006; 96:2830–2839. [PubMed: 17110737]

Wingfield, A.; Stine-Morrow, EAL. Language and speech. In: Craik, FIM.; Salthouse, TA., editors. The handbook of aging and cognition. Mahwah, NJ: Erlbaum; 2000. p. 359-416.

Wingfield A, Tun PA. Spoken language comprehension in older adults: Interactions between sensory and cognitive change in normal aging. Seminars in Hearing. 2001; 22:287–302.

Yoon, J.; Marton, K.; Suranyi, Zs; Goral, M.; King-Garcia, A.; Obler, LK. Interference control in young adults. Presented at the 9th International Symposium on Bilingualism; Singapore. 2013. Retrieved from http://linguistics.hss.ntu.edu.sg/ISB9/ISB9_Proceedings_Book.pdf

Zacks, RT.; Hasher, L. Capacity theory and the processing of inferences. In: Light, LL.; Burke, DM., editors. Language, memory, and aging. New York: Cambridge University Press; 1988. p. 155-169.

Zacks RT, Radvansky GA, Hasher L. Studies of directed forgetting in older adults. Journal of Experimental Psychology: Learning, Memory, and Cognition. 1996; 22:143–156.

Author Manuscript
Author Manuscript
Author Manuscript

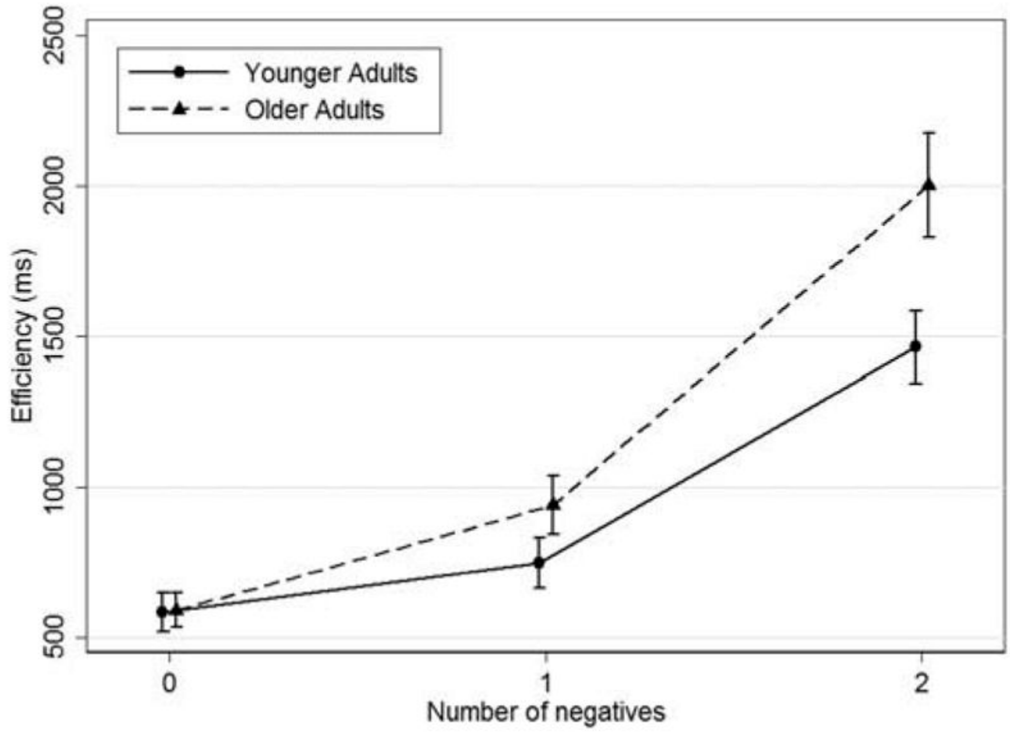

Figure 1.

Language comprehension performance (efficiency) by group and number of negatives. Error bars: ±*SE*.

