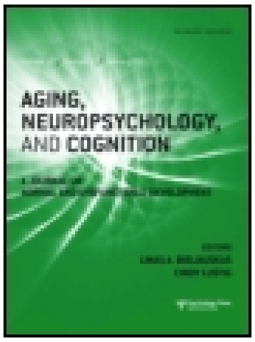

Routledge
Taylor & Francis Group

Aging, Neuropsychology, and Cognition

A Journal on Normal and Dysfunctional Development

ISSN: 1382-5585 (Print) 1744-4128 (Online) Journal homepage: http://www.tandfonline.com/loi/nanc20

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AGING, NEUROPSYCHOLOGY, AND COGNITION, 2015
http://dx.doi.org/10.1080/13825585.2015.1111291

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Dalia Cahana-Amitay[a,d], Avron Spiro III[b,c,d], Jesse T. Sayers[a,d], Abigail C. Oveis[a,d], Eve Higby[a,d,e], Emmanuel A. Ojo[a,d], Susan Duncan[e,g], Mira Goral[a,d,e,f], Jungmoon Hyun[a,d,e], Martin L. Albert[a,d] and Loraine K. Obler[a,d,e]

[a]Department of Neurology, Boston University School of Medicine, Boston, MA, USA; [b]Department of Epidemiology, School of Public Health, Boston University, Boston, MA, USA; [c]Department of Psychiatry, Boston University School of Medicine, Boston, MA, USA; [d]Veterans Affairs Boston Healthcare System, Boston, MA, USA; [e]The Graduate Center, City University of New York, New York, NY, USA; [f]Lehman College, City University of New York, New York, NY, USA; [g]Department of Cognitive Sciences and Neurology, University of California, Irvine, CA, USA

ABSTRACT

This study examined the effects of executive control and working memory on older adults' sentence-final word recognition. The question we addressed was the importance of executive functions to this process and how it is modulated by the predictability of the speech material. To this end, we tested 173 neurologically intact adult native English speakers aged 55–84 years. Participants were given a sentence-final word recognition test in which sentential context was manipulated and sentences were presented in different levels of babble, and multiple tests of executive functioning assessing inhibition, shifting, and efficient access to long-term memory, as well as working memory. Using a generalized linear mixed model, we found that better inhibition was associated with higher accuracy in word recognition, while increased age and greater hearing loss were associated with poorer performance. Findings are discussed in the framework of semantic control and are interpreted as supporting a theoretical view of executive control which emphasizes functional diversity among executive components.

ARTICLE HISTORY
Received 15 April 2015
Accepted 17 October 2015

KEYWORDS
Word recognition; babble; predictability; executive functions; working memory

Introduction

Word recognition in adverse listening conditions, such as presence of interfering noise or talkers, reverberation, can be a challenging task for older adults (e.g., Craik, 2007; Wingfield & Tun, 2007). Research exploring the sources of this difficulty has focused on the interplay between two important factors in aging: (1) decline in hearing acuity (e.g., 2007; Humes, 1996; Schneider, Daneman, Murphy, & See, 2000) and (2) neurocognitive changes affecting working memory (WM), attention, and processing speed (e.g., Rabbitt et al., 2007; Salthouse, 1996; Wingfield & Stine-Morrow, 2000). A central claim about this interplay (e.g., Rabbitt, 1968), conceived by some as the "effortfulness hypothesis"

CONTACT Dalia Cahana-Amitay dcamitay@bu.edu

(McCoy et al., 2005), has been that hearing loss increases the effort required to accurately perceive a spoken word, thus consuming limited cognitive resources. These resources would otherwise be allocated to processing the linguistic information encoded in that word, in order to rule out other lexical candidates that potentially match the input (e.g., Gosselin & Gagne, 2011; Tun, McCoy, & Wingfield, 2009; Wingfield & Tun, 2007).

One's ability to select a target among several candidates declines with age, a hypothesis known as the inhibitory deficit hypothesis (Hasher & Zacks, 1988; Lustig, Hasher, & Zacks, 2007). The basic assumption is that older adults' reduced ability to ignore task-irrelevant information, compared to that of younger adults, impairs their performance by introducing a higher cognitive interference. The presence of interference effects can lead in older adults to distinct problems with (1) ignoring concurrent distraction, (2) clearing irrelevant information from attention and WM systems, and (3) controlling incorrect or inappropriate responses (e.g., Guerreiro, Murphy, & Van Gerven, 2010; Hasher, Zacks, & May, 1999; Lustig et al., 2007; Sommers & Danielson, 1999).

Older adults' reduced inhibitory control has been considered an important contributor to their difficulties recognizing words, especially against background noise (e.g., Pichora-Fuller, 2003; Schneider & Pichora-Fuller, 2001; Tun et al., 2009; Wingfield & Tun, 2007; Wingfield, Tun, & McCoy, 2005). For example, their performance on nonauditory measures of inhibition, such as visual Stroop (1935), has been associated with auditory distractibility for stimuli presented against competing multitalker background (e.g., Desjardins, 2011; Guerreiro et al., 2010; Janse, 2012; Janse & Jesse, 2014; Tun, O'Kane, & Wingfield, 2002). Janse (2012) specifically found that Stroop performance (measured by hit rate) accounted for older adults' difficulties inhibiting competing speech beyond the effects of hearing loss.

As compared to younger adults, older adults can benefit from contextual information to enhance their word recognition performance (e.g., Pichora-Fuller & Souza, 2003). They are accustomed to dealing with perceptual challenges associated with hearing loss and are highly skilled in the use of contextual cues to compensate for these reductions, showing disproportionate reliance on context (e.g., Gordon-Salant & Fitzgibbons, 1997; Pichora-Fuller, Schneider, & Daneman, 1995; Sommers & Danielson, 1999; Wingfield et al., 2005). Their linguistic experience presumably increases the activation levels of contextually appropriate lexical items, and in doing so reduces the inhibitory demands associated with word discrimination (e.g., Sommers & Danielson, 1999). Thus, older adults are able to use syntactic and semantic cues when a target word is presented in a sentential context (rather than in isolation), or in a conversational context in which the topic is familiar to the listener (e.g., Benichov, Cox, Tun, & Wingfield, 2012; Bilger, Nuetzel, Rabinowitz, & Rzeczkowski, 1984; Kalikow, Stevens, & Elliott, 1977; Lash, Rogers, Zoller, & Wingfield, 2013; Nittrouer & Boothroyd, 1990; Pichora-Fuller, 2003). This contextual facilitation decreases the disparity observed in noisy conditions between older and younger adults' word recognition performance in terms of level of signal-to-noise ratios (e.g., Dubno, Ahlstrom, & Horwitz, 2000; Sheldon, Pichora-Fuller, & Schneider, 2008; Sommers & Danielson, 1999; Surprenant, 2007) and degree of release from informational masking in response to auditory priming of sentential context (Ezzatian, Li, Pichora-Fuller, & Schneider, 2010).

