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The role of executive functions in object- and action-naming among older adults

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Abstract

Background/Study Context: Lexical retrieval abilities and executive function skills decline with age. The extent to which these processes might be interdependent remains unknown. The aim of the current study was to examine whether individual differences in three executive functions (shifting, fluency, and inhibition) predicted naming performance in older adults.

Methods: The sample included 264 adults aged 55–84. Six measures of executive functions were combined to make three executive function composites scores. Lexical retrieval performance was measured by accuracy and response time on two tasks: object naming and action naming. We conducted a series of multiple regressions to test whether executive function performance predicts naming abilities in older adults.

Results: We found that different executive functions predicted naming speed and accuracy. Shifting predicted naming accuracy for both object and action naming while fluency predicted response times on both tests as well as object naming accuracy, after controlling for education, gender, age, working memory span, and speed of processing in all regressions. Interestingly, inhibition did not contribute to naming accuracy or response times on either task.

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Conclusion: The findings support the notion that preservation of some executive functions contributes to successful naming in older adults and that different executive functions are associated with naming speed and accuracy.

Keywords

Aging; Lexical retrieval; Shifting; Inhibition; Fluency; Reaction Time

Introduction

Language production is a rapid and dynamic process. Although some aspects of language production are thought to be relatively automatic (e.g., semantic priming), many aspects of language production require top-down control. The control mechanisms involved in successful language production are not fully understood, but some researchers have proposed that even relatively simple language production tasks like single word retrieval involves cognitive control abilities, such as efficiency of access to long-term memory, resolving competition among candidate representations, and monitoring (Adrover-Roig, Sesé, Barceló, & Palmer, 2012; Nozari & Novick, 2017; Shao, Roelofs, & Meyer, 2012).

Older adults experience increased difficulty retrieving word forms, a problem that may result from an age-related weakening in the strength of connections in the linguistic system (Burke, MacKay, Worthley, & Wade, 1991) and/or increased lexical competition during word retrieval (LaGrone & Spieler, 2006). To overcome the challenges older adults experience retrieving words from memory, they may engage cognitive control¹. However, age-related declines in cognitive control among some older adults may reduce their ability to compensate for changes in the linguistic system. The current study addresses whether successful word retrieval ability in older adulthood is related to the maintenance of cognitive control, in particular, to executive functions, such as inhibition, shifting, and fluency.²

Language production difficulties in aging

Current models of language production assume that a speaker's intended message activates a set of conceptual representations, which then spread activation across various levels of representation, including lexical, phonological, and structural representations (Hartsuiker, Pickering, & Veltkamp, 2004; Levelt, Roelofs, & Meyer, 1999; Roelofs, 1992). This activation is not limited to only the target words and structure, however. It is widely assumed that activation propagates to other representations that share features with the target, e.g., semantically similar words (*boat* and *canoe*) or words with overlapping phonology (*star* and *stair*). The degree of activation may differ across the various candidates (Roelofs, 1992), with the target receiving the most activation since it is the closest match. However, other factors may influence activation levels, such as the word's frequency and recency of use

¹Some researchers use the term 'executive functions' to refer to the same set of control abilities. In this paper, we employ the term 'cognitive control' to refer to the general concept of top-down control mechanisms used to perform cognitive operations efficiently. We use 'executive functions' to refer to specific aspects of cognitive control such as inhibition or shifting.

²The term 'fluency' in this paper is used to reference the executive function engaged in a task such as the verbal fluency task. Some researchers have called this component "efficiency of access to long-term memory" (Adrover-Roig, Sesé, Barceló, & Palmer, 2012; Fisk & Sharp, 2004) and have found evidence that it is separable from other executive functions such as inhibition, working memory, and shifting.

(Forster, Booker, Schacter, & Davis, 1990; Jescheniak & Levelt, 1994). This increased activation leads to competition among activated representations for selection (Levelt et al., 1999).

How is such competition resolved so that the appropriate words and structures are selected? Much of the research on language production has focused on lexical selection, though similar processes appear to operate at other levels of representation, such as phonological selection and articulation (Nozari, Freund, Breining, Rapp, & Gordon, 2016) and structural selection (January, Trueswell, & Thompson-Schill, 2009; Vosse & Kempen, 2000). There has been much debate surrounding how lexical selection occurs, particularly whether competing candidates need to be suppressed (Crowther & Martin, 2014; Green, 1998), or whether the target representation's activation is boosted (Oppenheim, Dell, & Schwartz, 2010). The term *controlled semantic cognition*, or *semantic control*, has been used to describe the process of accessing lexical-semantic content from long-term memory (Lambon Ralph, Jefferies, Patterson, & Rogers, 2017). Cognitive control is recruited in this process in the form of searching for semantic information that would help identify the target and in the form of inhibition to suppress competitors (Cahana-Amitay & Albert, 2014). Furthermore, Wagner, Paré-Blagoev, Clark, & Poldrack (2001) showed that top-down cognitive control is engaged during semantic retrieval with increasing retrieval demands, even when retrieval did not require selecting against competing representations. Cahana-Amitay and Albert (2014, 2015) have integrated the idea of semantic control into a broader framework of "neural multifunctionality," which refers to the dynamic interaction among the neural networks specializing in cognitive, affective, and praxic functions. Few language production models incorporate the role of cognitive control, however (Cahana-Amitay & Albert, 2014).

Aging may increase the need for cognitive control during language production due to changes in the representational system and/or increased susceptibility to lexical competition. Older adults experience increased difficulty retrieving the names of objects or people (e.g., Barresi, Nicholas, Connor, Obler, & Albert, 2000; Burke & Shafto, 2008; Connor, Spiro III, Obler, & Albert, 2004; Goral, Spiro, Albert, Obler, & Connor, 2007; MacKay, Connor, Albert, & Obler, 2002). They also report having more tip-of-the-tongue experiences compared to young adults, a situation in which they know the word they want to express but cannot access its word form, or phonology (Burke et al., 1991; Osshers, Flegel, & Lustig, 2013). The Transmission Deficit Hypothesis posits that the source of older adults' word retrieval difficulties is a weakening in the strength of connections between representational levels in the language production system (Burke et al., 1991). This weakening is particularly detrimental to the retrieval of the word form because there are few alternative routes to accessing the phonology when retrieval fails.

There is little research investigating how people resolve word-retrieval difficulties such as the experience of trying to retrieve low-frequency words. Behaviorally, older adults use strategies such as circumlocutions to communicate the idea they want to express when they are unable to access the particular word for that concept (Nicholas, Obler, Albert, & Goodglass, 1985). However, this strategy may be chosen only once attempts to retrieve the precise word fails. Before the decision occurs to produce a circumlocution, the speaker may attempt to overcome the difficulty accessing the word form in other ways. Phonological

primes have been found to increase word-retrieval success for low-frequency words and to help resolve tip-of-the-tongue (TOT) states for both younger and older adults (Abrams, White, & Eitel, 2003; Meyer & Bock, 1992; but see White & Abrams, 2002). Burke et al. (1991) obtained data from TOT diaries showing that many respondents engaged in an active memory search strategy such as going through the alphabet in order to prime the phonological onset of the word. Thus, speakers may try to find ways to prime themselves to get to the target word or to probe the mental lexicon for synonyms that would be appropriate. This strategy may reflect one aspect of semantic control – cuing of the lexical-semantic network to increase transmission to the target word's phonology.