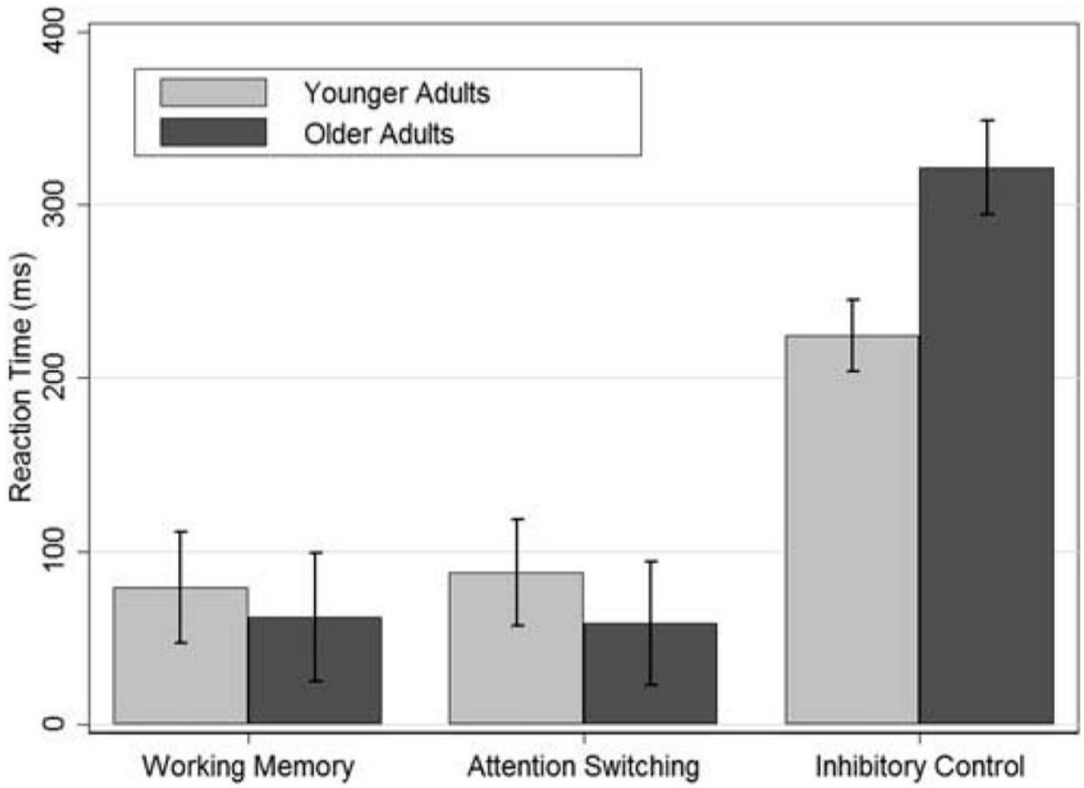

Figure 2.

Executive function performance (RT data) by groups and tasks. The bars indicate the difference between baseline performance and performance on each task. Error bars: ±*SE*.

Table 1

Demographic data summary

Characteristic	**YA (*n* = 41)**	**OA (*n* = 40)**
Age in years, Mean (*SD*)	26.20 (4.2)	64.60 (6.1)
Female:Male	26:14	25:15
Years of education, Mean (*SD*)	16.19 (1.9)	16.40 (2.6)
MMSE (max 30)	29.27	29.10

Note. YA = younger adults; OA = older adults; MMSE = Mini-Mental State Examination.

Table 2

Language comprehension performance: Descriptive statistics for accuracy, reaction time, and efficiency by group and condition

	Younger adults (*n* = 41)			Older adults (*n* = 40)		
Condition	**Accuracy**	**RT**	**Efficiency**	**Accuracy**	**RT**	**Efficiency**
Plausible						
No-negative	0.96 (0.1)	521 (812)	535 (438)	0.98 (0.06)	509 (342)	523 (348)
One-negative	0.95 (0.1)	732 (661)	749 (656)	0.92 (0.12)	817 (565)	909 (633)
Two-negative	0.88 (0.17)	1027 (703)	1163 (786)	0.87 (0.17)	1292 (709)	1578 (1023)
Implausible						
No-negative	0.95 (0.1)	614 (548)	628 (506)	0.97 (0.1)	633 (412)	654 (452)
One-negative	0.92 (0.13)	692 (652)	746 (588)	0.96 (0.08)	925 (708)	984 (774)
Two-negative	0.84 (0.21)	1493 (960)	1744 (1033)	0.76 (0.2)	1683 (799)	2429 (1456)

Note. Data are mean (*SD*). RT = reaction time in milliseconds; Efficiency = see text for description.