In a recent study of word recognition, both younger and older adults required less onset information when targets were presented in highly informative context (Lash et al., 2013). The underlying assumption was that amount of linguistic context is inversely related to the degree of uncertainty associated with number and strength of potential responses, a phenomenon known as *response entropy*, which is at its highest when all response candidates are equally likely targets for sentence completion. The authors found that semantically less constraining sentences with high response entropy posed a word discrimination challenge for older adults regardless of their levels of hearing acuity. They attributed these difficulties to age-related decreases in inhibitory control, which degrade one's ability to suppress lexical competitors. However, as measures of inhibition were not included in the study, this proposal remained speculative. This idea is, nonetheless, consistent with the claim that age-related impaired inhibition differentially drives spoken word recognition in high versus low predictability sentential context (e.g., Sommers & Danielson, 1999).

A study by Benichov and colleagues offers more direct evidence of the roles of cognition and hearing in word recognition abilities in aging (Benichov et al., 2012). They demonstrated that word recognition thresholds for targets with low, medium, and high probabilities were affected by cognitive abilities, as measured by tasks evaluating episodic memory, WM, and speed of processing, adjusting for hearing acuity. They found graded changes in the relationship between cognitive and hearing contributions to word recognition, based on the strength of the linguistic context in which the target was embedded. In neutral contexts, word recognition relied heavily on participants' hearing abilities and moderately on their cognition; in highly informative contexts, performance was still dependent on the cognitive abilities tested, but no longer on hearing. The authors also note that age remained a significant predictor of performance after cognition was controlled for but suggest that this result may be related to the specific cognitive tests used, which may have failed to reflect the full range of cognitive performance in aging. In addition, these results may reflect changes in supra-threshold auditory processing abilities, not captured by an audiometric assessment, which are known to decline with age (Füllgrabe, 2013; Füllgrabe, Moore, & Stone, 2015). It is well established that older listeners, with (Moore, Glasberg, Stoev, Füllgrabe, & Hopkins, 2012) or without (Füllgrabe et al., 2015) peripheral hearing loss, show degradation of the speech signal due to age-related changes in supra-threshold auditory processing, sometimes as early as midlife (Füllgrabe, 2013).

The importance of age as a predictor of word recognition performance in sentential context was shown in a recent study by Janse and Jesse (2014). They examined and demonstrated that use of contextual information to identify phonemes in sentential context was modulated by verbal WM, age, and hearing. They used an online speeded response phoneme-monitoring task, in which participants were required to quickly identify phonemes in sentences presented under three conditions: no background noise, fluctuating speech noise, and competing speech from a single speaker. They found that speed of phoneme recognition was positively affected by contextual probability and that greater contextual facilitation was predicted by increased verbal WM, younger age, and better hearing. Because reduced contextual facilitation effects among the older but not younger adults were associated with response latencies, the authors conjectured that they reflected age-related differences in online semantic integration, similar to findings reported in event-related potentials (ERP) studies, which we touch on in the Discussion section.

Age-related changes in word recognition performance can thus be attributed to increases in older adults' audiometric thresholds, changes in their supra-threshold auditory processing, as well as to changes in their cognitive performance. The focus of the current study is on the latter. Studies examining whether older adults' word recognition in sentential context varies as a function of individual differences in cognitive abilities are often underpowered to detect individual variation, given small and heterogeneous samples. In addition, the different studies do not offer an explicit theoretical grounding for how cognitive mechanisms operate in identifying a sentence-final word when noise is overlaid. The current study was designed to address this issue by exploring the effects of cognition on spoken word recognition of sentence-final words which varied in terms of predictability in conditions of differing levels of babble in a large sample of older adults with normal hearing sensitivity for their age (Cruickshanks et al., 1998; Moscicki, Elkins, Baurn, & McNarnara, 1985).

We propose considering the notion of *semantic control* (e.g., Badre & Wagner, 2007; Jefferies & Lambon Ralph, 2006) for explaining how participants identify potential targets for the final word of a sentence. In this framework, cognitive control helps identify the item with the most task-relevant characteristics from among several target-related competitors available for selection. The role of executive functions can thus be understood to control all prior information that may be of relevance for generating target competitors, as one processes sentence-level stimuli to predict the final word. Once acoustic information is available for the final word – degraded as it may be when noise is overlaid – the cognitive control system helps navigate among the previously generated competitors to select an appropriate response that meets both semantic and phonetic constraints. This proposal is consistent with the claim that the relevance of cognitive processes in adverse listening conditions increases if the matching of representations in long-term memory (LTM) and linguistic input is insufficient to enable lexical access (e.g., Janse & Jesse, 2014). What the semantic control model leaves unresolved is whether some unified phenomenon of cognitive control predicts performance on such tasks, or whether discrete subcomponents of executive functions (e.g., inhibitory control, set shifting, cognitive efficiency) and WM capacity contribute independently to performance (e.g., McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010; Miyake & Friedman, 2012).

To answer this question, we followed Miyake's model of executive functions (Friedman & Miyake, 2004; Friedman et al., 2006; Miyake et al., 2000), which accounts for individual differences in performance of complex cognitive tasks, including complex language tasks implicating lexical access/retrieval processes (see Shao, Roelofs, & Meyer, 2012). This account posits a three-component cognitive control system, comprising (1) an inhibiting system which controls dominant responses, (2) a shifting system which governs the transition among mental sets, and (3) an updating system of WM representations. Within this framework, generic WM functions (e.g., maintenance) are considered to be a relatively discrete cognitive component (for a recent discussion, see Ecker, Lewandowsky, & Oberauer, 2014; Ecker, Lewandowsky, Oberauer, & Chee, 2010). We examined an additional executive component termed *efficiency of access to long-term memory* (see Fisk & Sharp, 2004), which has been used to examine age-related changes in executive control (e.g., Robinson, Shallice, Bozzali, & Cipolotti, 2012). Thus, the measures obtained from the tests of executive functions included in our battery were categorized into three groups: inhibition, shifting, and efficiency of access to LTM. In this study, we had no tests that directly evaluate updating, as defined by Miyake and colleagues. Our battery did contain tests of WM span, which have been found to correlate with updating measures (Engle, Tuholski, Laughlin, & Conway, 1999; Lehto, 1996; Schmiedek, Hildebrandt, Lövdén, Wilhelm, & Lindenberger, 2009). However, because these studies did not conclusively demonstrate that these span measures index executive functions, we did not consider span measures as updating measures in our analyses.