Older adults may also experience more lexical competition than younger adults, which would require a greater need for control of competitors (J. M. Logan & Balota, 2003). In spoken word identification, lexical competition is greater for older adults than younger adults (Blumenfeld, Schroeder, Ali, & Marian, 2009; Sommers & Danielson, 1999). Similar findings have been shown for language production. Older adults showed greater interference from naming lexical distractors that were incompatible with the task (color or object naming) than younger adults (Kray, Eber, & Lindenberger, 2004). Older adults have also shown larger effects of name agreement on picture naming speed (LaGrone & Spieler, 2006), which may be due to age differences in selection among semantically related competitors rather than lexical competitors (Britt, Ferrara, & Mirman, 2016). Name agreement refers to the degree to which participants gave the same name or a variety of different names for a given picture, with low name agreement resulting in slower naming speeds. This slowing is thought to be due to competition among the alternative names for selection (Alario et al., 2004; Cheng, Schafer, & Akyürek, 2010). Hasher and Zacks (1988) proposed that poor inhibitory control results in decreased ability to restrict irrelevant information from working memory, causing greater interference. Thus, at least two factors may be responsible for older adults' word retrieval difficulties: weakening of connections within the language system and increased interference.

The role of cognitive control in language production

It is widely accepted that older adults attempt to compensate for neural and cognitive declines in order to maintain behavioral efficiency (e.g., Martins, Joannette, & Monchi, 2015; Reuter-Lorenz & Cappell, 2008). Neuroimaging evidence has shown that, during language comprehension tasks, older adults engage neural networks outside of the traditional core language networks, which is thought to reflect compensatory mechanisms such as cognitive control for successful language use (Peelle, Troiani, Wingfield, & Grossman, 2009; Wingfield & Grossman, 2006).

In fact, there is evidence that both older and younger adults rely on executive functions for various aspects of language processing. Those with better inhibitory control show better speech discrimination and speech perception in noise, independent of age effects, suggesting that cognitive control is important for dealing with lexical competition and competing input (Cahana-Amitay et al., 2016; Sommers & Danielson, 1999). Furthermore, higher executive function performance has been found to correlate with word retrieval ability in older adults

(Constantinidou, Christodoulou, & Prokopiou, 2012; Crowther & Martin, 2014) and sentence comprehension (Goral et al., 2011; Yoon et al., 2015).

Evidence for the role of cognitive control in language production comes from both behavioral and brain studies. Several studies have shown that individual differences in specific executive functions predict performance on language tasks. For example, in healthy younger and older adults, Crowther and Martin (2014) found that inhibitory control skills predicted participants' ability to deal with lexical-semantic competition. Shao, Roelofs, and Meyer (2012) investigated the relationship between three executive functions and speed of picture naming in a sample of young adults. They found that inhibition correlated with both action and object naming response times, and working memory correlated with action naming response times only. Shifting did not correlate with response times on either task. Shao, Janse, Visser, and Meyer (2014) reported a relationship between individuals' performance on a verbal fluency task and speed of picture naming. These findings suggest that specific executive functions may indeed contribute to naming performance, as they do to other language skills such as sentence comprehension (e.g., Goral et al., 2011).

The contribution of cognitive control to language production tasks also receives support from neurological and electrophysiological studies. The N2 is an event-related potential that is elicited in tasks requiring response inhibition (e.g., Carriero, Zalla, Budai, & Battaglini, 2007; Dong, Yang, Hu, & Jiang, 2009; Heil, Osman, Wiegmann, Rolke, & Hennighausen, 2000). Shao, Roelofs, Acheson, and Meyer (2014) reported larger N2 amplitudes for naming pictures with low name agreement compared to pictures with high name agreement. Pictures with low name agreement also exhibit longer response times (Székely et al., 2003) and place higher demands on lexical selection due to increased competition (Shao, Roelofs, et al., 2014). Costa, Strijkers, Martin, and Thierry (2009) found that N2 amplitude increased on successive picture presentation from the same semantic category, which is thought to induce cumulative interference. Thus, the N2 provides a neural marker of top-down inhibitory control for both linguistic and non-linguistic tasks.

The prefrontal cortex is heavily involved in tasks requiring cognitive control (Braver, Paxton, Locke, & Barch, 2009; Ridderinkhof, Van Den Wildenberg, Segalowitz, & Carter, 2004), and this region is also implicated in language control. Patients with left prefrontal brain lesions show greater lexical interference effects than patients with right prefrontal lesions and healthy controls (Piai, Riès, & Swick, 2016; Riès, Greenhouse, Dronkers, Haaland, & Knight, 2014; Schnur, Schwartz, Brecher, & Hodgson, 2006). Furthermore, people with Broca's aphasia, whose lesions typically involve the inferior frontal lobe, produced more errors when naming pictures in semantically blocked conditions, which result in greater semantic interference, than people with other types of left-hemisphere lesions who were classified as non-Broca's. Furthermore, the errors produced by people with Broca's aphasia tended to be competitors from the semantic set (Schnur et al., 2006). Together, these studies strongly suggest that the neural mechanisms underlying cognitive control are engaged during language production tasks.

Changes in executive functions in aging

Most of the research examining cognitive control and language production comes from younger adults. This relationship may change somewhat with aging due to factors mentioned earlier – weakened connections in the language system and increased susceptibility to interference. However, executive functions also tend to decline in aging (Daniels, Toth, & Jacoby, 2006; Fisk & Sharp, 2004). For example, older adults often show worse performance than younger adults on tasks tapping inhibitory control (Collette, Germain, Hogge, & Van der Linden, 2009; Duchek, Balota, Faust, & Ferraro, 1995), though some have argued that older adults, while slower for all conditions, are not differentially disadvantaged for conditions requiring inhibition (Verhaeghen, 2011).

If cognitive control is useful in successful language production, then declining cognitive control abilities may also contribute to the increasing word-retrieval difficulties seen in aging. There are substantial individual differences in cognitive changes with aging (e.g., Wilson et al., 2002) as well as in brain changes (e.g., Raz et al., 2005). In a longitudinal study with older adults, individuals showed similar slopes in rate of change over time across various cognitive domains, suggesting some commonality across domains within individuals (Wilson et al., 2002). The domains tested in this study included episodic memory, working memory, perceptual speed, visuospatial ability, and semantic memory (including word retrieval), but no explicit measures of cognitive control. The current study addresses the relationship between individual differences in cognitive control and word retrieval.