Table 3

Language comprehension performance: Summary of mixed-design analysis of variance

Effect	*F1*			*F2*			*minF′*	
	***F*(*df*)**	***p***	η_p^2	***F*(*df*)**	***p***	η_p^2	***F*(*df*)**	***p***
Accuracy								
Group	0.1 (1, 77)	.757	0.001	1.64 (1, 16)	.219	0.093	0.09 (1, 85)	.763
Pl	4.62 (1, 77)	.035	0.057	3.53 (1, 16)	.079	0.181	2 (1, 44)	.164
Pl × Group	0.01 (1, 77)	.923	0.000	0.006 (1, 16)	.937	0.000	0.01 (1, 41)	.952
Neg	36.3 (2, 154)	<.001	0.320	36.7 (2, 32)	<.001	0.696	18.2 (2, 107)	.000
Neg × Group	2.17 (2, 154)	.117	0.027	0.81 (2, 32)	.452	0.048	0.59 (2, 59)	.556
Pl × Neg	6.16 (2, 154)	.003	0.074	4.13 (2, 32)	.025	0.205	2.47 (2, 82)	.091
Pl × Neg × Group	3.55 (2, 154)	.031	0.044	0.52 (2, 32)	.600	0.031	0.45 (2, 42)	.639
Response time								
Group	1.39 (1, 77)	.242	0.018	0.09 (1, 16)	.770	0.006	0.08 (1, 18)	.776
Pl	18.8 (1, 77)	<.001	0.196	9.08 (1, 16)	.008	0.362	6.12 (1, 34)	.019
Pl × Group	1.4 (1, 77)	.24	0.018	0.07 (1, 16)	.793	0.004	0.07 (1, 18)	.798
Neg	106 (2, 154)	<.001	0.579	79.9 (2, 32)	<.001	0.833	45.6 (2, 88)	.000
Neg × Group	4.25 (2, 154)	.016	0.052	0.99 (2, 32)	.381	0.059	0.81 (2, 48)	.452
Pl × Neg	11.2 (2, 154)	<.001	0.127	5.92 (2, 32)	.006	0.270	3.88 (2, 71)	.025
Pl × Neg × Group	1.42 (2, 154)	.246	0.018	1.13 (2, 32)	.336	0.066	0.63 (2, 91)	.536
Efficiency								
Group	4.59 (1, 77)	.035	0.056	0.18 (1, 16)	.677	0.011	0.17 (1, 17)	.682
Pl	31.3 (1, 77)	<.001	0.289	11.9 (1, 16)	.003	0.428	8.65 (1, 30)	.006
Pl × Group	1.53 (1, 77)	.22	0.019	0.11 (1, 16)	.742	0.007	0.1 (1, 18)	.750
Neg	144 (2, 154)	<.001	0.652	74.4 (2, 32) <	.001	0.823	49.1 (2, 70)	.000
Neg × Group	7.47 (2, 154)	.001	0.088	0.42 (2, 32)	.660	0.026	0.4 (2, 36)	.674
Pl × Neg	19.8 (2, 154)	<.001	0.204	7.26 (2, 32)	.003	0.312	5.31 (2, 58)	.008
Pl × Neg × Group	0.31 (2, 154)	.737	0.004	0.63 (2, 32)	.537	0.038	0.21 (2, 160)	.814

Note. *F1* = analysis by subjects; *F2* = analysis by items; *minF′* = combined results of by-subject and by-item analyses (see text for description). Group = factor variable with two levels (younger adults and older adults); Pl = factor variable with two levels (plausible and implausible); Neg = factor variable with three levels (0-, 1-, and 2-negative).

