Bilingual Experience and Executive Control over the Adult Lifespan: The Unsung Role of Biological Sex

Sivaniya Subramaniapillai

Department of Psychology
McGill University, Montreal

February 2017

A thesis submitted to McGill University in partial fulfillment of the requirements of the degree of Master of Science in Psychology

Table of Contents

Abstract

We investigated whether bilingual language experience over the lifespan buffers against age-related declines in executive control. Some studies have reported reduced age-related decline in executive control in bilingual adults, compared to monolingual adults. However, other studies have failed to find this effect. Here, we investigate this issue using an unspeeded measure of executive control, the Wisconsin Card Sort Task, in an adult lifespan sample that varied in bilingual language experience. The results suggested that women showed the greatest age-related decline across WCST measures, and were more likely than men to show improved performance with increased bilingual experience. We consider implications of this finding for advancing our understanding of the relation between bilingualism and cognition, and also the effects of biological sex on cognitive aging.

Résumé

Nous avons étudié si l'expérience linguistique bilingue au cours de la durée de vie contribue à lutter contre les baisses des fonctions exécutives liées à l'âge. Certaines études ont rapporté une diminution réduite des fonctions exécutives chez les adultes bilingues, relativement aux adultes monolingues. Cependant, d'autres études n'ont pas réussi à démontrer cet effet. Ici, nous étudions ce problème en utilisant une épreuve sans limite de temps mesurant les fonctions exécutives, le Wisconsin Card Sorting Test, dans un échantillon adulte variant dans expérience linguistique bilingue. Les résultats suggèrent que les femmes démontraient le plus grand déclin relatif à l'âge dans les mesures du WCST et étaient plus susceptibles que les hommes de présenter une performance améliorée avec une expérience bilingue accrue. Nous considérons les implications de cette découverte pour faire progresser notre compréhension de la relation entre le bilinguisme et la cognition, ainsi que les effets du sexe biologique sur le vieillissement cognitif.

Acknowledgments

I would like to express my gratitude to my supervisors Drs. Debra Titone and Natasha Rajah for their mentorship and support through the learning process of this thesis. Thank you so much for your patience.

I thank Stamatoula Pasvanis for her dedication in assisting with the study, and Jason Gullifer for his feedback, and assistance navigating through the effects package in R. Finally, I'd like to thank members of the Rajah and Titone Labs for providing a supportive team environment. Thank you to Charana Rajagopal, Stamatoula Pasvanis, Naomi Vingron, and Shannon Riley for being great allies through this journey. I would also like to thank my family and friends for supporting me in all ways possible and unimaginable.

To Genevieve Dalglish, whose friendship I will always cherish. I am so grateful for the letters and emails that provided me company during my studies. I will always find inspiration in your boundless love, courage, and kindness. Thank you so much for inviting me along for part of your journey, and for teaching me so much about the importance of living life with openness, optimism, and fearlessness.

Preface and Contribution of Authors

Recruitment of participants and administration of the Wisconsin Card Sort Task was done by Stamatoula Pasvanis. The statistical analysis, the interpretation and writing was primarily done by me with the help and supervision of Drs. Debra Titone and Natasha Rajah.

Introduction

Executive control refers to the domain-general neurocognitive coordination of skills or habits that allow us to successfully implement goal-directed behaviour (e.g., Braver, 2012; Braver & West, 2008; Miyake et al., 2000; Miyake & Friedman, 2012). Healthy aging is generally associated with declines in executive control (e.g., Amer, Campbell, & Hasher, 2016; Salthouse, 2009, 2010; Stuss, 2011), however, there is great variability in how age-related declines manifest across various executive control tasks (Christensen et al., 1999; Mungas et al., 2010; Wilson et al., 2002; Zelinski, Gilewski, & Schaie, 1993). Of relevance here, recent work suggests that certain lifestyle factors (e.g., education level, socioeconomic status) differentially modulate executive control capacity over the adult lifespan (Mungas et al., 2010; Scarmeas & Stern, 2003; Stern, 2012). Given that the number of older adults will markedly increase over the next several decades (Alzheimer's Association, 2015; Beard, 2015), it is crucial we rigorously evaluate which potential lifestyle factors may promote successful aging so that we can optimize the neurocognitive health of this population (Davis, Marra, Najafzadeh, & Liu-Ambrose, 2010; Forte, Boreham, de Vito, & Pesce, 2015; Vaughan & Giovanello, 2010).

One such factor that has received great attention in recent years is *bilingualism*, that is, the knowledge, acquisition and regular use of two or more languages in daily life (Bialystok, Abutalebi, Bak, Burke, & Kroll, 2016; Bialystok, Craik, Klein, & Viswanathan, 2004; Coderre, Smith, van Heuven, & Horwitz, 2016; Costa & Sebastián-Gallés, 2014; Kroll, Bobb, & Hoshino, 2014; Kroll & Bialystok, 2013). Bilingualism is thought to protect against age-related executive control declines because people who regularly speak more than one language face unique cognitive challenges compared to people who speak only one language (i.e., monolinguals). These unique cognitive challenges, in turn, cause bilinguals to more frequently recruit executive control processes, which over time leads to a more exercised and strengthened executive control capacity.

While a great deal of work has investigated whether and how the bilingual experience impacts domain-general cognition among many populations, including older adults, the emerging story is not clear for a variety of reasons. These include a tendency in the literature to investigate different dimensions of bilingual experience, to use age-group comparisons rather than a continuous lifespan approach, and the failure to examine other variables that may also modulate executive control performance over the lifespan, such as biological sex. In this paper, we investigate whether different attributes of bilingual experience modulate executive control performance across the adult lifespan (i.e., including younger, middle-aged, and older adults), as a function of biological sex, using a non-speeded executive control task that is ideal for directly comparing people across the lifespan (i.e., the Wisconsin Card Sorting Task).

We first discuss the obvious question, *How would bilingual experience modulate domain-general executive control?* One way this occurs is that bilinguals must monitor and select the appropriate language to use within a given context. For example, this may involve appropriately suppressing the impulse to use English in one's French-speaking workplace, but doing the reverse when conversing with exclusively Anglophone friends (Abutalebi, Tettamanti, & Perani, 2009; Green, 1998; Guo, Liu, Misra, & Kroll, 2011; Kroll, Bobb, Misra, & Guo, 2008; Meuter & Allport, 1999; Misra, Guo, Bobb, & Kroll, 2012; Pivneva, Palmer, & Titone, 2012; von Studnitz & Green, 2002). Bilinguals must also suppress activation of specific sound patterns, words, or meanings from other known languages when speaking or reading (Blumenfeld & Marian, 2011; Christoffels, Firk, & Schiller, 2007; Dijkstra, 2005; Green, 2011; Guo et al., 2011; Kroll et al., 2008; Macizo, Bajo, & Martin, 2010; Martin, Macizo, & Bajo, 2010; Misra et al., 2012; Pivneva, Mercier, & Titone, 2014). For example, by inhibiting the French meaning of *chat* when reading that word in an English context. Consequently, the need to routinely exercise executive control to suppress knowledge of a whole language, or to suppress specific representations within a particular language, is hypothesized to enhance executive control capacity over the lifespan (see review by Baum & Titone, 2014). In older adults, it is possible that heightened executive control capacity could also contribute to greater *cognitive reserve*. Cognitive reserve is a construct that refers to the idea that certain life experiences and activities ameliorate age-related changes in neurocognitive function and may slow the progression of both normal age-related cognitive decline and pathological aging (i.e., dementia) (Calvo, García, Manoiloff, & Ibáñez, 2016; Scarmeas & Stern, 2003; Stern, 2002, 2009, 2012; Tucker & Stern, 2011).

Empirical support for the idea that bilingualism mitigates the effects of age-related decline in domain-general executive control is mixed. Though, like others, we think the totality of evidence leans in the direction of supporting this relationship (see reviews by Ardila & Ramos, 2010; Bak, 2016a,b; Bialystok, 2016; Friedman, 2016; Watson, Manly, & Zahodne, 2016; Titone et al., in press). Indeed, some studies offer clear support for a link between bilingualism and executive control in older adults. Yet, other studies have obtained mixed support, in that effects occur for some measures but not others, or as a function of bilingual experience (Ansaldo, Ghazi-Saidi, & Adrover-Roig, 2015; Grady, Luk, Craik, & Bialystok, 2015; Kousaie, Sheppard, Lemieux, Monetta, & Taler, 2014; Zahodne, Schofield, Farrell, Stern, & Manly, 2014). Though of note, some studies have failed to support this view (de Bruin, Bak, & Della Sala, 2015; Gathercole et al., 2014; Kirk, Fiala, Scott-Brown, & Kempe, 2014; Kousaie & Phillips, 2012).

As previously mentioned, variable findings likely arise because studies differ, sometimes dramatically, in the kind of bilingual individual tested, and the kind of executive control tasks administered (Baum & Titone, 2014; Titone & Baum, 2014; Titone et al, in press). Moreover, one especially important way executive control tasks differ with respect to the study of older adults is in terms of their reliance on speeded or unspeeded decision making. Indeed, the most common executive control tasks used to address the bilingualism question require participants to make rapid decisions about what they see or hear (e.g., Simon task, Stroop task, etc.). Use of such tasks may be particularly problematic for testing the bilingualism hypothesis with older adults because of known difficulties associated with generalized slowing (Salthouse, 1996; Verhaeghen & Cerella, 2002), which may psychometrically overwhelm any subtle effects of bilingual language experience, particularly in studies with relatively small sample sizes.