There is no agreed-upon definition of cognitive control or the various executive functions that make up this construct. Using factor analyses, researchers have identified several interrelated but distinct components of cognitive control such as inhibition (also described as resistance to interference), task-shifting, working memory updating, coordinative ability (i.e., divided attention), and strategic retrieval from long-term memory (i.e., fluency) (Adrover-Roig et al., 2012; Fisk & Sharp, 2004; Fournier-Vicente, Larigauderie, & Gaonac'h, 2008; Miyake et al., 2000; Verhaeghen, 2011). Several of these have been noted to decline in aging. Since we were interested in the relation between age-related changes in executive functions and lexical retrieval, the current study included measures of three executive functions: inhibition, task-shifting, and fluency.

Current study

The premise of the study is that lexical retrieval is dependent not on language alone but on the interaction of language and cognitive processes. To understand this interaction, we examine whether individual differences in cognitive control among older adults predict their word retrieval speed and accuracy. We examine word retrieval speed and accuracy on two different picture naming tasks (object and action naming) and ask whether performance can be predicted by three different aspects of cognitive control: inhibition, shifting, and fluency. Relations between specific aspects of cognitive control and word retrieval performance can reveal the cognitive mechanisms underlying successful word retrieval in older adults. We aim to understand what types of cognitive abilities predict successful and unsuccessful word retrieval in aging in an effort to contribute to an emerging picture of the role of cognitive control in language production.

The majority of naming studies in older adults report only accuracy rates or an analysis of errors. Naming latencies are rarely discussed despite the fact that aging is associated with increased latencies on a wide variety of language and cognitive tasks (e.g., Eckert, 2011; Salthouse, 1996). Among those studies that included latency data, most reported that naming responses are slower among older adults than younger adults (Fogler & James, 2007; Morrison, Hirsh, & Duggan, 2003; Tsang & Lee, 2003; Verhaegen & Poncelet, 2013; Wierenga et al., 2008; but see Evrard, 2002). Reaction time may be a more sensitive measure of subtle differences in performance due to the broad range of possible 'scores' as compared to accuracy measures, which are limited by the number of items on the task. Furthermore, older adults commonly complain about slowed retrieval (Ossher et al., 2013). Including both naming accuracy and latencies among the measures of lexical retrieval performance can provide a more nuanced picture of older adults' lexical retrieval performance than currently available.

Methods

Participants

The data for this study were collected as part of a longitudinal project on changes in cerebrovascular health and cognitive functioning in aging and their relation to word retrieval and sentence comprehension. The sample was 305 community-dwelling middle-aged and older adults from the Boston area, aged 55–84 ($M = 71.59$; $SD = 7.70$), with a mean education of 15.01 years ($SD = 1.95$), and with an equal proportion of males and females (154M/151F). Participants were recruited from several sources; some were previously tested as part of the Language in the Aging Brain Lab, and others were men from the Veterans Affairs Normative Aging Study (NAS) and their wives or persons from the general Boston area recruited via flyers and mailings by the Harvard Cooperative Program on Aging. All participants either were native speakers of English or had learned English before age 7 with English serving as their primary language thereafter. Those who were included in the study reported having no history of stroke, head trauma, neurodegenerative or significant psychological disorders, nor were undergoing treatments such as electroconvulsive therapy, dialysis, or interferon treatment at time of testing, or had undergone general anesthesia within six months of testing or chemotherapy or radiation treatment within one year. Participants with poor vision used corrective lenses. All participants provided written consent before commencing the experiment. The procedures were approved by the IRBs of the Veterans Affairs Boston Healthcare System and the Boston University School of Medicine, and the study was conducted according to the principles of the Helsinki Declaration.

To assess general cognitive functioning, we administered the Mini-Mental State Examination (MMSE). Total correct out of a possible score of 30 was calculated. Education was measured by years of schooling.

Materials

The tasks reported here were administered as part of a larger battery of language, cognitive, and health tests included in the Language in the Aging Brain (LAB) project. Computerized

tasks were completed on a Lenovo ThinkCentre M81 computer with a 19-inch monitor (resolution 1600 × 900). Average distance between participants and the monitor was 68 centimeters.

Picture naming—Two picture naming tasks were administered: the Boston Naming Test (BNT; Kaplan, Goodglass, & Weintraub, 1983) is an object naming task comprising 60 black-and-white line drawings including both low and high frequency items. Pictures were presented on a computer screen one at a time using E-Prime software (Psychology Software Tools, Inc.) and participants were instructed to verbally name the object pictured.

The Action Naming Test (ANT; Obler & Albert, 1979) includes 55 black-and-white line drawings of actions, both high and low frequency. Instructions were similar to those for the BNT except that participants were told to name an action pictured. For both the BNT and ANT, accuracy (the total number correct divided by the total number of items, converted to percent) and response time (in msec) were included as measures of naming performance. Accuracy included only unprompted productions or those in response to a phonemic cue. Response times were collected through E-Prime using a voice-triggered microphone, and item response times were discarded when the response was preceded by a cough or other vocalization. All responses were recorded for later verification and scoring.

Cognitive measures—To evaluate executive functions, we employed six standard neuropsychological tasks. The tests assessed three types of executive functions: set shifting (“Shifting”), efficiency of access to long-term memory (“Fluency”), and inhibitory control (“Inhibition”), each of which was computed as a composite score, calculated by averaging the z-scores from two different tasks (e.g., Lopez, Lincoln, Ozonoff, & Lai, 2005; Waters & Caplan, 2001). Additionally, we included working memory capacity (“Working memory”) and speed of processing (“Speed”) as covariates. The composite scores for these two variables were computed as the average of z-scores among three measures.

Shifting consisted of scores from the Trail Making Test (Spreen & Strauss, 1991) and Alternating Category fluency task (e.g., Henry & Phillips, 2006). In the first condition of the Trail Making Test, participants drew a line connecting numbers in an array in numerical order. In the second condition, the array contains both numbers and letters, and participants drew a line alternating between numbers and letters in order (i.e., 1, A, 2, B, etc.). The time difference between the two conditions was used to measure shifting ability. The second measure of shifting was the Alternating Category fluency task, a verbal fluency measure in which participants are asked to generate a list of items from two different categories, *fruits* and *pieces of furniture*, alternating between the two categories until the end of the trial. The total number of category switches made within 60 seconds was used to measure shifting.

Fluency comprised scores from two different verbal fluency tasks: phonemic and semantic (Tombaugh, Kozak, & Rees, 1999). Both tasks required participants to generate as many words as possible for a given category within the 60-second time limit. The phonemic fluency task included three trials; for each, participants generated words that started with a single letter: F, A, and then S, and the sum of the three trials was calculated. The semantic fluency task included one trial, in which participants generated words belonging to the

semantic category *animals*. The measure was total number of correct items produced in the time limit, excluding repetitions.