A study of word recognition in sentential context among older adults with varying levels of hearing loss should also consider the potential contribution of *working memory* to performance, even in syntactically simple sentences. This suggestion is in line with empirical data for older hearing-impaired listeners (e.g., Foo, Rudner, Rönnberg, & Lunner, 2007; Lunner & Sundewall-Thorén, 2007; Lunner, 2003) and claims of some recent models of spoken language processing (e.g., Heald & Nusbaum, 2014; Rönnberg et al., 2013). Heald and Nusbaum (2014), for example, have proposed that speech perception is an *active cognitive process*. According to their account, contextual constraints on word recognition are part and parcel of the forces that determine which cognitive resources are recruited in service of speech perception. These cognitive functions include, but are not limited to, focused attention, WM, and learning mechanisms. The notion that WM plays a role in older adults' word recognition in sentential context would also be consistent with theoretical accounts put forth to explain sentence comprehension performance in reading among young participants (e.g., Just & Carpenter, 1992; King & Just, 1991). One such model is that of Just and Carpenter (1992), who proposed a memory-limited capacity mechanism to support the storage and manipulation of linguistic elements, provided that activation of these elements is kept above a minimal threshold. If the activation threshold falls below the minimum required, linguistic processing is scaled back, as activation is reallocated to other elements being stored and processed in WM. This reallocation results in less efficient information processing. Thus, impaired sentence comprehension, measured, for example, by reduced accuracy, is expected when total activation demands on WM exceed available activation resources. In this framework, age-related difficulties in sentence processing are associated with a reduction in WM capacity, as measured by reduced span (e.g., Salthouse, 1994). However, not all researchers agree on the nature of the relationship between WM and sentence processing (for an alternative view, see, for example, Caplan & Waters, 1999) or on its precise manifestation in aging (e.g., Kemper & Herman, 2006; Waters & Caplan, 2001). Moreover, the observation that WM fails to affect word recognition in young normal-hearing adults (Füllgrabe & Rosen, 2015) suggests that additional mechanisms other than WM need to be considered to account for performance.

Current study

In this study, we used measures of executive functions and WM capacity to predict word recognition accuracy in sentential context, adjusting for demographics (age, education, gender), and hearing sensitivity. In order to assess these effects, we examined older adults' ability to identify sentence-final words using the well-known Speech Perception in Noise-Revised task (SPIN-R; Bilger et al., 1984; Kalikow et al., 1977), in which sentences are presented against high and low levels of babble, while the predictability of sentential context is manipulated, such that half of the stimuli contain highly predictable sentence-final words, and half sentence-final words that are not easily predicted from context.

We were specifically interested in determining whether the effects of context on word recognition performance differed as a function of individual differences in cognitive functions (e.g., does the effect of context on sentence-final word recognition differ for those with higher executive function/ WM scores vs. those with lower scores?). We included two measures of hearing sensitivity because of the well-documented effects of decline in hearing acuity on older adults' spoken word recognition abilities (e.g., Akeroyd, 2008; Benichov et al., 2012; Humes et al., 2012; Pichora-Fuller, 2003, 2008; Tun, Williams, Small, & Hafter, 2012; Wingfield & Tun, 2007; Wingfield et al., 2005).

We hypothesized that accuracy of word recognition in sentences presented under the *high-level babble conditions* would be positively associated with measures of both executive functions and working-memory capacity. We reasoned that poor inhibition would impede participants' ability to override interfering background noise and maintain focus on task-relevant information. This prediction is in line with the observation that interference effects are noticeable when distractors involve meaningful speech (Desjardins, 2011; Guerreiro et al., 2010; Janse & Jesse, 2014; Janse, 2012; Tun et al., 2002). We also expected that low WM capacity would reduce participants' ability to retain the linguistic information encoded in the early parts of the sentences presented, impeding the implicit match between linguistic input and LTM representation required for successful lexical access (e.g., Janse & Jesse, 2014).

For the *low-predictability conditions*, we hypothesized that poorer inhibition would hamper older adults' ability to suppress additional lexical candidates that could potentially match the low-constraining semantic environment, consistent with Lash et al.'s (2013) finding that higher response entropy becomes more challenging with advancing age.

We also considered the possibility that word recognition in all sentence types would be affected by poor cognitive shifting, which would impair the participants' ability to shift from one response to the next, reducing their ability to process task-relevant information.

With respect to *age* effects, based on Benichov et al. (2012) and Janse and Jesse (2014), we hypothesized that age would modulate some of the effects of cognition on word recognition performance in our sample.

Methods

The data for this study were collected as part of a larger longitudinal project titled Language in the Aging Brain (LAB), which was designed to evaluate the changes in lexical retrieval and sentence comprehension in aging, as related to older adults' cognitive decline and deteriorating cerebrovascular health. The assessments, procedures, and overall design for the study were developed in 2003 and data were collected from 2004 through 2007.

Participants

The study included 173 adults aged 55–84 years, a subset of participants tested in a previous study (Goral et al., 2011). Mean age was 71 years (standard deviation (*SD*) 7.7), with an average of 15.6 years of education (*SD* 2.3), and 60% were women. Data in the Results section are also presented by 10-year-wide age groups. Participants were recruited from several sources, including participants from prior testing years of the LAB, the Veterans Affairs Normative Aging Study (NAS), and from the Boston area via flyers and mailings by the Harvard Cooperative Program on Aging. All participants were native speakers of English (for bilingual participants, they all learned English before age 7, with English serving as their primary language throughout their lives). Those with a history or evidence of neurological or psychiatric disorders were excluded, as were people who had general anesthesia within the past six months, radiation treatment within the past year, or prior loss of consciousness for more than 2 hours. Hearing and vision were assessed for all participants, as part of a general health assessment administered to each participant (see Procedure).

This study complied with all applicable ethical rules and regulations and was approved by the institutional review boards from Boston University Medical Center and Veterans Affairs Boston Healthcare System. All participants provided written informed consent.

Procedure

Participants first completed a telephone screen to determine study eligibility. Those deemed eligible were mailed a 20-page survey to complete prior to the first visit. This survey assessed demographic information (e.g., age, sex, education, ethnicity, and occupation), health history, health behaviors, health status, and medication use.

Participants then came in for two visits, each lasting approximately 3–4 hours, scheduled within 6 weeks of one another. During the first visit, participants received brief medical and neurological examinations, after which they began an extensive battery of neurolinguistic and neuropsychological tests administered over two visits. To minimize effects of fatigue on performance, the tests were administered such that tasks with different processing demands were interspersed and participants were given as many breaks as they needed. Hearing tests were administered during the second visit. Participants who used hearing aids ($N = 35$) were asked to remove them for the hearing assessments. The results reported here are based on a subset of these data, including data from the SPIN-R test,[1] hearing tests, and tests of executive functions and WM, as described below.

Assessment of sentence-final word recognition

Participants' sentence-final word recognition abilities were evaluated using the SPIN-R test (Bilger et al., 1984; Kalikow et al., 1977). Participants listened through headphones to recorded sentences of a male voice and wrote down the last word of each sentence they heard. The target sentences were played against background noise consisting of the sound of people talking – babble – as if at a cocktail party. Speech babble was a standardized masker, taken from the SPIN-R test (Bilger et al., 1984). Babble persisted throughout the task, with transition from one trial to the next being signaled by a brief tone indicating the new trial. The background babble was lowered at this point, to ensure the participants heard the tone. Trials were seven seconds apart, but no official time constraint was given to the participants. If they required more time to identify the target word, sentence presentation was paused. Before testing began, participants listened to three practice sentences. Practice sentences were repeated until instructions were understood. During this time the volume was set to suit what participants described as "comfortable listening conditions." Volume was not adjusted relative to the participants' hearing sensitivity because hearing evaluations were typically completed at the end of the testing session (for technical reasons, such as availability of hearing booth).