Consider first a study that failed to obtain evidence of an impact of bilingual language experience on executive control. De Bruin, Bak, and Della Sala investigated a non-immigrant elderly sample of English monolinguals and Gaelic-English active or inactive bilinguals from the Hebrides (Scotland) using a speeded Simon task (de Bruin et al., 2015). De Bruin et al found no bilingual vs. monolingual group difference in the magnitude of the congruency effect, which led them to conclude that there was no impact of bilingual language experience on executive control. However, the failure to find this effect could have arisen because of: i) the small sample size (n = 24 - 28 participants in each group), ii) the specific kind of bilingual language experience typical of English-Gaelic bilinguals in the Scottish Hebrides, iii) the fact that speeded binary decision tasks may be less sensitive for revealing such effects with older adults, or iv) some combination of such factors.

Indeed, a more recent study using a similar but larger sample (n = 853) from another part of Scotland (Edinburgh) did show group differences between bilinguals and monolinguals (Bak, Nissan, Allerhand, & Deary, 2014). This study was noteworthy in making use of previously collected longitudinal data from a variety of intelligence tasks, some of which would now be classified as measures of executive control. Participants were first tested as children (at 11 years of age in 1947), and then as older adults approximately 60 years later. The results suggested that bilingual experience delayed age-related cognitive decline across all domains, irrespective of the degree of bilingualism (i.e., age of L2 acquisition, number of languages, and frequency of L2 usage), and after controlling for childhood intelligence, sex, or socioeconomic status. This, and other work, provide evidence that bilingualism can protect against age-related cognitive decline (Bialystok, Craik, Binns, Ossher, & Freedman, 2014; Bialystok, Craik, & Freedman, 2007; Bialystok et al., 2004; Bialystok, Craik, & Luk, 2012; Gold, 2015; Gold, Johnson, & Powell, 2013; Kavé, Eyal, Shorek, & Cohen-Mansfield, 2008; Luk, Bialystok, Craik, & Grady, 2011; Schweizer, Ware, Fischer, Craik, & Bialystok, 2012).

In addition to the many ways that bilinguals and executive control tasks can differ across studies, past work may also be affected by the tendency to focus on older adults exclusively rather than taking a lifespan approach that treats age as a continuous factor from younger to older adulthood. Lifespan approaches enable an examination of the links between different factors as they unfold over developmental time, either cross-sectionally across people of different ages or longitudinally for the same participants at different time points. For example, Zahodne et al. longitudinally evaluated a large sample (n=1067) of Spanish-English immigrants living in a "Spanish-speaking enclave" in Northern Manhattan, who were tested regularly for up to 23 years. The results showed that bilingualism was associated with better executive function at baseline. However, bilingualism did not ameliorate age-related cognitive decline or reduce the incidence of dementia conversion in this sample. They interpreted these findings as failing to support cognitive reserve theory, specifically because of the lack of change over time, though the connection between bilingualism and executive control at baseline speaks to a role of language experience. Moreover, because the composite executive control measure used in this study included both verbal and non-verbal performance, it could have been partially measuring L1 language proficiency, which would also certainly vary as a function of bilingual language experience. It is also possible that several of the covariates included in their models (e.g., education, time spent in the United States, etc.) might have been confounded with the degree of bilingualism, and thus, may have statistically diluted the expression of bilingual effects.

Finally, one additional factor that has not been systematically addressed with respect to the bilingualism hypothesis, to our knowledge, is biological sex. While the literature on this topic is also somewhat variable (Geary, Saults, Liu, & Hoard, 2000; Hyde, 1981; Li et al., 2009; Roivainen, 2011), several studies support the idea that biological sex modulates various cognitive and executive control domains over the lifespan. Specifically, several studies have shown that men outperform women on tasks assessing spatial and visuospatial ability, inhibition, and task-switching (Bieri, Bradburn, & Galinsky, 1958; Finkel, Reynolds, McArdle, Gatz, & Pedersen, 2003; Karlsson, Thorvaldsson, Skoog, Gudmundsson, & Johansson, 2015; Reimers & Maylor, 2005; Tun & Lachman, 2009; Voyer et al., 1995), whereas women outperform men on tasks assessing memory, reasoning and verbal ability (Duff & Hampson, 2001; Finkel et al., 2003; Maitland, Herlitz, Nyberg, Bäckman, & Nilsson, 2004; McCarrey, An, Kitner-Triolo, Ferrucci, & Resnick, 2016). Many tasks used to investigate the role of bilingualism on executive control are non-verbal and biased towards measuring processes that are hypothesized to be exercised through bilingual use (e.g., inhibitory control, task-switching). It is thus possible that these executive control tasks may favour greater performance in men compared to women (Clayson, Clawson, & Larson, 2011; Colzato, Hertsig, van den Wildenberg, & Hommel, 2010; Evans & Hampson, 2015; Halari et al., 2005; Halari & Kumari, 2005; Stoet, 2010). Such findings are also consistent with the idea that sex differences in hormones and physiology unique to a particular phase of life (e.g., puberty, menopause) could differentially influence the cognitive aging trajectory of women, compared to men (Janicki & Schupf, 2010; Keenan, Ezzat, Ginsburg, & Moore, 2001; Shanmugan & Epperson, 2014). Thus, biological differences in men and women may impact executive control performance, in a manner that could also interact with other factors, such as bilingualism. If true, it would be difficult to interpret past findings about bilingualism and executive control as being generally applicable to all people, or more or less specific to men vs. women.

The Present Study. To summarize, a growing body of work suggests that bilingual language experience modulates age-related declines in executive control, presumably by increasing cognitive reserve among older adults. However, the findings across studies are mixed, likely due to cross-study variability in individual differences among bilinguals, heterogeneity across tasks, the tendency to use speeded executive control tasks, the failure to take a lifespan approach, and the heretofore unstudied factor of biological sex. Thus, we investigate whether individual differences in bilingual language experience relate to performance on a well-established, unspeeded measure of executive control, the Wisconsin Card Sorting Task (WCST), in an adult lifespan sample. The WCST is thought to measure cognitive flexibility and set shifting, which are hypothesized to be specifically exercised by bilingualism. Given the constraints of our sample, and the individual difference measures available to us, we consider the potential impact of three aspects of bilingual experience: the age of second language (L2) acquisition, the number of languages known, and the percentage of non-native (i.e., non-L1) language usage.

Our specific predictions were:

1. Given sex differences in particular executive control processes (which are also considered to underlie the WCST), and changes specific to mid-life that may affect cognitive performance of women to a greater extent than men, we predict greater decline in WCST performance with aging in women compared to men.
2. Greater language experience (i.e., earlier age of L2 acquisition, greater non-native language usage, and greater number of languages known) will have a beneficial effect on WCST performance measures, particularly for women who may have more room to improve given prediction 1.

Methods

Participants

Participants consisted of 152 bilingual and multilingual adults (98 females, 54 males; age range 19 – 76 yrs; M_{age} = 48.23, SE_{age} = 1.31) who had no self-reported history of psychiatric illness, neurological disorders, or substance abuse. A total of 41 participants could be classed as younger adults (19 – 35 yrs of age; M_{age} = 25.59, SE_{age} = .61), 66 as middle aged adults (40 – 58 yrs of age; M_{age} = 49.68, SE_{age} = .66), and 45 as older adults (60 – 76 yrs of age; M_{age} = 66.73, SE_{age} = .59). Of note, we examined the effects of age continuously in all analyses, while controlling for individual differences in each participants' total number of years of education, which served as a proxy for socioeconomic status. Participants were recruited through a variety of means, which included advertisements (i.e., newspapers, magazines, etc.) and community and social engagement (i.e., TV and radio interviews), as part of a larger study investigating the role of episodic memory across the adult lifespan (Ankudowich, Pasvanis, & Rajah, 2016).

All participants had at least a high school education ($M_{education}$ = 15.68, $SE_{education}$ = .16), and were right-handed as measured by the Edinburgh Inventory for Handedness (Oldfield 1971). All participants completed the Language and Social Background Questionnaire (LSBQ; Luk & Bialystok, 2013). Based on this measure, we determined that our sample contained 109 bilinguals, 39 trilinguals, and 4 multilinguals (knowing four languages). Participants spoke a variety of languages, including: Tamil, Spanish, Hungarian, Bulgarian, Greek, Polish, Arabic, Chinese, Italian, Gujarati, Creole, German, and Swedish, however, a large percentage were either English-French or French-English bilingual (68%). Thus, the first language (L1) was identified as English for 45 participants, French for 87 participants, and another language for 20 participants. The second language (L2) was identified as English for 96 participants, French for 50 participants, and another language for 6 participants. The age of L2 acquisition in the sample ranged from 0 to 22 years.