Table 4

Language comprehension efficiency performance: Post hoc comparisons for the Negatives × Plausibility interaction (*minF′* analysis)

Comparison	minF′ (df)	*p* value[a]
Pl 1 neg vs. Pl 0 neg	0.902 (1, 38)	1
Pl 2 neg vs. Pl 0 neg	6.23 (1, 55)	.14
Pl 2 neg vs. Pl 1 neg	2.25 (1, 69)	1
Imp 1 neg vs. Imp 0 neg	0.292 (1, 25)	1
Imp 2 neg vs. Imp 0 neg	21.253 (1, 55)	<.001
Imp 2 neg vs. Imp 1 neg	15.563 (1, 64)	.002
Imp 0 neg vs. Pl 0 neg	0.305 (1, 23)	1
Imp 1 neg vs. Pl 1 neg	0.001 (1, 17)	1
Imp 2 neg vs. Pl 2 neg	9.28 (1, 41)	.037

Note. Pl = plausible condition; Imp = implausible condition; 0 neg = 0-negative condition; 1 neg = 1-negative condition; 2 neg = 2-negative condition.

[a] *p* values are Bonferroni adjusted.

Author Manuscript

Author Manuscript

Author Manuscript

Table 5

Language comprehension efficiency performance: Post hoc comparisons for the Negatives × Group interaction (by-subject analysis)

Comparison	*t*(*df*)	*p* value[a]	*d*[b]
YA 1 neg vs. YA 0 neg	0.43 (39)	1	0.335
YA 2 neg vs. YA 0 neg	2.9 (39)	.036	1.308
YA 2 neg vs. YA 1 neg	2.47 (39)	.135	1.04
OA 1 neg vs. OA 0 neg	1.64 (38)	.936	0.667
OA 2 neg vs. OA 0 neg	4.54 (38)	.000	1.478
OA 2 neg vs. OA 1 neg	2.91 (38)	.036	1.13
OA 0 neg vs. YA 0 neg	−1.02 (78)	1	0.018
OA 1 neg vs. YA 1 neg	0.23 (78)	1	0.337
OA 2 neg vs. YA 2 neg	0.8 (78)	1	0.56

Note. YA = younger adults; OA = older adults; 0 neg = 0-negative condition; 1 neg = 1-negative condition; 2 neg = 2-negative condition.

[a] *p* values are Bonferroni adjusted.

[b] Cohen’s *d* effect size.

Table 6

Executive functions performance: Descriptive statistics for accuracy, reaction time, and efficiency by group and condition

	Younger adults (n = 41)			Older adults (n = 40)		
Condition	**Accuracy**	**RT**	**Efficiency**	**Accuracy**	**RT**	**Efficiency**
Base	0.96 (0.039)	976 (172)	1011 (161)	0.94 (0.065)	1147 (288)	1208 (294)
WM	0.96 (0.038)	1055 (171)	1094 (186)	0.95 (0.038)	1210 (191)	1276 (217)
AS	0.96 (0.04)	1063 (169)	1113 (201)	0.95 (0.044)	1206 (195)	1274 (223)
INH	0.082 (0.14)	1200 (211)	1524 (471)	0.84 (0.15)	1469 (335)	1783 (631)

Note. Data are mean (*SD*). RT = reaction time in milliseconds; Efficiency = see text for description; Base = baseline task; WM = working memory task; AS = attention switching task; INH = inhibition task.

Table 7

Executive functions performance: Summary of mixed-design analysis of variance

Effect	*F*(*df*)	*p* value	η_p^2
Accuracy			
Group	0.11 (1, 77)	.737	0.001
Task	55.97 (3, 231)	<.001	0.421
Task × Group	1.31 (3, 231)	.273	0.017
Reaction time			
Group	18.74 (1, 77)	<.001	0.382
Task	58.01 (3, 231)	<.001	0.43
Task × Group	3.47 (3, 231)	.017	0.043
Efficiency			
Group	12.02 (1, 77)	<.001	0.178
Task	77.48 (3, 231)	<.001	0.502
Task × Group	0.56 (3, 231)	.645	0.007

Note. Group = factor variable with two levels (younger adults and older adults); Task = factor variable with four levels (baseline, working memory, attention switching, and inhibition).