Inhibition included scores from a modified Stroop task (Stroop, 1935) and the Stop Signal Paradigm (SSP; G. D. Logan, Cowan, & Davis, 1984). The Stroop task included a list of color words that were printed in a different colored ink (e.g., the word ‘red’ printed in blue ink). In the first condition, participants read aloud the color words while in the second condition, they named the ink color. Participants had two minutes for each condition to complete as many items as they could. The measure of inhibition was the difference between the number correct responses in the two conditions.

The SSP involved a primary visual-motor response while withholding the response on trials in which a tone was sounded. The primary task was a choice reaction time task, in which participants responded by button press to an arrow pointing left or right. On a random subset of the trials, the stop signal tone was played just after the visual stimulus appeared. The stop signal delay (the time between the presentation of the visual stimulus and the stop signal) was adapted to each participant’s performance such that participants were able to successfully inhibit responses about 50% of the time. The measure of inhibition calculated from the SSP was the Stop Signal Reaction Time (SSRT). This was calculated by finding the response time in the distribution of non-stop-signal (“Go”) trials for participants that corresponded to their probability of stopping on stop-signal (“Stop”) trials. The mean stop signal delay for each participant was then subtracted from the value obtained in the first step to obtain the SSRT for that participant.

Working memory was derived from three measures: Listening span (adapted from Daneman & Carpenter, 1980), Digit ordering, and Month ordering (modeled on MacDonald, Almor, Henderson, Kempler, & Andersen, 2001). For the Listening span task, participants listened to sentences, judged them as true/false, and held the final word of each sentence in memory until cued to recall them. For Digit and Month ordering, participants heard a list of numbers or months and repeated them back in chronological order. The working memory span score for each task was the highest level at which the participant’s recall was correct. For general **speed of processing**, we combined the scores from three measures: the Choice Reaction Time (CRT) task, which was the same as that used as the primary task in the SSP but without the stop-signal tone and administered before the SSP task was given, and the Letter and Pattern Comparison tasks. On the comparison tasks, participants determined whether two strings of letters or two patterns of lines were the same or different. For each task, they were instructed to complete as many as they could in 30 seconds.

Data Analysis

Composite scores—Composite scores were created by calculating the mean of the z-scores for each of the task measures used to test the cognitive variables examined here: shifting, fluency, inhibition, working memory capacity, and speed of processing. Composites were used to obtain a broader representation of the underlying construct and reduce task-specific variance that may not be related to the cognitive skill being investigated. Correlations between the tasks in each construct were moderately high except for Inhibition (see Table 2). Although low correlations have often been reported between inhibition tasks

(e.g., Friedman & Miyake, 2004), the literature clearly suggests that both tasks both measure aspects of inhibitory control.

Missing data and outlier analysis—We excluded 14 participants who were missing data on education and two who had scores of 0 on one of the cognitive tasks (semantic fluency and month ordering). Response times for inaccurate trials were discarded. Response times for BNT, ANT, and CRT were trimmed to exclude outliers: first, times exceeding 20 seconds were excluded, and then trials greater than 2.5 SDs above and below the participant's mean RT on each task. For the calculation of the Stop Signal Response Time (SSRT), we employed the “conservative” criteria described in Congdon et al. (2012) in order to identify participants whose performance did not meet the assumptions of the horse-race model of response inhibition that the task was designed to capture (see Verbruggen & Logan, 2008). The adaptive algorithm attempts to maintain the participants' accuracy at 50% on Stop trials. Therefore, the first step involved removing participants whose accuracy on Stop trials was less than 40% or greater than 60% ($n = 13$, 4.5% of the sample). Second, participants with less than 75% accuracy on Go trials (the primary task) were excluded ($n = 10$, 3.5% of the sample). Third, participants with more than 10% errors on Go trials that had a response (i.e., not including no-response trials) are supposed to be excluded, but we did not have any participants who met this criterion. Lastly, participants with a SSRT that is negative or less than 50 ms were excluded ($n = 2$, 0.7% of the sample). Thus, 25 participants were removed for not meeting the criteria of the Stop Signal Response Time. Missing data on the language and cognitive variables were imputed using the EM algorithm (Graham, 2012). The resulting sample size included in the analyses was 264. Demographic information for this sample and descriptive statistics are presented in Table 1.

Analytic approach—Pearson correlations were examined among the demographic and cognitive variables in order to check for any potential issues of multicollinearity before conducting the regressions. To investigate whether executive functions predicted naming speed and/or accuracy, we conducted multiple regressions for each of the four dependent variables, namely, accuracy and response time for object and action naming. For each dependent variable, we first entered age, education, gender, speed of processing, and working memory as covariates. Gender was coded as 1 = female, 0 = male. In the second step, we included the three executive function composites: shifting, fluency, and inhibition. In the third step, we added interaction terms between age and each of the three executive functions. A final regression analysis that included only the significant variables ($p < .05$) from step 3 was conducted. Analyses were conducted using R Studio version 1.1.456 (RStudio Team, 2015).

Results

Correlations

Correlations among the executive function constructs, working memory, and speed of processing were low to moderate. Table 3 presents the correlations. None of the correlations between the composite scores is high enough to suggest that the constructs are measuring the same cognitive skill. All five cognitive composite measures correlated significantly with

age – in all cases, increasing age was associated with poorer performance. Shifting and fluency correlated with BNT/ANT accuracy and response times whereas inhibition did not. BNT/ANT accuracy and response times significantly correlated.

Because three of the cognitive tasks involved lexical retrieval (phonemic fluency, semantic fluency, and alternating category fluency), we investigated the degree to which these tasks correlated with the naming measures. If correlations between naming scores and the EF tasks involving lexical retrieval were higher than the correlations between naming scores and the EF tasks not involving lexical retrieval, it suggests that performance on the naming and EF tasks may result from the same skills. For shifting, the correlation between the Trail Making Test and naming accuracy ($r = .32$ for BNT and $r = .38$ for ANT) was similar to that found between alternating category fluency and naming accuracy ($r = .28$ for BNT and $r = .34$ for ANT). The two fluency tasks showed small to moderate correlations with naming accuracy ($r = .14$ (BNT) and $.19$ (ANT) for phonemic fluency and $r = .40$ (BNT) and $.36$ (ANT) for semantic fluency). The two inhibition tasks also showed small correlations with naming accuracy ($r = .11$ (BNT) and $.10$ (ANT) for Stroop and $r = .06$ (BNT) and $.06$ (ANT) for Stop Signal Reaction Time). Among the six EF tasks, Trail Making (which does not explicitly involve lexical retrieval) had the highest correlation with ANT accuracy and the second-highest correlation (after semantic fluency) with BNT accuracy. Phonemic fluency, by contrast, which does involve lexical retrieval, had very low correlations with both BNT and ANT accuracy. Therefore, we did not find evidence that the cognitive tasks that involved word retrieval were more strongly related to naming scores than those that did not involve word retrieval.

Regressions

A series of multiple regressions was conducted to identify which executive function variables predicted performance on each of the naming tests and whether they interacted with age. All regressions included age, education, gender, speed of processing, and working memory as covariates. Multicollinearity for each of the predictor variables was examined using the Variance Influence Factor (VIF) values. None of the VIF values exceeded 2, leading us to conclude that multicollinearity was not a concern among the variables included in the regression analyses.