Procedure

Upon arriving at the lab, participants signed a consent form approved by the ethics board of the Faculty of Medicine, McGill University. Participants then completed the WCST as part of a battery of neuropsychological tests. We specifically chose the WCST from this larger battery as it was the only task administered that would tap into executive control in a non-linguistic manner. Participants were given a computerized version of the WCST (Mueller & Piper, 2014) using the Psychology Experiment Building Language Version 0.13 (retrieved from http://pebl.sourceforge.net). Each trial required participants to match a card to one of four cards (with no prior rule to match). For example, a participant might be given a card with four yellow circles which they must match to one of four cards that vary in terms of shape, colour, and number (e.g., one red triangle, two green stars, three yellow plus signs, four blue circles). Since the participant is given no rules to match, logically, they can match their card based on shape (i.e., circle), colour (i.e., yellow), or the number of shapes present (i.e., four). Thus, in this case, there are two possible cards they could reasonably pick (i.e., three yellow plus signs or four blue circles). Feedback is given after every trial by informing participants whether the match was correct or incorrect. If the correct way to match is by colour (i.e., yellow), then the participant must apply that rule for 10 consecutive trials to achieve a category, after which the rule changes (i.e., to shape or number) unbeknownst to the participant. Based on the negative feedback, participants must learn that the previously used rule to match no longer works and must determine and apply a new rule to match. Categories (i.e., rules) varied by colour, number, and form. The task is completed when the participant successfully sorts nine categories (three categories repeated three times) or alternatively, progresses through 128 card sort trials.

The dependent variables of interest are the number of Perseverative Errors, the number of Non-perseverative Errors, and the number of Categories Completed. Perseverative Errors are the total number of errors made following a rule change (e.g., errors made immediately after an implicit rule change from colour to shape). Non-perseverative Errors are the total number of errors made after a rule change that are not perseverative errors (e.g., the participant matches the card based on shape when they should be sorting based on colour and they haven't received negative feedback to prompt them to try another card sorting rule). The variable of number of

Categories Completed can range from 0 to 9, where one category is achieved when a participant correctly responds to ten consecutive trials, after which the rule to match is changed without the participant's knowledge.

Results

We performed a series of multiple linear regressions using robust regression with maximum-likelihood estimation. These regression models were implemented using iterated re-weighted least squares (IRLS) with Huber weights using the rlm of the MASS package, version 7.3-45 (Venables & Ripley, 2002) in R (R Development Core Team, 2016). Robust regression allows us to use all the observations present in the data, but attenuates the effect of large residuals (i.e., outliers or influential points). This allows us to include outlier participants (i.e., older participants) that deviate from the norm. An analysis of the regression diagnostics showed heteroskedasticity of the residuals and no outlier points showing large Cook's distance, demonstrating that model assumptions were met.

We conducted regression models to test the impact of specific measures of bilingualism (discussed below), Age, Sex, and their interaction, on the following critical WCST measures: Perseverative Errors, Non-perseverative Errors, and Categories Completed. Our three bilingual language variables of interest were **Model 1:** L2 age of acquisition (L2 AoA, that is, the earliest age at which participants started to learned their L2 language either at home or school); **Model 2:** the Number of Languages Known; and **Model 3)** the percentage of Non-native Language Usage (calculated as 100% minus the percentage of L1 usage). We chose these three variables as they were the most reliable indicators of individual differences in bilingual language experience that could be extracted from this somewhat heterogeneous group of bilinguals. Across models we tested the three-way interaction between Age, Sex and each bilingual language experience variable individually, while statistically controlling for the number of years of education and the two other language variables not included as part of the three-way interaction. Thus, in terms of R syntax, the specific models fitted were: Model 1: DV ~ Age*Sex*L2 AoA + Years of Education + Languages Known + Non-Native Language Usage; Model 2: DV ~ Age*Sex*Languages Known + Years of Education + L2 AoA + Non-Native Language Usage; Model 3: DV ~ Age*Sex*Non-Native Language Usage + Years of Education + Languages Known + L2 AoA.

All fixed effect variables were treated as continuous, with the exception of Sex, which was treated as categorical through deviation coding (-0.5, 0.5). All continuous fixed effects variables were standardized using a Z-score transformation, thus permitting comparisons in the effect size of the model regression coefficients. Tables 1-3 (see appendix) shows a summary of the regression output results for Models 1-3, respectively. Figures 1-4 (see appendix) present the partial effects plots of the results, and are discussed in detail below.

The Number of Perseverative Errors

Recall, a high number of Perseverative Errors would indicate that participants had difficulty using executive control to inhibit use of a sorting rule that was no longer operative following an implicit rule change (e.g., when there was a switch in whether participants were expected to sort on the basis of color, shape, or number). Thus, a Perseverative Error would be present if a participant made an error indicating that they were using an immediately prior sorting rule on a new switched trial.

Model 1, which examined the interaction of Age x Sex x L2 AoA, showed a significant Age x Sex interaction ($\beta = 3.13$, $SE = 1.28$, $t = 2.43$, $p = .01$), indicated that women made a greater number of Perseverative Errors than men beginning around mid-life (see Figure 1). There was no effect of L2 AoA either as a main effect or in the context of any interaction.

Model 2, which examined the interaction of Age x Sex x the Number of Languages Known, also showed an Age x Sex interaction ($\beta = 3.20$, $SE = 1.19$, $t = 2.69$, $p = .01$). With respect to the Number of Languages Known, there were no significant main effects or interactions similar to L2 AoA above.

Model 3, which examined the interaction of Age x Sex x Non-native Language Usage, showed a significant interaction between Non-native Usage and Sex ($\beta = -3.26$, $SE = 1.64$, $t = -1.99$, $p < .05$), indicating that females who had a higher degree of Non-native Language Usage made fewer Perseverative Errors than females who had a lower degree of Non-native Language Usage (see Figure 2). Further, when sub-analyses were conducted separately for females ($n = 98$), there was a significant effect of Age ($\beta = 3.21$, $SE = .73$, $t = 4.41$, $p < .01$), there was a marginally significant effect of Non-native Language Usage ($\beta = -1.51$, $SE = .79$, $t = -1.90$, $p = .06$), and the overall model was significant, $F(6, 91) = 4.45$, $p < .01$. However, when sub-analyses were conducted separately for males, there were no significant predictors, and overall the model was not significant, $F(6,47) = .61$, $p = .72$.

To summarize the results for the Number of Perseverative Errors, we observed an Age x Sex interaction such that women made more errors than men at around mid-life. In terms of bilingual language experience, there was no effect of L2 AoA or Number of Languages Known, however, there was an effect of Non-Native Language Usage x Sex, suggesting that women with greater non-native language usage made fewer Perseverative Errors than women with lower Non-Native Language Usage.

The Number of Non-Perseverative Errors

In contrast with a Perseverative Error, a Non-perseverative Error would be a situation when a participant made an error on a switch trial, however, this error would not indicate that they misapplied an immediately prior sorting rule on a new switched trial. Non-perseverative Errors reflect a failure to maintain attention within the same category in order to continue applying the same rule to subsequent trials within the same category.

Model 1, which examined the interaction of Age x Sex x L2 AoA, showed a significant three-way interaction between Age, L2 AoA, and Sex ($\beta = 2.06$, $SE = .99$, $t = 2.08$, $p = .04$), indicating that women made more Non-perseverative Errors than men overall, although earlier L2 AoA among women was associated with fewer Non-perseverative Errors (see Figure 3). Further, when sub-analysis were conducted on females alone, there were main effects of age ($\beta = 2.72$, $SE = .74$, $t = 3.70$, $p < .01$) in addition to L2 AoA ($\beta = 1.92$, $SE = .79$, $t = 2.42$, $p = .02$), and the overall model remained significant, $F(6, 91) = 4.35$, $p < .01$. Conversely, when sub-analysis were separately conducted for males alone, only a main effect of L2 AoA ($\beta = -1.59$, $SE = .64$, $t = -2.49$, $p = .02$) remained, although the overall model was marginally significant, $F(6, 47) = 1.95$, $p = .09$. This main effect among males indicated that earlier L2 AoA among males did not reduce Non-perseverative Errors, but rather was associated with greater Non-perseverative Errors.

Model 2, which examined the interaction of Age x Sex x the Number of Languages Known, also showed a significant Age x Sex interaction ($\beta = 2.50$, $SE = 1.09$, $t = 2.29$, $p = .02$).

However, there were no significant main effects or interactions with respect to the Number of Languages Known.

Model 3, which examined the interaction of Age x Sex x Non-native Language Usage, also showed an Age x Sex interaction ($\beta = 2.62$, $SE = 1.20$, $t = 2.18$, $p = .03$), however, there were no significant main effects or interactions involving Non-native Language Usage.

To summarize the results for Non-Perseverative Errors, we again found an interaction between Age and Sex such that women performed worse than men at around mid-life, similar to the results observed for Perseverative Errors. With regards to the potential mitigating effects of bilingual language experience on task performance, we observed an Age x L2 AoA x Sex interaction showing that women with earlier L2 AoA made less Non-perseverative Errors than women with greater L2 AoA.

The Number of Categories Completed

In contrast with Perseverative and Non-perseverative errors, the number of Categories Completed could range from 0 to 9, and each category is achieved when the participant successfully completes 10 consecutive correct responses associated with a card sorting rule (i.e., colour, shape, or number). This WCST measure reflects overall global performance, where the greater number of Categories Completed corresponds to better performance on the WCST.