Author Manuscript

Author Manuscript

Author Manuscript

Table 8

Executive functions efficiency performance: Post hoc comparisons for the effect of task

Comparison	*t*(*df*)	*p* value[a]	*d*[b]
Base vs. WM	−1.9 (79)	.356	0.318
Base vs. AS	−2.12 (79)	.213	0.349
Base vs. INH	−13.6 (79)	<.001	1.1
WM vs. AS	−0.22 (79)	1.000	0.035
WM vs. INH	−11.7 (79)	<.001	0.943
AS vs. INH	−11.5 (79)	<.001	0.928

Note. Base = baseline task; WM = working memory task; AS = attention switching task; INH = inhibition task.

[a] *p* values are Bonferroni adjusted.

[b] Cohen’s *d* effect size.

Table 9

Executive functions performance (reaction time): Post hoc comparisons for the Task × Group interaction

Comparison	*t*(*df*)	*p* value[a]	*d*[b]
YA Base vs. YA WM	−2.59 (39)	.16	0.39
YA Base vs. YA AS	−2.86 (39)	.08	0.45
YA INH vs. YA Base	7.32 (39)	<.001	1.69
YA AS vs. YA WM	0.28 (39)	1	0.11
YA INH vs. YA WM	4.73 (39)	<.001	0.66
YA INH vs. YA AS	4.46 (39)	<.001	0.63
OA Base vs. OA WM	−2 (38)	.752	0.27
OA Base vs. OA AS	−1.89 (38)	.96	0.21
OA INH vs. OA Base	10.4 (38)	<.001	1.88
OA AS vs. OA WM	−0.11 (38)	1	0.05
OA INH vs. OA WM	8.35 (38)	<.001	0.8
OA INH vs. OA AS	8.46 (38)	<.001	1.07
OA Base vs. YA Base	5.56 (77)	<.001	0.72
OA WM vs. YA WM	5.01 (77)	<.001	0.86
OA AS vs. YA AS	4.62 (77)	<.001	0.78
OA INH vs. YA INH	8.71 (77)	<.001	0.96

Note. YA = younger adults; OA = older adults; Base = baseline task; WM = working memory task; AS = attention switching task; INH = inhibition task.

[a] *p* values are Bonferroni adjusted.

[b] Cohen's *d* effect size.

Table 10

Regression analyses predicting comprehension of implausible 2-negative sentences

	Model 1			Model 2			Model 3			Model 4		
Variable	***B***	**SE B**	β	***B***	**SE B**	β	***B***	**SE B**	β	***B***	**SE B**	β
Pl 2 neg	0.62	0.14	0.45***	0.60	0.13	0.43***	0.59	0.13	0.43***	0.60	0.14	0.43***
Base	1.65	1.16	0.31	1.21	1.16	0.23	1.44	1.23	0.27	2.07	2.10	0.39
Group	20.95	248.06	0.01	125.7	247.9	0.05	80.37	259.6	0.03	102.6	266.8	0.04
INH	0.18	1.11	0.04	−0.76	1.18	−0.16	−0.87	1.21	−0.18	−1.60	1.81	−0.33
INH × Group				2.11	1.03	0.32*	1.82	1.12	0.28	2.64	2.57	0.40
WM							0.85	1.18	0.15	0.14	1.70	0.02
AS							−0.645	1.15	−0.11	0.33	1.62	0.06
WM × Group										1.18	2.47	0.14
AS × Group										−2.21	2.49	−0.24
Base × Group										−0.38	2.71	−0.06
Constant	2062	167.3		1887	184.6		1926	194.8		1910	203.4	
R^2(R^2 change)		.423 (.423)			.456 (.033)			.46 (.004)			.469 (.009)	
Adjusted R^2		.39			.417			.404			.386	
F for R^2 change		12.83 ($p < .001$)			4.2 ($p = .044$)			0.26 ($p = .77$)			0.34 ($p = .79$)	

Note. Pl 2 neg = plausible 2-negative condition. Base = baseline task; WM = working memory task; AS = attention switching task; INH = inhibition task.

* $p < .05$;

** $p < .01$;

*** $p < .001$.