The stimuli comprised a total of 100 sentences: (1) 50 sentences presented against high-level babble and (2) 50 sentences presented against low-level babble. The stimuli were administered in two sentence lists (Lists A and B). Participants were randomly assigned to these lists, but sentences from the first list (A or B) were always given in low-level babble, while sentences from the other list (B or A) were always given in high-level babble. Both lists were administered in the same visit, but each list was separated by a series of different language and cognitive tests included in our larger test battery. Before the administration of the second list, participants were given another opportunity to readjust the volume of stimulus presentation to "comfortable listening conditions." The decision to always begin with the low-level babble sentences was based on pilot data, which indicated that participants who were given high-level babble sentences first typically aborted the remainder of the task. This design is limited in that it under- or over-estimates the effects of noise on word recognition due to learning or fatigue effects, but we proceeded with it, in order to avoid attrition rates that would have compromised the completion of the larger project.

Within each list, sentences varied in level of predictability, containing 25 high- and 25 low-predictability sentences, which were randomly ordered. The high-predictability sentences included sentence-final words that were easily predicted from sentential context (e.g., "A rose bush has prickly thorns"). In the low-predictability sentences (e.g., "Bob can't talk about the thorns"), syntactic and/or semantic cues were limited, and sentence-final word recognition depended primarily on the participant's ability to access the acoustic properties and lexical information encoded in the last word of each sentence.

Each sentence consisted of 5–8 words and 6–8 syllables, and the target word was always a monosyllabic noun. Sentences were balanced for level of difficulty, number of syllables, and vowel and consonant types, as defined in Bilger et al. (1984). In the high-level babble block, the target sentences were four decibels louder than the babble. In the low-level babble block, the target sentences were seven decibels louder than the babble. According to Bilger et al. (1984), signal-to-noise ratio in many daily life situations stands at +8 dB, where adult listeners with no hearing impairment typically show 100%

speech perception accuracy. Babble at +7 dB approximates this level, reflecting low-level background noise, whereas at +4 dB, listening conditions become more challenging.

Each response was scored for accuracy. Omitted responses were considered incorrect. These included also omissions of word endings, such as the plural marker "s." Thus, a response was coded as incorrect if a participant produced the noun "pen" instead of the target "pens." Similarly, the addition of the plural marker was also considered incorrect (unless the target word was meant to contain the plural marker). For example, if the target word was the noun "grain," and the word "grains" was provided as a response, it was scored as incorrect. Spelling errors were not penalized. Thus, homophones, for example, "brews" and "bruise," were marked as correct.

Hearing assessment

Participants' hearing acuity was assessed through tests of pure tone average (PTA) and speech recognition threshold (SRT), using a GSI 61 clinical audiometer with Telephonics TDH-50P headphones. The SRT stimuli were played on an integrated Sony 5-Disc Ex-Change System with optical digital output and a high-density linear converter. Approximately half the participants completed PTA and SRT testing in a quiet room (n = 93) and the remainder in a sound-proofed booth (n = 80).[2]

Pure tone average

Participants were presented with tones first in the right ear and then in the left one. Threshold was measured respectively at 1,000, 2,000, 4,000, and 500 Hz. Tones were presented for 1–2 s starting at 30 dB HL for each frequency. If the participant responded correctly, the level was lowered by 10 dB. When the participant failed to respond, the level was raised 5 dB. Threshold was determined when the participant correctly responded to at least two ascending tracks at a given level with at least 50% accuracy at that level. In our analysis, we used the Fletcher average, which represents the two best hearing thresholds of 500, 1,000, and 2,000 Hz of the participants' better ear. An analysis using a four-frequency PTA yielded comparable results to the final model (data not shown).

Speech recognition threshold (Wilson & Margulis, 1983)

The starting decibel level for each ear was set 20 dB above the PTA average for that ear, rounded up to a multiple of 5. First the tester read the participant an alphabetized list of 36 two-syllable spondee words which would be used in the SRT task (Auditec of St. Louis). Participants were then asked to repeat any words they heard from a recording of a male speaker; the words were presented in random order in each ear. The left ear was always tested first. If the participant responded correctly, the level was lowered by 10 dB. If the participant failed a trial, the next trial was presented 5 dB higher. The decibel level yielding 50% accuracy was taken as the participant's threshold.

Assessment of executive functions

Participants were tested on five commonly used tests of executive functions (EF) (e.g., Diamond, 2013), including Stroop (1935) color-word interference task, trail making test parts A and B (Spreen & Strauss, 1998), stop signal task (Logan & Cowan, 1984), verbal fluency of categories (animals) and letters (FAS), and alternating category fluency (Benton & Hamsher, 1989). The tests were administered by trained research assistants, using standard clinical procedures, where applicable. The measures obtained from these tests are assumed to probe different EF components that reflect Miyake and colleagues' approach to the fractionation of the executive control system (Friedman et al., 2006; Miyake et al., 2000), modified by including the component of *efficiency of access to long-term memory* (Adrover-Roig, Sesé, Barceló, & Palmer, 2012; Fisk & Sharp, 2004). Thus, we categorized the measures into (1) inhibition, (2) shifting, and (3) efficiency of access of LTM.

Measures of inhibition

Stroop color-word interference

The paper-and-pencil Stroop task assesses the ability to inhibit automatic responses. Stimuli were presented in two conditions: initial and interference. In the initial condition, participants read a set of printed color words (i.e., red, blue, tan, green, blue, etc.). In the interference condition, they said aloud the color of the ink in which the words were printed, ignoring the word's meaning. Participants were given two minutes for each condition to read as many words or name as many colors on the list as possible, returning to the beginning of the list if they reached the end before the two minutes were up. When a participant made an error, the administrator would say "no," in response to which the participant was to correct the mistake and keep going. Self-corrections produced before the administrators prompt were not counted as errors. Number of errors and total number of items read or labeled correctly in each condition were tallied. Stroop Difference Score was calculated by subtracting the percent correct scores in the initial (congruent) condition from the percent correct scores in the interference (incongruent) condition, where each correct percent score was calculated as the number of items correctly named divided by the number attempted.

Stop signal paradigm

The stop signal paradigm estimates an implicit measure of inhibitory control abilities when a prepotent response must be inhibited. The primary test involved a visuo-motor choice reaction time task during which the participant responded as quickly as possible to left- and right-pointing arrows visually presented on a computer screen. Total number of trial was 388. On a subset of the trials (14%), following the presentation of the arrow, the participant heard a tone (through a loudspeaker), which signaled that they should withhold their response on that trial. The ability to hear the tone was established for each participant prior during the right training trials preceding testing. The latency of the stop signal adapted to an individual's inhibition abilities; the tone latency was increased by 50 ms following an error trial (i.e., failure to inhibit the response when a tone was present). The increased time delay between the presentation of the arrow and the presentation of the tone facilitated the ability to inhibit one's response on the next trial, increasing the likelihood of successful inhibition. Similarly, a correct stop trial resulted in the stop signal latency on the next stop trial occurring 50 ms earlier, making inhibition more challenging. This adaptive latency technique allowed all participants to inhibit stop trials about 50% of the time, which takes into account individual differences in speed of response and also provides an estimation of each individual's stop signal response time (SSRT), a reliable measure of inhibitory control abilities (Alderson, Rapport, & Kofler, 2007; Band, Van Der Molen, & Logan, 2003; Congdon et al., 2012). Mean reaction time on correct responses was calculated.