Model 1, which examined the interaction of Age x Sex x L2 AoA, showed a significant Age x Sex interaction ($\beta = -1.15$, $SE = .37$, $t = -3.11$, $p < .01$), but no main effects or interactions involving L2 AoA with respect to the number of Categories Completed. This Age x Sex interaction indicated that although women complete more categories than men at a younger age, this pattern is inversed starting around mid-life, with older women showing worse performance than older men (see Figure 4).

Model 2, which examined the interaction of Age x Sex x the Number of Languages Known, also showed a significant Age x Sex interaction (β = -1.29, *SE* = .38, *t* = -3.45, $p < .01$), but no main effects or interactions involving the Number of Languages Known.

Model 3, which examined the interaction of Age x Sex x Non-native Language Usage, also showed a significant Age x Sex interaction (β = -1.10, *SE* = .39, *t* = -2.84, $p < .01$). Similar to the previous Age x Sex interactions from past models, this interaction showed that participants achieved less categories with age, but that females showed a greater performance decrement compared to males as early as mid-life.

To summarize the results for the Number of Categories Completed, we consistently observed Age x Sex interactions across all the models, such that females complete less categories compared to males at older age. However, there was no modulating effect of bilingual language experience on this measure of the WCST.

Discussion

We investigated whether and how bilingual language experience, age and biological sex jointly modulated performance on the WCST, using an adult lifespan sample. With respect to the past literature investigating the impact of bilingual language experience on domain-general cognition, which typically involves fewer participants (i.e., Ns ranging from 20 – 30) who are limited to particular age cohorts, this study had the following advantages: 1) we examined the effects of age continuously from young adulthood to older adulthood in a relatively large sample, thus enabling us to assess whether any effects would emerge in mid-life; 2) we systematically investigated interactions with biological sex that might be expected given inherent neurobiological and neurocognitive differences between women and men that emerge in mid-life; 3) we used an executive control task, the WCST, that had no overt speed requirements, thus making it more feasible to directly compare performance over the lifespan in a manner that would be uncompromised by general cognitive slowing (Fristoe, Salthouse, & Woodard, 1997; Salthouse, 1996, 2009). Finally, we always controlled for education, a proxy measure of socioeconomic status.

The findings indicated that women both had the greatest age-related cognitive decline across all WCST measures, and were more likely than men to show improved performance with increased bilingual experience. We discuss each of these findings in greater detail below.

The Impact Of Age And Biological Sex On WCST Performance. Consistent with past work (Axelrod & Henry, 1992; Daigneault, Braun, & Whitaker, 1992; Fristoe et al., 1997; Kousaie et al., 2014; Rhodes, 2004), our results showed that performance on the WCST declined with age. Specifically, as people aged, they made more Perseverative and Non-perseverative Errors, and they achieved fewer Categories Completed. Past work indicates that this age-related decline in WCST performance is related to declines in multiple executive control processes, specifically those related to working memory, processing speed, inhibition processes, and set-shifting (Ashendorf & McCaffrey, 2008; Fristoe et al., 1997; Hartman, Bolton, & Fehnel, 2001; Head, Kennedy, Rodrigue, & Raz, 2009). However, the specific executive control processes involved in the WCST is contentious and not clearly elucidated (Huizinga, Dolan, & van der Molen, 2006; Huizinga & van der Molen, 2007; Miyake et al., 2000). This is not surprising given that the WCST, like most executive control tasks, is not ‘process pure” and requires the engagement of various executive and non-executive cognitive processes (i.e., visual perception) (Miyake & Friedman, 2012; Valian, 2015).

We also observed that a greater age-related cognitive decline in women vs. men began to emerge as early as midlife. Other work has also shown age-related cognitive decline as early as midlife (Gunstad et al., 2006; Kwon et al., 2016; Singh-Manoux et al., 2012), however, past work rarely considered potential sex-related differences in the cognitive trajectory at this time point. Middle adulthood is a unique period of life when women experience significant hormonal changes as they transition from pre-menopause to peri- and post-menopause. Specifically, during menopausal transition women experience declines in endogenous estrogen levels, a primarily female sex hormone which has a neuroprotective role on cognition (Brinton, Yao, Yin, Mack, & Cadenas, 2015; Green & Simpkins, 2000; Janicki & Schupf, 2010). One class of estrogens, 17β-estradiol, acts on estrogen receptors that are densely populated in the prefrontal cortex and hippocampus – two of the key brain regions involved in higher cognitive processes (e.g., Brinton, 2009; Luine, 2014; Sherwin & Henry, 2008). Lower 17β-estradiol levels at mid-life has been related to changes in prefrontal and hippocampal activity and connectivity in post-menopausal women compared to pre-menopausal women, during a verbal working memory task (Jacobs et al., 2016). This suggests that estradiol, and potentially other sex steroid hormones that fluctuate during this transition at midlife, are critical for functions related to these brain regions, including executive functions i.e., working memory. Supporting this conjecture, depleting estrogen levels has been linked with greater age-related decline in women (Greendale et al., 2009; Henderson, 2009; Sherwin, 1996). Moreover, supporting our findings, greater age-related cognitive decline has been observed in women compared to men (Proust-Lima et al., 2008; Read et al., 2006), although other studies report contradictory findings (Barrett-Connor & Kritz-Silverstein, 1999; Larrabee & Crook, 1993; McCarrey et al., 2016; Meyer et al., 1999; Wiederholt et al., 1993).

The Impact Of Bilingual Language Experience On WCST Performance. In the present study, we found that women with greater Non-native Language Usage and earlier L2 AoA made fewer Perseverative and Non-perseverative Errors, respectively. Interestingly, this finding for women is inconsistent with past work investigating bilingualism and executive control with respect to the WCST (Gathercole et al., 2014; Kousaie et al., 2014). For example, Kousaie and colleagues used the WCST on their young and older participants, and tested monolingual Francophones (30 young and 30 older adults), monolingual Anglophones (40 young and 31 older adults) and French/English bilinguals (51 young and 36 older adults), who were non-immigrant adults from Ottawa or Quebec. They found that monolingual Francophones achieved more categories than monolingual Anglophones and bilinguals. However, other WCST measures (i.e., Perseverative and Non-perseverative Errors), which may be more sensitive to the effects of aging (e.g., Rhodes, 2004), were not reported.

As well, one other study investigated lifespan effects pertaining to bilingualism and executive control using a similar task in a sample of English-Welsh bilinguals in Wales (age 3 to older adults). Specifically, Gathercole et al. used a card sorting task similar to the WCST, only in their case it involved explicit, experimenter-induced rule changes (Gathercole et al., 2014). Here, there were some significant bilingual effects across groups, but the pattern was rather haphazard. However, several potential questions make it difficult to derive a completely coherent story in that that they used slightly different tasks over the different age ranges, in addition to measuring difference scores for accuracy and RT instead of using raw scores to assess global performance. Moreover, unlike the WCST which uses more specific performance measures (i.e., Perseverative, Non-perseverative Errors, etc.), this particular card sort task only assessed overall accuracy and RT. Finally, although they used a large overall sample (n=650), they binned their participants into seven smaller-N groups that were crossed with four language groups, ANOVA style, which may have reduced the power. Thus, the specific way the data were analyzed in these studies may have led to variable effects of bilingual experience on task performance.

In the present study, we use robust regression methods to investigate specific aspects of bilingual experience (i.e., L2 AoA, Number of Languages Known, percentage of Non-native Language Usage) across three WCST task measures: Perseverative Errors, Non-perseverative Errors, and the number of Categories Completed. Our findings suggest that specific aspects of bilingual experience (i.e., L2 AoA, Non-native Language Usage) enhanced WCST performance, and thus, may have acted as a source of cognitive reserve in healthy aging. Greater bilingual language experience can exercise executive control processes in ways that might make bilinguals more resilient to age-related cognitive decline compared to monolingual usage. Bilinguals have to constantly select, switch and inhibit one language vs. another, on an ongoing basis. Thus, this constant management of two or more languages might exercise executive control mechanisms and, of relevance, transfer over to stronger domain-general executive control processes (Kroll et al., 2014; Kroll, Dussias, Bice, & Perrotti, 2015).

Specifically, the results suggested that earlier L2 AoA was related to better WCST performance (i.e., fewer non-perseverative errors) in our sample, consistent with past work showing this variable to be important for forestalling age-related cognitive decline (Luk, De Sa, & Bialystok, 2011; Perquin et al., 2013). Given that both languages are constantly active in bilinguals (e.g., Kroll et al., 2015), earlier L2 AoA entails that individuals have greater life experience controlling and managing multiple languages, which may lead to more robust executive control processes over time. More specifically, a participant's ability to make fewer Non-perseverative Errors might reflect a greater ability to maintain a sorting rule in one's mind to successfully apply it to the task (Hartman et al., 2001; Paolo, Troster, Axelrod, & Koller, 1995; van der Linden, Frese, & Meijman, 2003). Thus, earlier L2 AoA might reflect greater executive control processes pertaining to superior attentional processes and/or reduced interference to distracting stimuli.