Naming accuracy—Of the three executive functions (shifting, fluency, and inhibition) added in Step 2, only shifting was a significant predictor of naming accuracy on both the BNT ($p = .001$) and ANT ($p < .001$), though fluency was marginally significant ($p = .052$) for BNT accuracy. None of the interactions between age and executive functions were significant predictors of naming accuracy, though the interaction between age and inhibition was marginally significant ($p = .068$). However, when the interaction terms were added to the model in step 3, fluency became a significant predictor of BNT accuracy ($p = .047$).

A final regression was run that included all covariates and cognitive measures that were significant in the second step of the regression. The final model was the best fitting model for both tests and it explained 24.0% of the variance for BNT accuracy and 19.9% for ANT accuracy. Shifting and fluency were the only significant cognitive predictors for both BNT

accuracy and shifting alone was significant for ANT accuracy. Older adults with better shifting and better fluency performance had better naming accuracy.

Naming response times—The same series of regressions was conducted for BNT and ANT response times. Out of the three executive functions, fluency was the only significant predictor of response times for both BNT ($p < .001$) and ANT ($p = .029$) response times in step 1 of the regression. Better fluency score predicted faster naming speed for both the BNT and ANT. When the interactions between age and executive functions were added in step 2, the interaction between age and shifting score was a significant predictor of BNT response times, in addition to the effect of fluency score. This interaction showed that older adults with better shifting abilities showed no age effect on BNT response times, but older adults with poorer shifting abilities showed a decline in naming speed with increasing age (see Figure 1). In other words, older adults with poor shifting ability who were at the older end of the age range (e.g., 70–85) had faster naming speeds than older adults with poor shifting ability who were at the younger end of the age range (e.g., 55–70). Older adults with good shifting ability had similar naming speeds at younger and older ages. For ANT response times, none of the interactions were significant.

A final regression was run that included only the significant predictors from the previous regression. The model was the best fit for both tests and explained 31.2% of the variance for BNT response times and 19.8% of the variance for ANT response times. To summarize, better fluency scores predicted faster naming speed on both tests, and poorer shifting ability was associated with a decrease in naming speed over the age range tested (55–84) while those with better shifting ability showed no age effect on BNT response times.

Discussion

This study investigated whether performance on two lexical retrieval tasks, object naming and action naming, is associated with executive function abilities among older adults. The results indicated that two of the three executive functions tested – shifting and fluency – were strong predictors of certain aspects of lexical retrieval performance. Shifting predicted naming accuracy for both the object and the action naming tests. Fluency predicted naming response times for both naming tests as well as BNT accuracy. Although some tasks, like those included in the fluency composite, involve word retrieval, we did not find evidence that the relationships were stronger between EF tasks that involved word retrieval and the picture naming measures than those between non-language EF tasks and naming. Thus, we conclude that the cognitive mechanisms underlying EF tasks and those recruited for successful naming are related, at least in healthy older adults, and that declines in naming performance in older adulthood may be partly due to declines in certain executive functions.

For naming accuracy, shifting showed the strongest relationship with performance on both tests. The shifting measure we used comprised scores on the Trail Making Test and Alternating Category fluency. Since one of the two measures comprising the shifting composite is a fluency task, one could argue that the fluency score may be driving the effect. However, correlational analysis showed that the correlations between the two tasks and naming accuracy were similar and that in general the EF tasks involving lexical retrieval did

not have higher correlations with naming accuracy compared to the EF tasks that did not involve lexical retrieval. Thus, the relation between the shifting composite and naming accuracy cannot simply be attributed to the similarity between the two types of lexical retrieval tasks.

We also found an interesting interaction between age and shifting for BNT response times, indicating that response times were lower with advancing age for individuals with poorer shifting ability but remained the same for individuals with better shifting ability. We found a similar but non-significant ($p = .1$) interaction between age and shifting for BNT accuracy – individuals with poorer shifting ability showed lower scores with advancing age while those with better shifting showed no age effect on accuracy. Thus, individuals with worse shifting abilities show the largest age-related effects on both accuracy and response times – at older age, naming accuracy decreases, but, for pictures that were named accurately, response times are faster.

One possible explanation for the role that shifting plays in a picture naming task considers resolution of Tip-of-the-Tongue state (TOTs). In our study, individuals with higher shifting abilities showed greater success in retrieving the target names of the pictured items. Older adults tend to experience more TOTs than younger adults (e.g., Burke et al., 1991). Perhaps the older adults who are more successful on the naming tasks are those who can resolve a TOT state more efficiently. Various strategies can be employed to resolve a TOT state, and when one strategy does not prove successful, moving to a different strategy should facilitate retrieval better than persisting with the first one. The ability to shift strategies to facilitate retrieval may engage similar mechanisms to those required on tasks such as the Trail Making Test and the Alternating Category fluency task. For example, to access the phonological form of a word that is in a TOT state, one might shift attentional focus between different semantic features of the word or to semantic category cohorts to prime the target word form. Neuroimaging evidence supports this proposal. Bilateral anterior insula is important for attention shifting tasks of the type employed in the present study (Wager, Jonides, & Reading, 2004). Shafto, Stamatakis, Tam, and Tyler (2010) reported that greater activation in left insula among older adults during TOT states was associated with fewer TOTs overall, i.e., with more successful lexical retrieval. This evidence, together with our findings regarding the role of shifting abilities in lexical retrieval success, suggests that successful lexical retrieval in older adults relies on efficient use of shifting abilities, perhaps involving insular cortex, to overcome challenging word retrieval situations. If older adults with better shifting abilities are attempting to resolve TOT states and succeeding, that would result in higher accuracy, but also longer average response times (since resolving a TOT takes longer than immediately accessing the picture name). If TOTs cannot be resolved, accuracy would be lower and response times would be faster, since average response times include only correct trials. This is the pattern we found for older adults with high and low shifting abilities on BNT performance.

We also found that differences in naming latencies on both naming tasks were predicted by our fluency composite measure. Thus, this executive function appears to selectively reflect the *speed* with which one is able to successfully access the word's representation in long-term memory for production. These results are consistent with those of Shao, Janse, et al.

(2014), who found that fluency scores related to object naming latencies in a sample of older adults.

Fisk and Sharp (2004) and Adrover-Roig et al. (2012) considered fluency tasks to measure efficiency of access to long-term memory. Efficiency can be defined as reflecting both speed and accuracy (i.e., correct recall that is completed quickly). Since only latencies for correct responses were included in the analyses, the finding that fluency predicts naming speed on successful trials supports the proposal that fluency represents efficiency of access of items in long-term memory. The ability to access and retrieve the names of familiar objects from memory is likely to underlie both the verbal fluency task (which is a speeded word retrieval task) and the speed of picture naming.