Measures of shifting

Alternating category fluency

The alternating category fluency task is a list generation test designed to evaluate verbal set-shifting abilities, requiring participants to generate as many words as possible within 60 s, switching between two semantic categories (fruit and furniture) (Costa et al., 2014; Downes, Sharp, Costall, Sagar, & Howe, 1993; Iudicello et al., 2008). Performance on this task was measured by number of correct switches. We also computed the ratio of correct switches to total correct responses.

Trail making tests A and B

The paper-and-pencil trail making tests assess sustained and alternating attention abilities. In Trails A, participants are required to draw lines to connect circled numbers (1–25) as quickly as possible. In part B, they are asked to connect circled numbers (1–13) and letters (A–L), alternating between numbers and letters (e.g., 1-A-2-B, etc.). When participants made errors, they were required to correct them before proceeding with the test. A difference score comparing the time taken to complete each part was computed. This computed measure is commonly used (Corrigan & Hinkeldey, 1987; Drane, Yuspeh, Huthwaite, & Klingler, 2002; Lange, Iverson, Zakrzewski, Ethel-King, & Franzen, 2005; Strauss, Sherman, & Spreen, 2006, p. 657).

Measures of efficiency of access to long-term memory

Semantic verbal fluency

Participants were given the category "Animals" and were asked to verbally generate as many exemplars pertaining to that category as they could within 60 s. The number of acceptable responses produced in the allotted time was calculated.

Phonemic verbal fluency

Similar to the semantic verbal fluency, participants produced as many responses as possible within 60 s. In the Phonemic Fluency task, participants completed three trials: words that begin with the letters "F," "A," and "S." The total number of responses produced for the three trials was calculated for each participant.

Assessment of working memory capacity

Participants were tested on three commonly used tests of WM capacity (e.g., Diamond, 2013): listening span (modeled on Daneman & Carpenter, 1980), digit ordering, and month ordering (MacDonald, Almor, Henderson, Kempler, & Andersen, 2001). Span and percent accuracy were measured for each task.

Listening span

In this computerized task, participants listened to short sentences (4–7 words) (through headphones) and judged them as true or false with a button press, maintaining the last word of each sentence in memory. Sentences were presented at an average speaking rate. At the end of each sentence, participants were given as much time as they needed to make their judgment. Presentation of the next sentence commenced immediately after the button press. The participants were made aware of this procedure when given the instructions for the task. During training, we ensured that participants understood the instructions and heard the materials clearly. When cued, they recalled aloud the word(s) held in memory. Sentences were presented in increasingly longer sequences (from 1 to 7 sentences) until the participant was no longer able to correctly recall all of the final words from a given sequence. The accuracy of the judgments, the mean response latency to correct judgments, and the number of sequential sentences for which the last accurate recall occurred were recorded.

Digit ordering task

Participants were read groups of digits between 1 and 19 and were then asked to repeat them back in order from smallest to largest. Presentation rate was one item per second. Before beginning, they were given two examples, each comprising sets of two numbers, followed by up to three practice sets, to ensure they understood the task. For each group of numbers, the participants were given four separate sequences, starting with sets of two numbers. If they correctly ordered three out of the four sequences, they were then presented with four new sets, each of which contained an additional number. The task continued with increasingly longer lists of digits being read, until the participant no longer repeated them correctly. The highest level at which each participant's recall was correct was his or her digit ordering span. This span was calculated as number of completed levels (correct ordering of three of four sequences), plus .25 for each trial correct on the subsequent incomplete level). For example, if a participant had three trials correct at level 6 (series of six digits), and one trial correct at level 7 (series of seven digits), the total score would be 6.25.

Month ordering task

Participants were read lists of months that were not in chronological order and were told to repeat them back in chronological order. The task continued with increasingly longer lists being read, until the participant no longer repeated them correctly. The longest list for which the participant's recall was correct was his or her memory span. Scoring procedure was identical to that of the digit ordering task,

Statistical analyses

First, we created composites assessing inhibition, shifting, LTM access, and WM by transforming the component measures to *z*-scores and computing the mean of the relevant transformed measures to define the composite. We followed this procedure because each component measure includes both general and specific variance, and we combined measures to define a more general variance. Missing data on tasks used to define the composites (ranging from 1 to 16 participants) were imputed using the EM algorithm (Graham, 2012). For shifting, we used the mean of *z*-scores for difference in time between Trails conditions A and B and for the number of correct switches in alternating fluency. For inhibition, we used the mean of *z*-scores for SSRT from the stop signal task and the difference in percent correct for the two conditions on the Stroop task. The access to LTM composite was the mean of *z*-scores for phonemic and semantic fluency tasks. The WM composite was the mean of *z*-scores for accuracy on digit and month ordering and listening span. The four EF composites were tested for normal distribution using SAS Proc Univariate by the Anderson–Darling statistic. Normality was observed for the WM and LTM composites; the shifting and inhibition composites were both somewhat right-skewed, with longer tails in that direction (skewness = 0.83, 1.8, respectively). For the two inhibition tasks, larger values indicated greater degree of inhibition (longer time/delay); for the other tasks, larger values indicated better performance. Lower *z*-scores thus indicated faster response, less inhibition, less shifting than the sample mean.

Next, we used the generalized linear mixed model (GLMM) (Molenberghs & Verbeke, 2005) to examine the association between cognitive composites and word recognition, adjusting for demographics and hearing. This method, which we also employed in the Goral et al. (2011) study, allowed us to address the fact that responses were (1) dichotomous with (2) repeated measures per subject. The GLMM is analogous to hierarchical linear modeling for continuous normal responses in that responses to SPIN-R items were nested within person. Items were assumed to be binomially distributed; pseudo-likelihood estimation was used with a logit function linking the response to the predictors. All analyses were conducted using Version 9.2 of the Statistical Analysis System (SAS, Cary NC), including Proc GLIMMIX for estimating the GLMMs (SAS Institute, 2008).

We first fit a null model, Model 1, for the overall mean; in the second model, Model 2, we added the SPIN-R task effects (noise and predictability, both having low and high conditions), and their interaction. Model 3 added demographics (age, gender, and years of education) and hearing (Fletcher average, SRT in better ear). Model 4 included the four cognitive composites. Model 5 considered interactions, first among the demographic and hearing variables; then among cognitive and demographic factors; and finally interactions of the SPIN-R conditions with demographic, hearing, or cognitive factors. All models included a random effect for participant, and the covariance matrix of repeated measures for the four SPIN-R conditions was fit as an unstructured covariance matrix. Nonsignificant terms in a given model were omitted from the subsequent models.