However, other studies suggest that benefits of L2 AoA may depend on other factors, such as childhood IQ. For example, in Bak et al.'s large-N longitudinal study investigating bilingualism on later-life cognition, participants with higher childhood IQ benefited more from earlier L2 AoA, but conversely, children with lower IQ performed better with later L2 AoA (Bak, Nissan, Allerhand, & Deary, 2014). Thus, factors, such as childhood IQ, might interact with participant sex to result in different effects of age of L2 acquisition observed in later life. Furthermore, earlier L2 AoA may not necessarily mean that participants actively use their known languages. Thus, the joint activation of two or more languages *in addition* to the continual daily use of these languages may be necessary to confer an executive control benefit, as compared to individuals who had earlier L2 AoA but do not actively use multiple languages in daily life.

The results also showed that greater Non-native Language Usage, that is, the active use of non-L1 language(s), related to improved task performance in Perseverative Errors. Reduced Perseverative Errors reflects a greater ability to inhibit a no longer relevant card sort rule in order to apply a new rule. It is possible that individuals with greater non-native language usage have greater practice inhibiting the non-target language(s), which might transfer to greater inhibitory processes that may be reflected in this task as a reduction in the number of Perseverative Errors. Moreover, this finding is consistent with Kavé et al. (2008), who found that bilinguals who self-reported a higher degree of non-native vs. native language fluency performed better on a cognitive screening test (assessing time orientation, memory and concentration) (Katzman et al., 1983) than those who self-reported a higher degree of native vs. non-native language fluency

(Kavé et al., 2008). Similarly, Prior and Gollan (2013) report a significant link between executive control and bilingual language control, particularly for non-dominant language production and error monitoring (Prior & Gollan, 2013). Thus, greater use of non-L1 languages may involve greater demand for language control which may be associated with more efficient task-switching processes and consequently, more robust executive control processes. However, greater non-native language usage (e.g., those with greater than 90% non-native usage) might also indicate that participants no longer use their L1 language and perhaps more dominantly use their non-L1 language(s) (rather than balanced usage of two languages). This is conceivable in our study sample where individuals may have learned their native language at home early in life, but may have started to more frequently use another language (i.e., French/English) in a new cultural context. This may attenuate the influence of non-native language usage on task performance (as 'greater' does not necessarily mean 'better').

Interestingly, our results showed no effect of number of languages known, a dimension that has previously been reported to have a significant effect in delaying cognitive decline in older adults (Ihle, Oris, Fagot, & Kliegel, 2016; Kavé et al., 2008), and in delaying symptom onset of dementia (Chertkow et al., 2010). For example, Kavé et al. explored whether the role of self-reported number of languages spoken predicted performance on two cognitive screening tests. They conducted a longitudinal study using a large sample of Israeli Jewish bilinguals and multilinguals that were tested three times across the 12 year-span of the study. The results showed that self-reported number of languages spoken positively predicted cognitive tests scores independent of age, sex, place of birth, age at immigration, and education. Other work also supports a more protective role of multilingualism (i.e., knowing 3 or more languages) compared to bilingualism in protecting cognition in older age, suggesting that the use and practice of more than two languages has a more significant effect on cognition, potentially through greater exercise of executive control mechanisms, and thereby acting as a more powerful source of cognitive reserve (Bak et al., 2014; Chertkow et al., 2010; Kavé et al., 2008; Perquin et al., 2013). Therefore, it is possible that the lack of variability in our study in terms of the number of languages known (with a smaller sample of multilinguals) possibly attenuated any effects related to this language experiential variable on cognitive performance of the WCST.

Moreover, variations in bilingual and multilingual patterns of use can differentially exercise executive control processes (e.g., Bak, 2016a). Prior work using the WCST in younger adult bilinguals report differences in performance depending on how bilinguals use their languages [i.e., non-switchers vs. switchers (Festman & Münte, 2012), interpreters vs. bilinguals (Yudes, Macizo, & Bajo, 2011)]. Thus, a hypothesis of greater bilingual language experience may not necessarily entail greater cognitive outcome, but an additional important factor is how these bilinguals use their languages in daily life which may also exert an effect on cognition. This is not a direct factor that we consider in our study but we did repeat our analyses on a subset of our English/French bilinguals living in Montreal (where the study was conducted).

Given our diverse multilingual sample, it is possible that participants may not use their native languages in a way that is similar to the usage patterns of English and French in Montreal. For example, previous research suggests that inactive bilinguals (i.e., balanced bilinguals in early life but actively used one language in later life) performed more like monolinguals than active bilinguals (de Bruin et al., 2015; de Bruin, Della Sala, & Bak, 2016). French is the city’s official language, but there is frequent switching between English and French across and within social contexts, suggesting similar patterns of language usage across participants. Of note, our general pattern of results were obtained when we recomputed our analyses on this subset of homogeneous participants that were French/English bilinguals alone. This suggests that the results reported using the whole sample is not necessarily due to within-population variability, but in differences in bilingual language acquisition and usage.

Finally, education level consistently emerged as a significant covariate under the analysis of Categories Completed in our analyses. The participants in our sample had a minimum of high school education, and did not vary significantly in terms of number of years of education. Education level is a potent source of cognitive reserve and in maintaining cognitive function in normal aging or dementia (Bennett et al., 2003; Jefferson et al., 2011; Rhodes, 2004; Sattler, Toro, Schönknecht, & Schröder, 2012; Stern et al., 1994). Other studies have also reported an effect of bilingualism on promoting cognition independent of education level (e.g., Kavé et al., 2008). However, Gollan and colleagues (2011) suggest that the effect of education level can potentially obscure the influence of bilingual language experience on cognitive performance (Gollan, Salmon, Montoya, & Galasko, 2011).

By extension, a benefit of bilingualism may not be easy to detect if it is competing or interacting with other cognitive reserve factors that are masking its influence (Valian, 2016). It is possible that these language dimension variables did not consistently show across WCST measures if competing cognitive reserve factors make the influence of bilingualism 'invisible' (Valian, 2016). Although factors like greater bilingual language experience and higher education contribute to cognitive reserve, it is challenging to tease apart the role of any one factor if they are confounded with other factors (Jones et al., 2011). For example, Chertkow et al found that bilingual immigrants showed significantly greater cognitive outcomes compared to non-immigrant bilinguals (Chertkow et al., 2010). Moreover, supporting Valian's claims, factors such as immigration status can also mask the influence of any bilingual effect on cognitive performance (Kousaie & Phillips, 2012), which can contribute to the null or mixed findings in the literature. Moreover, some studies report an advantage of bilingualism on executive control that persists, independent of potentially confounding factors such as education, socioeconomic status, and immigration status (Alladi et al., 2013; Perquin et al., 2013; Schweizer, Craik, & Bialystok, 2013). These findings seem to support that bilingualism does contribute to cognitive reserve, independent of other factors, but also in complex ways that involve the interaction of other cognitive reserve factors.

To conclude, the results of the present study suggest that factors reflecting increased bilingual language experience, when investigated in combination with biological sex, modulate performance in an unspeeded executive control task as a function of increasing age. Specifically, women overall showed greater age-related declines in WCST performance compared to men, however, greater bilingual language experience (i.e., earlier age of L2 acquisition) was related to better WCST performance as people aged. Thus, a strong consideration of age-related executive control trajectories across men and women may be crucial when investigating the relative impact of other factors, such as bilingual language experience. Future work characterizing the complex relationships between bilingual language experience, executive control, and other mitigating factors such as biological sex, will certainly be enhanced by the use of converging measures of executive control function, such as functional neuroimaging, a topic we are currently pursuing.

References

Abutalebi, J., Tettamanti, M., & Perani, D. (2009). The bilingual brain: Linguistic and non-linguistic skills. *Brain and language, 109*(2-3), 51-54. doi:10.1016/j.bandl.2009.04.001

Alladi, S., Bak, T. H., Duggirala, V., Surampudi, B., Shailaja, M., Shukla, A. K., Chaudhuri, J.R., & Kaul, S. (2013). Bilingualism delays age at onset of dementia, independent of education and immigration status. *Neurology*, *81*(22), 1938–1944. http://doi.org/10.1212/01.wnl.0000436609.20587.65

Alzheimer's Association. (2015). 2015 Alzheimer's disease facts and figures. *Alzheimer's and Dementia: The Journal of the Alzheimer's Association, 11*(3), 332-384.

Amer, T., Campbell, K. L., & Hasher, L. (2016). Cognitive Control As a Double-Edged Sword. *Trends in Cognitive Sciences*, *20*(12), 905–915. http://doi.org/http://dx.doi.org/10.1016/j.tics.2016.10.002

Ankudowich, E., Pasvanis, S., & Rajah, M. N. (2016). Changes in the modulation of brain activity during context encoding vs. context retrieval across the adult lifespan. *NeuroImage*, *139*, 103–113. http://doi.org/10.1016/j.neuroimage.2016.06.022

Ansaldo, A. I., Ghazi-Saidi, L., & Adrover-Roig, D. (2015). Interference Control In Elderly Bilinguals: Appearances Can Be Misleading. *Journal of Clinical and Experimental Neuropsychology*, *2*(1), 1–16. http://doi.org/10.1080/13803395.2014.990359

Ardila, A., & Ramos, E. (2010). Bilingualism and Aging. *Perspectives on Communication Disorders and Sciences in Culturally and Linguistically Diverse Populations*, *17*(3), 74–81. http://doi.org/10.1044/cds17.3.74

Ashendorf, L., & McCaffrey, R. J. (2008). Exploring age-related decline on the Wisconsin Card Sorting Test. *The Clinical Neuropsychologist*, *22*(2), 262–272.

http://doi.org/10.1080/13854040701218436

Axelrod, B. N., & Henry, R. R. (1992). Age-related performance on the wisconsin card sorting, similarities, and controlled oral word association tests. *The Clinical Neuropsychologist*, *6*(1), 16–26. http://doi.org/http://dx.doi.org/10.1080/13854049208404113

Bak, T. H. (2016a). Cooking pasta in La Paz. *Linguistic Approaches to Bilingualism*, *6*(5), 699-717. http://doi.org/10.1075/lab.16002.bak

Bak, T. H. (2016b). The impact of bilingualism on cognitive aging and dementia. *Linguistic Approaches to Bilingualism*, *6*(1-2), 205-226.