Unlike Shao et al.'s (2012) study of young adults, who reported that inhibition correlated with response times for action and object naming, in our study inhibition did not predict response times for either of the naming tasks. This result may be due to the different characteristics of the two inhibition tasks we employed. While both tasks measure response inhibition, the Stop Signal Paradigm involves a stimulus-response conflict while the Stroop involves a stimulus-stimulus conflict (Sebastian et al., 2013). Given that scores on the two tasks did not correlate significantly within our sample, it is possible that the two tasks are measuring different aspects of inhibition. Future research should explore in more depth whether these different aspects of inhibitory control relate to naming performance.

In sum, our findings point to differential relationships between cognitive control mechanisms for two components of naming abilities in older adults: (1) retrieval *success* (i.e., accuracy), which is related to attention shifting, and (2) retrieval *speed* (i.e., response times), which is related to efficiency of access to long-term memory (fluency). The identification of specific relationships between executive control components and distinct aspects of lexical retrieval begins to shed light on the role that cognitive control may play in everyday language tasks and the effect that cognitive decline could have on diverse aspects of language processing.

There is a wealth of evidence showing that executive functions decline in older adulthood (Adrover-Roig et al., 2012; Albinet, Boucard, Bouquet, & Audiffren, 2012; Fisk & Sharp, 2004; MacPherson, Phillips, & Della Sala, 2002; Robbins et al., 1998). Indeed, our own data showed the same pattern – significant negative correlations between age and each of the cognitive composites. Word retrieval also becomes more difficult in older age (Barresi et al., 2000; Burke et al., 1991; Burke & Shafto, 2008; Connor et al., 2004; Goral et al., 2007; MacKay et al., 2002). Can declines in executive functions explain, in part, older adults' word retrieval problems? The current study suggests that the maintenance or decline of certain executive functions, such as shifting and fluency, explains a good amount of the age-related declines in word retrieval accuracy. Older adults with better shifting abilities were more accurate on both object and action naming, while older adults with better fluency abilities retrieved the same picture names more quickly.

Our findings are in line with the concept of neural multifunctionality (Cahana-Amitay & Albert, 2014, 2015). Within this framework, we propose that lexical retrieval is dependent

not on language alone but on the intimate, constant, and dynamic interaction of language with other cognitive functions, such as memory, executive system functions, etc. As these non-language cognitive capacities change with age, so does the capacity for lexical retrieval. The present study demonstrates ways in which components of executive system function interact with and influence lexical retrieval as people get older. Studies of cognitive aging in the future can be meaningful only if they also take into account both the variability of individual cognitive capacities in aging as well as the variability of the interactions among those cognitive capacities.

Several limitations should be acknowledged. First, our analyses of course do not demonstrate a causal relationship between executive control and lexical retrieval, but rather a correlational one. It is possible that deeper cognitive impairments underlie declines in both executive functions and naming. Second, Miyake et al. (2000) suggested that working memory updating is another important executive function. The working memory measures we included as covariates better reflect working memory storage rather than updating ability. It is possible that measures of working memory updating may provide additional insight into the relations between executive functions and naming. Third, several of our executive function measures involved lexical retrieval. Ideally, the measures of executive function would be non-verbal tasks. While we did not find any evidence to suggest that the EF tasks that involved word retrieval were more strongly related with naming than those that did not, future work should choose tasks carefully to avoid overlap between the EF and language measures that may reflect general language processes more than the interaction between language and cognitive control. Additionally, scores on our two measures of inhibition did not correlate, suggesting that these two tasks measure different aspects of response inhibition, which may be why our inhibition composite was not very potent as a predictor.

In conclusion, the current study suggests that decline in lexical retrieval abilities among older adults is related to decreases in certain cognitive abilities. Our study was designed to explore the contributions of executive functions to naming and not to further delineate specifically how these cognitive processes assist with lexical retrieval or to elucidate the stages of lexical retrieval at which different aspects of cognitive control are involved. Thus, an important next step will be in designing studies that tease apart the roles that executive functions play in lexical retrieval processes and comparing how these processes may differ for younger and older adults and for older adults with non-normal neuropsychological patterns.

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Figure 1.

Predicted BNT response times by Age and Shifting ability

BNT = Boston Naming Test; Low shifting = Shifting composite is 1 standard deviation below the mean, Average shifting = Shifting composite is set to the mean, High shifting = Shifting composite is 1 standard deviation above the mean

Table 1.

Descriptive statistics for naming and cognitive measures (n = 264)

	Mean or %	SD	Minimum	Maximum
Demographics				
Age	71.49	7.83	55	84
Education	15.00	1.97	9	17
Gender (% female)	50%			
Language Tasks				
Naming				
BNT Accuracy (%)	83.92	9.67	53.33	100.00
BNT Response Time (ms)	1297.79	261.47	696.02	2367.54
ANT Accuracy (%)	87.97	6.15	64.91	100.00
ANT Response Time (ms)	1353.10	266.50	790.02	2523.82
Cognitive Tasks				
Mini-mental state examination	28.91	1.13	24	30
Working memory span				
Digit ordering span	4.63	0.84	3.00	7.50
Month ordering span	4.30	0.92	2.00	6.50
Listening span	2.62	0.77	2.00	5.00
Working memory composite	0.00	0.78	-1.74	2.59
Speed of processing				
Choice Reaction Time (ms)	455.73	61.64	337.29	779.73
Letter comparison	17.01	3.78	9.00	27.00
Pattern comparison	28.61	5.41	9.00	44.00
Speed of processing composite	0.00	0.80	-2.20	1.94
Executive function: Shifting				
Trails RT difference (sec)	46.47	26.70	1.00	166.00
Alternating Categories (switches)	12.20	2.91	3.00	20.00
Shifting composite	0.00	0.84	-3.07	1.62
Executive function: Fluency				
Phonemic Fluency (sum)	46.12	12.45	14.00	94.00
Semantic Fluency	17.74	4.74	5.00	32.00
Fluency composite	0.00	0.81	-1.79	3.11
Executive function: Inhibition				
Stop Signal Response Time (ms)	226.54	72.29	53.13	595.38
Stroop accuracy difference	146.73	36.62	3.00	282.00
Inhibition composite	0.00	0.72	-2.68	2.35

Table 2.

Correlations for tasks combined to make composite scores (n = 264)

Construct	Tasks	R	p
Shifting	Trails & Alternating Categories	.399	<.001
Fluency	Phonemic & Semantic fluency	.307	<.001
Inhibition	Stroop & SSRT	.036	.565
Speed of processing	CRT & Letter comparison	.346	<.001
	CRT & Pattern comparison	.354	<.001
	Letter & Pattern comparison	.681	<.001
Working memory	Listening span & Month ordering	.369	<.001
	Listening span & Digit ordering	.341	<.001
	Month ordering & Digit ordering	.532	<.001

SSRT = Stop Signal Reaction Time, CRT = Choice Reaction Time

Table 3.