Results

First, we examined descriptive statistics for the study variables, including means by 10-year age group and correlations. Next, we examined the relation of demographic and cognitive variables to the accuracy of SPIN-R performance, using GLMMs.

Table 1. Descriptive statistics and means (standard deviation) of study variables.

Age range	55–64	65–74	75–84	F(2,170)	p Value
N	38	70	65		
Demographics					
Age	59.8 (2.7)	70.1 (2.9)	78.7 (2.9)		
Education	16.2 (1.96)[a]	15.6 (2.2)[a,b]	15.2 (2.35)[b]	2.31	.1
Gender: % female	79	56	54	$X^2(1) = 7.25$	<.03
Hearing					
Hearing-SRT in better ear	23.14 (13.3)	28.46 (15.1)	26.7 (13.9)	1.71	.18
Fletcher	9.9 (7.1)[a]	16.4 (12.2)[b]	18.3 (11.6)[b]	7.23	.001
Cognitive measures					
Inhibition	−.25 (.25)[a]	−.19 (.31)[a,b]	−.04 (.54)[b]	3.95	.022
Shifting	−.30 (.74)	−.17 (.63)	.01 (.88)	2.26	.11
Access to long-term memory	.48 (.71)[a]	.18 (.7)[b]	−.07 (.78)[b]	6.84	.001
Working memory	.05 (.46)	.05 (.68)	.01 (.66)	0.08	.9
SPIN-R performance					
Low babble-low predictability	55.26[a] (17.02)	45.28[b] (18.92)	35.38[b] (18.76)	13.8	<.001
Low babble-high predictability	94.84[a] (5.49)	87.37[b] (15.36)	83.14[b] (16.87)	7.84	<.001
High babble-low predictability	37.79[a] (19.39)	27.2[b] (19.60)	19.88[c] (14.78)	12.05	<.001
High babble-high predictability	81.37[a] (14.86)	67.66[b] (24.37)	55.26[c] (29.57)	13.47	<.0001

Means with the same superscript were not significantly different according to Duncan's follow-up test.

Descriptive findings

For the sample as a whole, sentence-final word recognition accuracy varied by condition, with low-level babble/high-predictability sentences being most accurate (87%), followed by high-level babble/high-predictability sentences (66%), low-level babble/low-predictability sentences (43%), and high-level babble/low-predictability (27%).

Table 1 compares means for all study variables among 10-year age groups (55–64, 65–74, 75–84) using one-way ANOVA; significant effects were examined using Duncan's follow-up test. Education did not differ among the three groups, but the youngest group included proportionally more women than did the two older groups. Speech reception thresholds did not differ, but the Fletcher average did, with the two older age groups having higher thresholds. Two of the three EF composite measures (shifting and access to LTM) differed among age groups, with the youngest group having better performance than the oldest; for shifting the 65–74-year-old group was comparable to both the younger and older age groups. Performance on inhibition and WM did not differ by age.

SPIN-R performance also varied across age groups. For the two low-level babble conditions, the younger age group did significantly better than the two older groups; for the high noise conditions, each of the age groups differed from one another, with performance showing a decline with older age.

Table 2 shows the correlation matrix for all study variables. Pearson correlations were examined among study variables. We found significant correlations between measures

Table 2. Correlation matrix for demographics, hearing, and SPIN-R variables.

	Demographics			Hearing		Sentence-Final Word Recognition (%)				Cognition		
	Age	Edu	Female	FA	SRT	LoB-LoP	LoB-HiP	HiB-LoP	HiB-HiP	Inhibition	Shifting	LTM
Demographics												
Edu	−.18*											
Female	−.18*	.02										
Hearing												
FA	.31***	−.05	−.10									
SRT better ear	.11	−.01	−.19*	.48***								
Sentence-Final Word Recognition												
LoB-LoP	−.39***	.20**	.30***	−.37***	−.27***							
LoB-HiP	−.35***	.08	.34***	−.36***	−.22**	.63***						
HiB-LoP	−.41***	.15*	.30***	−.33***	−.20**	.45***	.44***					
HiB-HiP	−.43***	.17*	.35***	−.46***	−.34***	.66***	.73***	.73***				
Cognition												
Inhibition	.25***	.02	.07	−.01	.13	−.21**	−.22**	−.13	−.20**			
Shifting	.22**	−.17*	−.23**	−.01	−.03	−.22**	−.14	.24**	−.23**	.23**		
LTM access	−.27***	.30*	.08	.01	−.01	.19*	.07	.19*	.21**	−.25***	−.46***	
WM	−.06	.14	.02	.13	.11	.09	.08	.4	.01	.15	−.29***	.29***

Edu = education; FA = Fletcher average; SRT = speech recognition threshold; LoB = low babble; LoP = low predictability; HiB = high babble; HiP = high predictability; LTM = long-term memory; WM = working memory.

***$p \leq .001$; **$p \leq .01$; *$p \leq .05$

of executive functions (inhibition, shifting, and efficiency of access to long-term memory) and SPIN-R performance. No significant correlations were found with WM.

Analysis of sentence final-word recognition

The initial, null model was estimated to provide a baseline, and it did not fit the data well. Model 2 fit the SPIN-R items as a function of noise, predictability, and their interaction. This model was a significant improvement over the null Model 1 ($X^2(8) = 3{,}610.15$, $p < .001$), based on the difference in −2 log pseudo-likelihoods, which is distributed as a chi-square with degrees of freedom (*df*) equal to the difference in parameters between the two models. In Model 2 (results not shown), high-predictability was associated with better SPIN-R performance, while high-level babble was associated with worse performance. The interaction between noise and predictability was significant.

In Model 3, we included demographic characteristics (age, education, gender), and hearing (best SRT, Fletcher average). After removing the nonsignificant term (best SRT), Model 3 provided a significant improvement over Model 2 ($X^2(5) = 66.08$, $p < .001$). In this model (results not shown), age and higher hearing threshold were associated with worse SPIN-R performance, while higher education was marginally associated ($p < .07$) with better performance, as was being female.

Model 4 added cognitive measures, including measures of executive functioning (shifting, inhibition, access to LTM) and WM. After removing the nonsignificant cognitive measures, only inhibition remained. This model was a significant improvement over Model 3 ($X^2(1) = 8.25$, $p < .005$).

Next, we examined various interactions among the demographic factors, and identified two as significant: age and hearing, and education and inhibition. The former interaction was negative, indicating that older age and worse hearing were associated with worse SPIN-R performance, and the latter positive, suggesting that those with better inhibition and higher education performed better on SPIN-R. The fit of Model 5 did not differ significantly from that of Model 4. We also examined whether there were interactions between the SPIN-R conditions and either demographic or cognitive factors, but none were identified as significant. Thus, Model 5 was adopted as the "best" model among those examined (see Table 3). It was

Table 3. Estimated effects for "best-fitting" GLMM (Model 5) predicting SPIN-R performance.