Bak, T. H., Nissan, J. J., Allerhand, M. M., & Deary, I. J. (2014). Does bilingualism influence cognitive aging? *Annals of Neurology*, *75*(6), 959–63. http://doi.org/10.1002/ana.24158

Barrett-Connor, E., & Kritz-Silverstein, D. (1999). Gender differences in cognitive function with age: the Rancho Bernardo study. *Journal of the American Geriatrics Society*, *47*(2), 159–164.

Baum, S., & Titone, D. (2014). Moving toward a neuroplasticity view of bilingualism, executive control, and aging. *Applied Psycholinguistics*, *35*(5), 857–894. http://doi.org/10.1017/S0142716414000174

Beard, J., Officer, A., Cassels, A. (2015). *World Report on Ageing and Health.* Luxembourg: World Health Organization Retrieved from http://apps.who.int/iris/bitstream/10665/186463/1/9789240694811_eng.pdf.

Bennett, D. A., Wilson, R. S., Schneider, J. A., Evans, D. A., de Leon, C. M., Arnold, S. E., Barnes, L.L., & Bienias, J. L. (2003). Education modifies the relation of AD pathology to level of cognitive function in older persons. *Neurology*, *60*, 1909–1915. http://doi.org/10.1212/01.WNL.0000069923.64550.9F

Bialystok, E. (2016). The signal and the noise: Finding the pattern in human behavior. *Linguistic Approaches to Bilingualism*, *6*(5), 517–534. http://doi.org/10.1075/lab.15040.bia

Bialystok, E., Abutalebi, J., Bak, T. H., Burke, D. M., & Kroll, J. F. (2016). Aging in two languages: Implications for public health. *Ageing Research Reviews*, *27,* 56-60. http://doi.org/10.1016/j.arr.2016.03.003

Bialystok, E., Craik, F. I. M., Binns, M. A., Ossher, L., & Freedman, M. (2014). Effects of bilingualism on the age of onset and progression of MCI and AD: Evidence from executive function tests. *Neuropsychology*, *28*(2), 290–304. http://doi.org/10.1037/neu0000023

Bialystok, E., Craik, F. I. M., & Freedman, M. (2007). Bilingualism as a protection against the onset of symptoms of dementia. *Neuropsychologia*, *45*(2), 459–464. http://doi.org/http://dx.doi.org/10.1016/j.neuropsychologia.2006.10.009

Bialystok, E., Craik, F. I. M., Klein, R., & Viswanathan, M. (2004). Bilingualism, Aging, and Cognitive Control: Evidence From the Simon Task. *Psychology and Aging*, *19*(2), 290-303. http://doi.org/10.1037/0882-7974.19.2.290

Bialystok, E., Craik, F. I. M., & Luk, G. (2012). Bilingualism: consequences for mind and brain. *Trends in Cognitive Sciences*, *16*(4), 240–250. http://doi.org/http://dx.doi.org/10.1016/j.tics.2012.03.001

Bieri, J., Bradburn, W. M., & Galinsky, M. D. (1958). Sex differences in perceptual behavior. *Journal of Personality*, *26*(1), 1–12. http://doi.org/10.1111/j.1467-6494.1958.tb01566.x

Blumenfeld, H. K., & Marian, V. (2011). Bilingualism influences inhibitory control in auditory comprehension. *Cognition, 118*(2), 245-257. doi:10.1016/j.cognition.2010.10.012

Braver, T. S. (2012). The variable nature of cognitive control: A dual mechanisms framework. *Trends in Cognitive Sciences*. http://doi.org/10.1016/j.tics.2011.12.010

Braver, T. S., & West, R. (2008). Working memory, executive control, and aging. *The handbook of aging and cognition, 3*, 311-372.

Brinton, R. D. (2009). Estrogen-induced plasticity from cells to circuits: predictions for cognitive function. *Trends in Pharmacological Sciences*, *30*(4), 212–222. http://doi.org/10.1016/j.tips.2008.12.006

Brinton, R. D., Yao, J., Yin, F., Mack, W. J., & Cadenas, E. (2015). Perimenopause as a neurological transition state. *Nature Reviews Endocrinology*, *11*(7), 393–405. http://doi.org/10.1038/nrendo.2015.82

Calvo, N., García, A. M., Manoiloff, L., & Ibáñez, A. (2016). Bilingualism and cognitive reserve: A critical overview and a plea for methodological innovations. *Frontiers in Aging Neuroscience, 7,* 249. http://doi.org/10.3389/fnagi.2015.00249

Chertkow, H., Whitehead, V., Phillips, N., Wolfson, C., Atherton, J., & Bergman, H. (2010). Multilingualism (but not always bilingualism) delays the onset of Alzheimer disease: Evidence from a bilingual community. *Alzheimer Disease & Associated Disorders*, *24*(2), 118–125. http://doi.org/10.1097/WAD.0b013e3181ca1221

Christensen, H., Mackinnon, A. J., Korten, A. E., Jorm, A. F., Henderson, A. S., Jacomb, P., & Rodgers, B. (1999). An analysis of diversity in the cognitive performance of elderly community dwellers: Individual differences in change scores as a function of age. *Psychology and Aging, 14*(3), 365-379. http://doi.org/10.1037/0882-7974.14.3.365

Christoffels, I. K., Firk, C., & Schiller, N. O. (2007). Bilingual language control: An event-related brain potential study. *Brain Research, 1147*, 192-208. doi:10.1016/j.brainres.2007.01.137

Clayson, P. E., Clawson, A., & Larson, M. J. (2011). Sex differences in electrophysiological indices of conflict monitoring. *Biological Psychology*, *87*(2), 282–289. http://doi.org/10.1016/j.biopsycho.2011.03.011

Coderre, E. L., Smith, J. F., van Heuven, W. J. B., & Horwitz, B. (2016). The Functional Overlap of Executive Control and Language Processing in Bilinguals. *Bilingualism: Language and Cognition*, *19*(3), 471–488. http://doi.org/10.1017/S1366728915000188

Colzato, L. S., Hertsig, G., van den Wildenberg, W. P. M., & Hommel, B. (2010). Estrogen modulates inhibitory control in healthy human females: Evidence from the stop-signal paradigm. *Neuroscience*, *167*(3), 709–715. http://doi.org/10.1016/j.neuroscience.2010.02.029

Costa, A., & Sebastián-Gallés, N. (2014). How does the bilingual experience sculpt the brain? *Nature Reviews Neuroscience*, *15*(5), 336–345. http://doi.org/10.1038/nrn3709

Daigneault, S., Braun, C. M. J., & Whitaker, H. a. (1992). Early effects of normal aging on perseverative and non-perseverative prefrontal measures. *Developmental Neuropsychology*, *8*(1), 99–114. http://doi.org/10.1080/87565649209540518

Davis, J. C., Marra, C. A., Najafzadeh, M., & Liu-Ambrose, T. (2010). The independent contribution of executive functions to health related quality of life in older women. *BMC Geriatrics*, *10*(1), 16. http://doi.org/1471-2318-10-16 [pii]\r10.1186/1471-2318-10-16

de Bruin, A., Bak, T. H., & Della Sala, S. (2015). Examining the effects of active versus inactive bilingualism on executive control in a carefully matched non-immigrant sample. *Journal of Memory and Language*, *85*, 15–26. http://doi.org/10.1016/j.jml.2015.07.001

de Bruin, A., Della Sala, S., & Bak, T. H. (2016). The effects of language use on lexical processing in bilinguals. *Language, Cognition and Neuroscience*, *31*(8), 967–974. http://doi.org/10.1080/23273798.2016.1190024

Dijkstra, T. (2005). Bilingual visual word recognition and lexical access. In J. F. Kroll & A. M. B. de Groot (Eds.), *Handbook of bilingualism: Psycholinguistic approaches* (pp. 179–201). New York: Oxford University Press.