Correlations among age, education, gender, and cognitive measures (n = 264)

	Cognitive measures										Executive function measures					Demographics					Composite scores					Naming measures										
	Speed of processing					Working memory					Shifting					Fluency					Inhibition					Shifting					Fluency			Inhibition		
	Choice Reaction Time	Letter comparison	Pattern comparison	Lettering span	Month ordering	Digit ordering	Trails	Alternating Category	Phonemic Fluency	Semantic Fluency	Stroop	Stop Signal	Age	Education	Gender	Speed of processing	Working memory	Shifting	Fluency	Inhibition	BNT Accuracy	ANT Accuracy	BNT Response Time													
Age	.07	*** -.31	*** -.46	*** -.29	*** -.12	*** -.06	*** .15	*** -.21	*** -.09	*** -.37	*** -.20	*** .13																								
Education	*** -.13	*** .24	*** .24	*** .30	*** .26	*** .21	*** -.25	*** .20	*** .29	*** .24	*** .02	*** -.02	*** -.18%																							
Gender	.06	*** .25	*** .15	*** .16	*** .06	*** -.09	*** -.03	*** .22	*** .14	*** .09	*** .01	*** .04	*** -.17	*** .03																						
Speed of processing composite	*** -.71	*** .84	*** .85	*** .30	*** .28	*** .20	*** -.40	*** .40	*** .43	*** .30	*** -.10	*** -.16	*** -.35	*** .25	*** .14																					
Working memory composite	*** -.19	*** .38	*** .23	*** .73	*** .81	*** .80	*** -.40	*** .31	*** .35	*** .38	*** -.12	*** -.16	*** -.20	*** .33	*** .06																					
Shifting composite	*** -.33	*** .45	*** .37	*** .23	*** .41	*** .33	*** -.84	*** .84	*** .43	*** .43	*** .01	*** -.07	*** -.21	*** .27	*** .15	*** .42																				
Fluency composite	*** -.29	*** .48	*** .41	*** .39	*** .42	*** .26	*** -.43	*** .46	*** .81	*** .81	*** -.08	*** -.20	*** -.29	*** .33	*** .14	*** .45	*** .53																			
Inhibition composite	.07	.06	.11	.01	.03	.03	-.13	-.03	-.03	.16	.72	.72	.23	.02	-.03	.04	.03	.06	.08																	
BNT Accuracy	*** -.17	*** .18	*** .23	*** .20	*** .28	*** .17	*** -.32	*** .28	*** .14	*** .40	*** .11	*** -.06	*** -.16	*** .25	*** -.20	*** .24	*** .28	.35	.33	.12																
ANT Accuracy	*** -.21	*** .21	*** .18	*** .25	*** .29	*** .20	*** -.38	*** .34	*** .19	*** .36	*** .10	*** -.06	*** -.19	*** .25	*** -.06	*** .25	*** .32	.43	.34	.11	*** .60															
BNT Response Time	*** .39	*** -.37	*** -.33	*** -.09	*** -.13	*** -.15	*** .20	*** -.20	*** -.22	*** -.40	*** .07	*** .08	*** .02	*** -.20	*** .06	*** -.45	*** -.15	*** -.24	*** -.38	*** -.01	*** -.24	*** -.16	*** .65													
ANT Response Time	*** .30	*** -.32	*** -.33	*** -.06	*** -.07	*** -.02	*** .19	*** -.19	*** -.14	*** -.29	*** -.00	*** .11	*** -.02	*** -.08	*** .06	*** -.40	*** -.07	*** -.23	*** -.27	*** -.08	*** -.33	*** -.12	*** .65													

* Correlation is significant at the 0.05 level (two-tailed)

** Correlation is significant at the 0.01 level (two-tailed)

Gender is coded as 0 = Male, 1 = Female

Table 4.

BNT accuracy: Summary of multiple regression analysis

BNT Accuracy					
	B	SE B	Beta	t	p
STEP 1 EXECUTIVE FUNCTIONS					
R ² = .256, Adj R ² = .232, F(8,255) = 10.944 (p < .001)					
(Intercept)	86.566	0.751		115.308	<.001
Age (centered)	-0.076	0.075	-0.062	-1.018	.310
Education (centered)	0.538	0.289	0.110	1.863	.064
Gender (female)	-5.249	1.072	-0.272	-4.897	<.001
Speed	0.299	0.811	0.025	0.368	.713
Working memory	0.968	0.791	0.078	1.223	.222
Shifting	2.663	0.795	0.230	3.352	.001
Fluency	1.657	0.849	0.139	1.951	.052
Inhibition	0.919	0.750	0.068	1.226	.221
STEP 2 INTERACTIONS: AGE & EXECUTIVE FUNCTIONS					
R ² = .275, Adj R ² = .243, R ² change = .020, F(11,252) = 8.694 (p < .001), F change = 2.260 (p = .082)					
(Intercept)	86.411	0.761		113.510	<.001
Age (centered)	-0.046	0.076	-0.037	-0.612	.541
Education (centered)	0.593	0.288	0.121	2.057	.041
Gender (female)	-5.185	1.067	-0.269	-4.860	<.001
Speed	0.602	0.820	0.050	0.734	.463
Working memory	0.901	0.787	0.073	1.145	.253
Shifting	2.520	0.814	0.218	3.095	.002
Fluency	1.687	0.843	0.141	2.000	.047
Inhibition	1.053	0.761	0.078	1.384	.168
Age*Shifting	0.152	0.093	0.031	1.634	.104
Age*Fluency	-0.052	0.098	-0.003	-0.526	.600
Age*Inhibition	-0.186	0.102	-0.015	-1.832	.068
STEP 3 SIGNIFICANT PREDICTORS					
R ² = .240, Adj R ² = .228, F(4,259) = 20.451 (p < .001)					
(Intercept)	86.520	0.748		115.706	<.001
Education (centered)	0.640	0.283	0.131	2.261	.025
Gender (female)	-5.159	1.061	-0.267	-4.862	<.001
Shifting	3.019	0.748	0.261	4.035	<.001
Fluency	2.219	0.789	0.186	2.812	.005

B = unstandardized regression coefficient, Beta = standardized regression coefficient

NOTE: Variables with p-values > .05 were dropped from Step 2 to Step 3.

Table 5.