Effect	Estimate	Standard error	*df*	*t* Value	*p* Value
Fixed effects					
Intercept	−1.3886	0.9673	166	−1.44	.153
Age	−0.00251	0.01156	515	−0.22	.8282
Education	0.07573	0.02692	515	2.81	.0051
Female	0.6815	0.1251	515	5.45	<.0001
Fletcher	0.1313	0.0617	515	2.13	.0339
Age × Fletcher	−0.00224	0.000842	515	−2.66	.008
Inhibition	−3.0205	0.9756	515	−3.1	.0021
Education × Inhibition	0.1608	0.05931	515	2.71	.0069
Babble	−0.8075	0.08141	515	−9.92	<.0001
Predictability	2.6967	0.09464	515	28.49	<.0001
Babble × Predictability	−0.7317	0.1018	515	−7.19	<.0001
Random effects					
Variance (Intercept)	0.5	0.06			

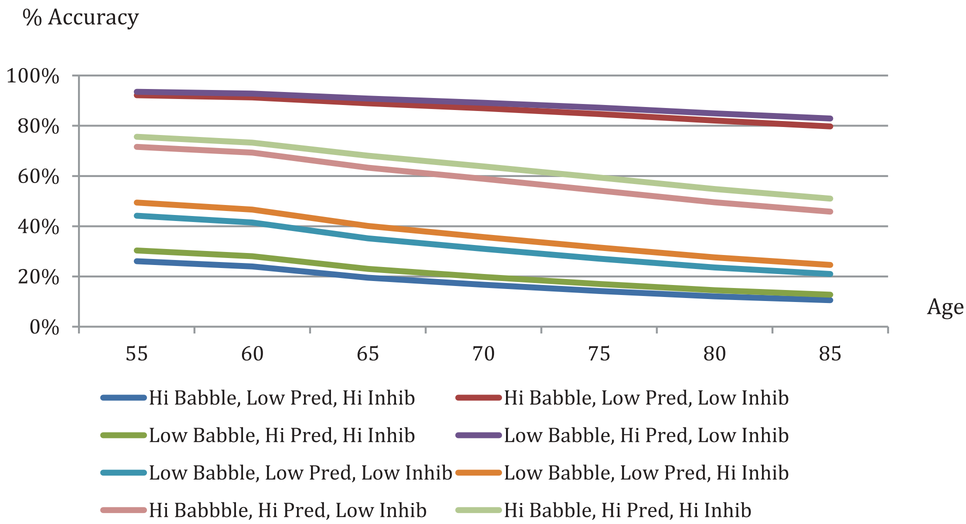

Figure 1. Estimated SPIN-R accuracy for men at the 25th and 75th percentiles of inhibition. [To view this figure in color, please see the online version of this journal.]

selected because it added two interaction terms of interest, and did not worsen the fit of the model to data.

Predicted probabilities (least-squares means) of success on the SPIN-R items were estimated based on Model 5, adjusted for the covariates (age, education, gender, hearing, inhibition) and their interactions, and were 22% for high noise-low probability, 38% for low noise-low probability, 66% for high noise-high probability, and 90% for low noise-high probability. Tukey–Kramer follow-up tests indicated that the differences among all pairs of conditions were significant, $p < .001$.

Based on the estimated coefficients from Model 5 (see Table 3), we estimated SPIN-R performance across age, for men at the 25th and 75th percentiles of inhibition in the four SPIN-R conditions; these estimated accuracies are presented in Figure 1. Women followed the same patterns as men, with higher accuracy (mean accuracies for men on the four conditions were: 88%, 61%, 34%, and 19%, compared to women, who were at 93%, 75%, 50%, and 32%).

Note that, with older age, SPIN-R performance worsens on all conditions. For each pair of curves, high inhibition is somewhat higher than for low inhibition, especially in two middle sets of curves (high-babble, high-predictability and low-babble, low-predictability). The high-predictability sentences were associated with better performance (curves 1–4, starting at top and moving down from 1–8).

Discussion

Results from this study are clearly aligned with the hearing literature, which demonstrates that age-related hearing loss degrades older adults' speech perception in adverse listening conditions, such as those imposed by presence of background babble noise (e.g., Craik, 2007; Wingfield & Tun, 2007). However, our findings also point to effects, even if small, which are not straightforwardly attributable to hearing. Specifically, our findings suggest that older adults' ability to correctly recognize sentence-final words is related to their inhibitory control. This claim needs to be qualified by the observation that other factors, such as supra-threshold auditory processing (Füllgrabe, 2013; Füllgrabe et al., 2015; Moore et al., 2012), which were not assessed in the current study, could have contributed to the results we found. Future studies should explore this idea more systematically.

The involvement of age-related decreases in inhibitory control has been reported in several studies of word recognition under different auditory challenges (Desjardins, 2011; Guerreiro et al., 2010; Janse, 2012), the assumption being that degradation of auditory input, related either to hearing loss or increased background noise, entails a greater need to engage cognitive resources to compensate for the incomplete information represented in the target sentence (Francis & Nusbaum, 2009; Rönnberg, 2003; Zekveld & Kramer, 2014; Zekveld, Kramer, & Festen, 2011).

Accordingly, we predicted, and found, that poor inhibitory control affected our participants' sentence-final word recognition performance in the high-level babble conditions, indicating difficulty filtering out interfering noise and focusing on task-relevant information. This result is consistent with findings from studies of older adults' difficulties ignoring competing speech reported in situations involving meaningful speech, which have been attributed to deficient executive control (see Introduction). This finding is further supported by neuroimaging studies of older adults linking their speech recognition abilities in adverse listening conditions to neural changes in prefrontal brain regions subserving executive control (Kane & Engle, 2002), such as increased activation or cortical thickening of prefrontal cortex (Hwang, Li, Wu, Chen, & Liu, 2007; Wong, Ettlinger, Sheppard, Gunasekera, & Dhar, 2010; Wong et al., 2009). These age-related brain changes suggest that older adults' executive control is recruited under challenging speech processing conditions and/or required as a support mechanism to increased demands on a system subject to multimodal declines in capacity.

Recall that the literature also suggests that age-related reduction in executive control, specifically in inhibition, also affects older adults' patterns of contextual facilitation (e.g., Sommers & Danielson, 1999). Studies of response entropy in aging suggest that the ability to analyze the semantic features of response candidates for sentence completion in mildly semantically constraining sentences decreases with age, likely due to a reduction in older adults' ability to suppress target competitors (Lash et al., 2013). We indeed found that better inhibition positively associated with word recognition accuracy in all sentence conditions, especially among individuals with higher education.