Duff, S. J., & Hampson, E. (2001). A sex difference on a novel spatial working memory task in humans. *Brain and Cognition*, *47*(3), 470–93. http://doi.org/10.1006/brcg.2001.1326

Evans, K. L., & Hampson, E. (2015). Sex-dependent effects on tasks assessing reinforcement learning and interference inhibition. *Frontiers in Psychology*, *6*, 1044. http://doi.org/10.3389/fpsyg.2015.01044

Festman, J., & Münte, T. F. (2012). Cognitive control in Russian-German bilinguals. *Frontiers in Psychology*, *3*(115). http://doi.org/10.3389/fpsyg.2012.00115

Finkel, D., Reynolds, C. a, McArdle, J. J., Gatz, M., & Pedersen, N. L. (2003). Latent growth curve analyses of accelerating decline in cognitive abilities in late adulthood. *Developmental Psychology*, *39*(3), 535–550. http://doi.org/10.1037/0012-1649.39.3.535

Forte, R., Boreham, C. A. G., de Vito, G., & Pesce, C. (2015). Health and quality of life perception in older adults: The joint role of cognitive efficiency and functional mobility. *International Journal of Environmental Research and Public Health*, *12*(9), 11328–11344. http://doi.org/10.3390/ijerph120911328

Friedman, N. P. (2016). Research on individual differences in executive functions: Implications for the bilingual advantage hypothesis. *Linguistic Approaches to Bilingualism*, *6*(5), 535–548. http://doi.org/10.1075/lab.15041.fri

Fristoe, N. M., Salthouse, T. a, & Woodard, J. L. (1997). Examination of age-related deficits on the Wisconsin Card Sorting Test. *Neuropsychology*, *11*(3), 428–436. http://doi.org/10.1037/0894-4105.11.3.428

Gathercole, V. C. M., Thomas, E. M., Kennedy, I., Prys, C., Young, N., Guasch, N. V., Roberts, E.J., Hughes, E.K., & Jones, L. (2014). Does language dominance affect cognitive performance in bilinguals? Lifespan evidence from preschoolers through older adults on card sorting, Simon, and metalinguistic tasks. *Frontiers in Psychology, 5*(11). http://doi.org/10.3389/fpsyg.2014.00011

Geary, D. C., Saults, S. J., Liu, F., & Hoard, M. K. (2000). Sex differences in spatial cognition, computational fluency, and arithmetical reasoning. *Journal of Experimental Child Psychology*, *77*(4), 337–353. http://doi.org/10.1006/jecp.2000.2594

Gold, B. T. (2015). Lifelong bilingualism and neural reserve against Alzheimer's disease: a review of findings and potential mechanisms. *Behavioural Brain Research*, *281*, 9–15. http://doi.org/10.1016/j.bbr.2014.12.006

Gold, B. T., Johnson, N. F., & Powell, D. K. (2013). Lifelong bilingualism contributes to cognitive reserve against white matter integrity declines in aging. *Neuropsychologia*, *51*(13), 2841–2846. http://doi.org/10.1016/j.neuropsychologia.2013.09.037

Gollan, T. H., Salmon, D. P., Montoya, R. I., & Galasko, D. R. (2011). Degree of bilingualism predicts age of diagnosis of Alzheimer's disease in low-education but not in highly educated Hispanics. *Neuropsychologia*, *49*(14), 3826–3830. http://doi.org/10.1016/j.neuropsychologia.2011.09.041

Grady, C. L., Luk, G., Craik, F. I. M., & Bialystok, E. (2015). Brain network activity in monolingual and bilingual older adults. *Neuropsychologia*, *66*, 170–81. http://doi.org/10.1016/j.neuropsychologia.2014.10.042

Green, D. W. (1998). Mental control of the bilingual lexico-semantic system. *Bilingualism: Language and Cognition, 1*, 67-81.

Green, D. W. (2011). Language control in different contexts: the behavioral ecology of bilingual speakers. *Frontiers in Psychology, 2*. doi:10.3389/fpsyg.2011.00103

Green, P. S., & Simpkins, J. W. (2000). Neuroprotective effects of estrogens: potential mechanisms of action. *International Journal of Developmental Neuroscience*, *18*(4), 347–358. http://doi.org/S0736-5748(00)00017-4 [pii]

Greendale, G. A., Huang, M. H., Wight, R. G., Seeman, T., Luetters, C., Avis, N. E., Johnston, J., & Karlamangla, A. S. (2009). Effects of the menopause transition and hormone use on cognitive performance in midlife women. *Neurology*, *72*(21), 1850–1857. http://doi.org/10.1212/WNL.0b013e3181a71193

Gunstad, J., Paul, R. H., Brickman, A. M., Cohen, R. a, Arns, M., Roe, D., Lawrence, J.J., & Gordon, E. (2006). Patterns of cognitive performance in middle-aged and older adults: A cluster analytic examination. *Journal of Geriatric Psychiatry and Neurology*, *19*(2), 59–64. http://doi.org/10.1177/0891988705284738

Guo, T., Liu, H., Misra, M., & Kroll, J. F. (2011). Local and global inhibition in bilingual word production: fMRI evidence from Chinese-English bilinguals. *NeuroImage, 56*(4), 2300-2309. doi:10.1016/j.neuroimage.2011.03.049

Halari, R., Hines, M., Kumari, V., Mehrotra, R., Wheeler, M., Ng, V., & Sharma, T. (2005). Sex differences and individual differences in cognitive performance and their relationship to endogenous gonadal hormones and gonadotropins. *Behavioral Neuroscience*, *119*(1), 104–117. http://doi.org/10.1037/0735-7044.119.1.104

Halari, R., & Kumari, V. (2005). Comparable cortical activation with inferior performance in women during a novel cognitive inhibition task. *Behavioural Brain Research*, *158*(1), 167–173. http://doi.org/10.1016/j.bbr.2004.08.022

Hartman, M., Bolton, E., & Fehnel, S. E. (2001). Accounting for age differences on the Wisconsin Card Sorting Test: decreased working memory, not inflexibility. *Psychology and Aging*, *16*(3), 385–399. http://doi.org/10.1037/0882-7974.16.3.385

Head, D., Kennedy, K. M., Rodrigue, K. M., & Raz, N. (2009). Age differences in perseveration: Cognitive and neuroanatomical mediators of performance on the Wisconsin Card Sorting Test. *Neuropsychologia*, *47*(4), 1200–1203. http://doi.org/10.1016/j.neuropsychologia.2009.01.003

Henderson, V. W. (2009). Cognitive changes after menopause : Influence of estrogen. *Clinical Obstetrics and Gynecology*, *51*(3), 618–626. http://doi.org/10.1097/GRF.0b013e318180ba10.Cognitive

Huizinga, M., Dolan, C. V, & van der Molen, M. W. (2006). Age-related change in executive function: Developmental trends and a latent variable analysis. *Neuropsychologia*, *44*(11), 2017–2036. http://doi.org/http://dx.doi.org/10.1016/j.neuropsychologia.2006.01.010

Hyde, J. S. (1981). How large are cognitive gender differences? A meta-analysis using !w^2 and d.. *American Psychologist*, *36*(8), 892–901. http://doi.org/10.1037/0003-066X.36.8.892

Ihle, A., Oris, M., Fagot, D., & Kliegel, M. (2016). The relation of the number of languages spoken to performance in different cognitive abilities in old age. *Journal of Clinical and Experimental Neuropsychology*, *38*(10), 1103–1114. http://doi.org/10.1080/13803395.2016.1197184

Jacobs, E. G., Weiss, B., Makris, N., Whitfield-Gabrieli, S., Buka, S. L., Klibanski, A., & Goldstein, J. M. (2016). Reorganization of Functional Networks in Verbal Working Memory Circuitry in Early Midlife: The Impact of Sex and Menopausal Status. *Cerebral Cortex*. http://doi.org/10.1093/cercor/bhw127

Janicki, S. C., & Schupf, N. (2010). Hormonal influences on cognition and risk for Alzheimer's disease. *Current Neurology and Neuroscience Reports*. http://doi.org/10.1007/s11910-010-0122-6

Jefferson, A. L., Gibbons, L. E., Rentz, D. M., Carvalho, J. O., Manly, J., Bennett, D. A., & Jones, R. N. (2011). A life course model of cognitive activities, socioeconomic status, education, reading ability, and cognition. *Journal of the American Geriatrics Society*, *59*(8), 1403–1411. http://doi.org/10.1111/j.1532-5415.2011.03499.x

Jones, R. N., Manly, J., Glymour, M. M., Rentz, D. M., Jefferson, A. L., & Stern, Y. (2011). Conceptual and measurement challenges in research on cognitive reserve. *Journal of the International Neuropsychological Society : JINS*, *17*(4), 593–601. http://doi.org/10.1017/S1355617710001748

Karlsson, P., Thorvaldsson, V., Skoog, I., Gudmundsson, P., & Johansson, B. (2015). Birth cohort differences in fluid cognition in old age: Comparisons of trends in levels and change trajectories over 30 years in three population-based samples. *Psychology and Aging*. http://doi.org/10.1037/a0038643

Katzman, R., Brown, T., Fuld, P., Peck, A., Schechter, R., & Schimmel, H. (1983). Validation of a short orientation-memory-concentration test of cognitive impairment. *The American Journal of Psychiatry*, *140*(6), 734–739. http://doi.org/10.1176/ajp.140.6.734

Kavé, G., Eyal, N., Shorek, A., & Cohen-Mansfield, J. (2008). Multilingualism and cognitive state in the oldest old. *Psychology and Aging*, *23*(1), 70-78. http://doi.org/10.1037/0882-7974.23.1.70

Keenan, P. A., Ezzat, W. H., Ginsburg, K., & Moore, G. J. (2001). Prefrontal cortex as the site of estrogen's effect on cognition. *Psychoneuroendocrinology*, *26*(6), 577–590.