ANT accuracy: Summary of multiple regression analysis

ANT Accuracy					
	B	SE B	Beta	t	p
STEP 1 EXECUTIVE FUNCTIONS					
$R^2 = .252$, Adj $R^2 = .228$, $F(8,255) = 10.720$ ($p < .001$)					
(Intercept)	88.826	0.479		185.412	< .001
Age (centered)	-0.061	0.048	-0.077	-1.274	.204
Education (centered)	0.300	0.184	0.096	1.627	.105
Gender (female)	-1.692	0.684	-0.138	-2.474	.014
Speed	-0.168	0.518	-0.022	-0.325	.746
Working memory	0.858	0.505	0.109	1.700	.090
Shifting	2.338	0.507	0.318	4.611	< .001
Fluency	0.713	0.542	0.094	1.315	.190
Inhibition	0.518	0.478	0.061	1.084	.280
STEP 2 INTERACTIONS: AGE & EXECUTIVE FUNCTIONS					
$R^2 = .259$, Adj $R^2 = .227$, R^2 change = .007, $F(11,252) = 8.010$ ($p < .001$), F change = 0.838 ($p = .474$)					
(Intercept)	88.745	0.490		181.172	< .001
Age (centered)	-0.056	0.049	-0.072	-1.156	.249
Education (centered)	0.314	0.185	0.101	1.692	.092
Gender (female)	-1.740	0.686	-0.142	-2.534	.012
Speed	-0.213	0.528	-0.028	-0.405	.686
Working memory	0.878	0.506	0.111	1.734	.084
Shifting	2.491	0.524	0.339	4.754	< .001
Fluency	0.717	0.543	0.094	1.322	.188
Inhibition	0.657	0.490	0.077	1.342	.181
Age*Shifting	-0.055	0.060	-0.018	-0.924	.356
Age*Fluency	0.049	0.063	0.004	0.775	.439
Age*Inhibition	-0.090	0.066	-0.012	-1.381	.169
STEP 3 SIGNIFICANT PREDICTORS					
$R^2 = .199$, Adj $R^2 = .193$, $F(2,261) = 32.418$ ($p < .001$)					
(Intercept)	88.760	0.486		182.668	< .001
Gender (female)	-1.560	0.688	-0.127	-2.266	.024
Shifting	3.291	0.412	0.447	7.980	< .001

B = unstandardized regression coefficient, Beta = standardized regression coefficient

NOTE: Variables with p-values > .05 were dropped from Step 2 to Step 3.

Table 6.

BNT response time: Summary of multiple regression analysis

BNT Response Times					
	B	SE B	Beta	t	p
STEP 1 EXECUTIVE FUNCTIONS					
$R^2 = .291$, Adj $R^2 = .269$, $F(8,255) = 13.091$ ($p < .001$)					
(Intercept)	1268.352	19.810		64.027	< .001
Age (centered)	-6.045	1.971	-0.181	-3.066	.002
Education (centered)	-8.961	7.624	-0.068	-1.175	.241
Gender (female)	58.535	28.284	0.112	2.070	.040
Speed	-137.700	21.412	-0.421	-6.431	< .001
Working memory	24.669	20.876	0.074	1.182	.238
Shifting	13.851	20.966	0.044	0.661	.509
Fluency	-89.947	22.408	-0.278	-4.014	< .001
Inhibition	-3.528	19.783	-0.010	-0.178	.859
STEP 2 INTERACTIONS: AGE & EXECUTIVE FUNCTIONS					
$R^2 = .322$, Adj $R^2 = .292$, R^2 change = .031, $F(11,252) = 10.862$ ($p < .001$), F change = 3.777 ($p = .011$)					
(Intercept)	1271.925	19.913		63.875	<.001
Age (centered)	-5.740	1.978	-0.172	-2.902	.004
Education (centered)	-6.829	7.540	-0.052	-0.906	.366
Gender (female)	63.853	27.905	0.122	2.288	.023
Speed	-124.663	21.454	-0.382	-5.811	< .001
Working memory	24.061	20.588	0.072	1.169	.244
Shifting	1.514	21.303	0.005	0.071	.943
Fluency	-88.249	22.058	-0.273	-4.001	< .001
Inhibition	-6.718	19.900	-0.018	-0.338	.736
Age*Shifting	5.810	2.433	0.044	2.388	.018
Age*Fluency	1.191	2.566	0.002	0.464	.643
Age*Inhibition	-3.058	2.663	-0.009	-1.148	.252
STEP 3 SIGNIFICANT PREDICTORS					
$R^2 = .312$, Adj $R^2 = .296$, $F(6,257) = 19.407$ ($p < .001$)					
(Intercept)	1273.700	19.479		65.389	< .001
Age (centered)	-5.712	1.877	-0.171	-3.043	.003
Gender (female)	65.483	27.716	0.126	2.363	.019
Speed	-124.493	21.312	-0.381	-5.842	< .001
Shifting	1.917	20.618	0.006	0.093	.926
Fluency	-86.432	21.046	-0.267	-4.107	< .001
Age*Shifting	6.417	2.010	0.012	3.193	.002

B = unstandardized regression coefficient, Beta = standardized regression coefficient

NOTE: Variables with p-values > .05 were dropped from Step 2 to Step 3.

Table 7.

ANT response time: Summary of multiple regression analysis

ANT Response Times					
	B	SE B	Beta	t	p
STEP 1 EXECUTIVE FUNCTIONS					
R ² = .228, Adj R ² = .204, F(8,255) = 9.409 (p < .001)					
(Intercept)	1325.833	21.072		62.921	< .001
Age (centered)	-6.586	2.097	-0.194	-3.141	.002
Education (centered)	2.305	8.110	0.017	0.284	.776
Gender (female)	54.135	30.086	0.102	1.799	.073
Speed	-138.801	22.776	-0.417	-6.094	< .001
Working memory	40.918	22.206	0.120	1.843	.067
Shifting	-17.232	22.301	-0.054	-0.773	.440
Fluency	-52.363	23.836	-0.159	-2.197	.029
Inhibition	-32.848	21.043	-0.089	-1.561	.120
STEP 2 INTERACTIONS: AGE & EXECUTIVE FUNCTIONS					
R ² = .228, Adj R ² = .195, R ² change = .001, F(11,252) = 6.785 (p < .001), F change = 0.063 (p = .979)					
(Intercept)	1325.651	21.644		61.248	< .001
Age (centered)	-6.485	2.150	-0.191	-3.016	.003
Education (centered)	2.603	8.196	0.019	0.318	.751
Gender (female)	54.665	30.332	0.103	1.802	.073
Speed	-137.096	23.319	-0.412	-5.879	< .001
Working memory	40.707	22.379	0.119	1.819	.070
Shifting	-18.432	23.155	-0.058	-0.796	.427
Fluency	-52.163	23.976	-0.158	-2.176	.031
Inhibition	-32.679	21.631	-0.088	-1.511	.132
Age*Shifting	0.793	2.645	0.006	0.300	.765
Age*Fluency	-0.037	2.789	-0.000	-0.013	.989
Age*Inhibition	-0.734	2.894	-0.002	-0.254	.800
STEP 3 SIGNIFICANT PREDICTORS					
R ² = .198, Adj R ² = .189, F(3,260) = 21.408 (p < .001)					
(Intercept)	1353.115	14.772		91.599	< .001
Age (centered)	-6.549	2.037	-0.192	-3.216	.001
Speed	-134.418	21.897	-0.404	-6.139	< .001
Fluency	-41.864	21.211	-0.127	-1.974	.049

B = unstandardized regression coefficient, Beta = standardized regression coefficient

NOTE: Variables with p-values > .05 were dropped from Step 2 to Step 3.