Based on our findings, we propose that the role of inhibition in meeting the demands of lexical access in word recognition is linked to optimizing focus on the most task-relevant response, reminiscent to the assumed role of cognitive control in the framework of semantic control (e.g., Badre & Wagner, 2007; Badre, Poldrack, Paré-Blagoev, Insler, & Wagner, 2005; Wagner, Paré-Blagoev, Clark, & Poldrack, 2001). Such a mechanism has been outlined in Crosson's (2013) work on intentional functions, where intention refers to the ability to select and initiate an action among several competing options, as opposed to attention, which involves the selection of a stimulus among competing stimuli and further processing that stimulus. This process has been associated with corticothalamo-cortical neural mechanisms of feedback and has been thought to ensure, for example, processing accuracy (Crosson, 2013).

We also hypothesized that poor WM would reduce our participants' ability to retain the linguistic information encoded in the target stimulus, adversely affecting their final-word recognition performance. Such findings would be in line with results from ERP studies of sentence-final word processing, which clearly demonstrate age-related difficulties in highly constraining semantic contexts. For example, in an online sentence processing reading task, in which half the sentential contexts contained highly predicable sentence-final words and half did not, Federmeier and Kutas (2005) showed that older adults had smaller and later peaks than younger adults in their N400 amplitude, which indexes a match between information provided or implied by the linguistic context and the target word being processed. Because these effects were correlated with advancing age and reduced performance on a reading span task, the authors proposed that with age, the ability to use contextual cues can be impeded by decrements in WM, compromising older adults' ability to retain the representation of the sentence-initial materials in memory sufficiently long for a retrospective analysis (Wingfield, Alexander, & Cavigelli, 1994), thus imposing a processing burden on retrieval and integrative functions (Federmeier & Kutas, 2005).

However, we did not find evidence for effects of WM on word recognition accuracy in our sample. One possible explanation for this pattern might be the off-line nature of SPIN-R. Being an off-line task, the SPIN-R may engage post-interpretive processes governed by executive-based processes that derive the appropriate word from the WM representation generated during the online phase of sentence processing, rather than by WM capacity *per se* (for related comments, see Newman, Malaia, Seo, & Cheng, 2013). Of course, we cannot rule out the possibility that our measures did not allow the detection of WM effects on processing of linguistic information, especially in light of Benichov et al.'s (2012) study, which used backward digit span to behaviorally assess WM effects on contextual facilitation in off-line conditions. Examples of potentially more sensitive measures of WM, which can be used in future studies, are complex span tasks, as described in Schmiedek, Lovden, and Lindenberger (2014).

We interpret the effects of our measures of inhibitory control but not of those of the other EF examined here on our participants' ability to correctly recognize words in sentential context as support for Miyake's approach to executive control which guided our study, that is, that executive functions share a degree of functional unity but also demonstrate diversity (e.g., Banich, 2009; Friedman et al., 2008; Garon, Bryson, & Smith, 2008; Miyake & Friedman, 2012; Murphy, Craik, Li, & Schneider, 2000). Interestingly, Janse and Jesse (2014) also called to adopt this perspective, based on the dissociation they found between the effects of WM and measures of executive control (attention) on the extent to which informational masking affected older adults' online phoneme discrimination task.

We acknowledge that inhibition cannot be easily teased apart from other cognitive control functions. These functions are mutually supportive and their effects are rarely observed independently (Diamond, 2013). For example, WM supports inhibitory control through goal maintenance, as the goal of the task must be kept in mind in order to determine which information is task-relevant and which information needs to be suppressed. At the same time, inhibitory control protects the mental space for WM from over-cluttering, by clearing irrelevant information as needed, thus allowing for integration of information in service of new ideas. Such a relationship could have been captured perhaps by the inclusion of updating measures in the study. Nonetheless, under certain circumstances WM and inhibitory skills can be disentangled, especially when contrasts in congruency are invoked (e.g., Diamond, 2013).

Our results differ in one important respect from those reported in many studies of word recognition in sentential context: the relative contribution of age to word recognition in sentential context. While researchers such as Benichov et al. (2012) demonstrated that age accounted for variance beyond that attributed to hearing and cognition, our findings indicate a more complex relation. While age had a significant and negative effect on word recognition in the preliminary analyses, this effect disappeared once interaction between age and hearing was included. In other words, older participants with worse hearing were those with poorest word recognition performance. It is possible that the wide age range (19–89 years) examined by Benichov et al. (2012) reflected differences between very young and much older participants, rather than a graded change that may emerge in later years, for example, between young-old and old-old adults. Age effects may not be evident among older adults in processing of sentential stimuli, as reported in an earlier sentence processing study from our lab, where we found no age effects on sentence comprehension accuracy among adults aged 55–85 years (Goral et al., 2011). Janse and Jense (2014) examined a similar age range, but did find age effects. Their sample, however, unlike ours, consisted of men only. The women in our study, as in the Goral et al. (2011) study, outperformed the men but were also slightly younger and may have had better hearing sensitivity, leaving the question of age effects unresolved. We thus follow Goral et al. (2011) in arguing that word recognition performance in sentential context is best explained in terms of cognitive functioning rather than age *per se*. Although the Goral and present studies used different language and cognitive measures, both indicate that preserved cognitive functioning among older adults enables them to compensate for decrements in language performance (e.g., Goaffaux, Phillips, Sinai, & Pushkar, 2008; Wingfiled & Grossman, 2006).

In sum, it appears that older adults' ability to correctly recognize sentence-final words varies as a function of their inhibitory control, where greater inhibitory abilities reflect better compensatory abilities for decreases in linguistic performance. Our findings also point to the utility of considering the framework of semantic control to explain how cognitive mechanisms operate among older adults in recognizing the final word of a sentence when noise is overlaid. They also indicate the usefulness of adopting a theoretical view of executive control, which emphasizes a certain level of functional diversity to account for patterns of word recognition in aging.

Notes

1. Two participants used hearing aids during the SPIN-R test. Their exclusion from analyses had no appreciable impact on the pattern of results reported here.
2. When we compared hearing measures between study participants assessed in the two conditions, we found a slight but significant difference in favor of those tested in hearing booths (Fletcher of 13.8 for those tested in a booth, vs. 18.0 for those tested in a room (*t*

(160) = 2.39, $p < .02$). However, when we adjusted for testing room in our final model, we did not find a significant effect (b = -.054, $p > .35$).

Acknowledgments

We would like to thank the participants of this study for their time and efforts. We would also like to thank Keely Sayers, Elaine Dibbs, Rossie Clark-Cotton, Shelley Amberg, Josh Berger, Dr. Jason Cohen and Dr. Jordan Awerbach for help in collecting the data, and Mitch Spring for helping compile and format the references.

Disclosure statement

All authors verify that they have no financial or personal conflict of interest with this article

Funding

This work was supported by the National Institute of Health (NIH) [grant number R01-AG014345], with Dr. Albert and Dr. Obler as Co-Principal Investigators. Dr. Spiro is the recipient of a Senior Research Career Scientist Award from the Department of Veterans Affairs Clinical Sciences Research and Development Program, U.S. Department of Veterans Affairs. He is also a co-investigator on grants from the NIH [grant number R01-AG014345], [grant number R24-AG039343], [grant number R01-AG032037], [grant number R01-AG018436], [grant number R01-AG034554].

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