http://doi.org/10.1016/S0306-4530(01)00013-0

Kirk, N. W., Fiala, L., Scott-Brown, K. C., & Kempe, V. (2014). No evidence for reduced Simon cost in elderly bilinguals and bidialectals. *Journal of Cognitive Psychology*, *26*(6), 640–648. http://doi.org/10.1080/20445911.2014.929580

Kousaie, S., & Phillips, N. A. (2012). Ageing and bilingualism: Absence of a “bilingual advantage” in Stroop interference in a nonimmigrant sample. *The Quarterly Journal of Experimental Psychology*, *65*(2), 356–369. http://doi.org/10.1080/17470218.2011.604788

Kousaie, S., Sheppard, C., Lemieux, M., Monetta, L., & Taler, V. (2014). Executive function and bilingualism in young and older adults. *Frontiers in Behavioral Neuroscience*, *8*(250). http://doi.org/10.3389/fnbeh.2014.00250

Kroll, J. F., & Bialystok, E. (2013). Understanding the Consequences of Bilingualism for Language Processing and Cognition. *Journal of Cognitive Psychology*, *25*(5), 497–514. http://doi.org/10.1080/20445911.2013.799170

Kroll, J. F., Bobb, S. C., & Hoshino, N. (2014). Two Languages in Mind: Bilingualism as a Tool to Investigate Language, Cognition, and the Brain. *Current Directions in Psychological Science*, *23*(3), 159–163. http://doi.org/10.1177/0963721414528511

Kroll, J. F., Bobb, S. C., Misra, M., & Guo, T. (2008). Language selection in bilingual speech: Evidence for inhibitory processes. *Acta Psychologica, 128*(3), 416-430. doi:10.1016/j.actpsy.2008.02.001

Kroll, J. F., Dussias, P. E., Bice, K., & Perrotti, L. (2015). Bilingualism, mind, and brain. *Annual Review of Linguistics*, *1*(1), 377–394. http://doi.org/10.1146/annurev-linguist-030514-124937

Kwon, D., Maillet, D., Pasvanis, S., Ankudowich, E., Grady, C. L., & Rajah, M. N. (2016).

Context Memory Decline in Middle Aged Adults is Related to Changes in Prefrontal Cortex Function. *Cerebral Cortex* , *26*(6), 2440–2460. http://doi.org/10.1093/cercor/bhv068

Larrabee, G. J., & Crook, T. H. (1993). Do men show more rapid age-associated decline in simulated everyday verbal memory than do women? *Psychology and Aging*, *8*(1), 68–71. http://doi.org/10.1037/0882-7974.8.1.68

Li, C. shan R., Zhang, S., Duann, J. R., Yan, P., Sinha, R., & Mazure, C. M. (2009). Gender differences in cognitive control: An extended investigation of the stop signal task. *Brain Imaging and Behavior*, *3*(3), 262–276. http://doi.org/10.1007/s11682-009-9068-1

Luine, V. N. (2014). Estradiol and cognitive function: Past, present and future. *Hormones and Behavior*, *66*(4), 602–618. http://doi.org/10.1016/j.yhbeh.2014.08.011

Luk, G., & Bialystok, E. (2013). Bilingualism is not a categorical variable: Interaction between language proficiency and usage. *Journal of Cognitive Psychology*, *25*(5), 605–621. http://doi.org/10.1080/20445911.2013.795574

Luk, G., Bialystok, E., Craik, F. I. M., & Grady, C. L. (2011). Lifelong Bilingualism Maintains White Matter Integrity in Older Adults. *Journal of Neuroscience*, *31*(46), 16808–16813. http://doi.org/10.1523/JNEUROSCI.4563-11.2011

Luk, G., De Sa, E., & Bialystok, E. (2011). Is there a relation between onset age of bilingualism and enhancement of cognitive control?. *Bilingualism: Language and Cognition*, *14*(4), 588-595. http://doi.org/10.1017/S1366728911000186

Macizo, P., Bajo, T., & Martin, M. C. (2010). Inhibitory processes in bilingual language comprehension: Evidence from Spanish-English interlexical homographs. *Journal of Memory and Language, 63*(2), 232-244. doi:10.1016/j.jml.2010.04.002

Maitland, S. B., Herlitz, A., Nyberg, L., Bäckman, L., & Nilsson, L.-G. (2004). Selective sex differences in declarative memory. *Memory & Cognition*, *32*(7), 1160–1169. http://doi.org/10.3758/BF03196889

Martin, M. C., Macizo, P., & Bajo, T. (2010). Time course of inhibitory processes in bilingual language processing. *British Journal of Psychology, 101*, 679-693. doi:10.1348/000712609x480571

McCarrey, A. C., An, Y., Kitner-Triolo, M. H., Ferrucci, L., & Resnick, S. M. (2016). Sex Differences in Cognitive Trajectories in Clinically Normal Older Adults. *Psychology and Aging*, *31*(1), 166–175. http://doi.org/10.1037/pag0000070

Meuter, R. F. I., & Allport, A. (1999). Bilingual language switching in naming: Asymmetrical costs of language selection. *Journal of Memory and Language, 40*(1), 25-40.

Meyer, J. S., Rauch, G. M., Crawford, K., Rauch, R. a, Konno, S., Akiyama, H., Terayama, Y., Haque, A. (1999). Risk factors accelerating cerebral degenerative changes, cognitive decline and dementia. *International Journal of Geriatric Psychiatry*, *14*(12), 1050–61. http://doi.org/10.1002/(SICI)1099-1166(199912)14:12<1050::AID-GPS56>3.0.CO;2-Z [pii]

Misra, M., Guo, T., Bobb, S. C., & Kroll, J. F. (2012). When bilinguals choose a single word to speak: Electrophysiological evidence for inhibition of the native language. *Journal of Memory and Language, 67*(1), 224-237. doi:10.1016/j.jml.2012.05.001

Miyake, A., & Friedman, N. P. (2012). The Nature and Organization of Individual Differences in Executive Functions: Four General Conclusions. *Current Directions in Psychological Science*, *21*(1), 8–14. http://doi.org/10.1177/0963721411429458

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The Unity and Diversity of Executive Functions and Their Contributions to

Complex "Frontal Lobe" Tasks: A Latent Variable Analysis. *Cognitive Psychology*, *41*(1), 49–100. http://doi.org/10.1006/cogp.1999.0734

Mueller, S. T., & Piper, B. J. (2014). The Psychology Experiment Building Language (PEBL) and PEBL Test Battery. *Journal of Neuroscience Methods*, *222*, 250–259. http://doi.org/10.1016/j.jneumeth.2013.10.024

Mungas, D., Beckett, L., Harvey, D., Farias, S. T., Reed, B., Carmichael, O., Olichney, J., Miller, J., & DeCarli, C. (2010). Heterogeneity of Cognitive Trajectories in Diverse Older Person. *Psychology and Aging*, *25*(3), 606–619. http://doi.org/10.1037/a0019502

Paolo, A. M., Troster, A. I., Axelrod, B. N., & Koller, W. C. (1995). Construct validity of the WCST in normal elderly and persons with Parkinson's disease. *Archives of Clinical Neuropsychology*, *10*(5), 463–473. http://doi.org/0887-6177(95)00052-6 [pii]

Perquin, M., Vaillant, M., Schuller, A. M., Pastore, J., Dartigues, J. F., Lair, M. L., & Diederich, N. (2013). Lifelong Exposure to Multilingualism: New Evidence to Support Cognitive Reserve Hypothesis. *PLoS ONE*, *8*(4). http://doi.org/10.1371/journal.pone.0062030

Pivneva, I., Mercier, J., & Titone, D. (2014). Executive control modulates cross-language lexical activation during L2 reading: evidence from eye movements. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 40*, 787-796. doi:10.1037/a0035583

Pivneva, I., Palmer, C., & Titone, D. (2012). Inhibitory control and L2 proficiency modulate bilingual language production: evidence from spontaneous monologue and dialogue speech. *Frontiers in Psychology, 3*. doi:ARTN 57 10.3389/fpsyg.2012.00057

Prior, A., & Gollan, T. H. (2013). The elusive link between language control and executive control: A case of limited transfer. *Journal of Cognitive Psychology*, *25*(5), 622–645. http://doi.org/10.1080/20445911.2013.821993

Proust-Lima, C., Amieva, H., Letenneur, L., Orgogozo, J.-M., Jacqmin-Gadda, H., & Dartigues, J.-F. (2008). Gender and education impact on brain aging: a general cognitive factor approach. *Psychology and Aging*, *23*(3), 608–620. http://doi.org/10.1037/a0012838

R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Read, S., Pedersen, N. L., Gatz, M., Berg, S., Vuoksimaa, E., Malmberg, B., Johansson, B., & McClearn, G. E. (2006). Sex Differences After All Those Years? Heritability of Cognitive Abilities in Old Age. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *61*(3), P137–P143. http://doi.org/61/3/P137 [pii]

Reimers, S., & Maylor, E. A. (2005). Task switching across the life span: effects of age on general and specific switch costs. *Developmental Psychology*, *41*(4), 661–671. http://doi.org/10.1037/0012-1649.41.4.661

Rhodes, M. G. (2004). Age-Related Differences in Performance on the Wisconsin Card Sorting Test: A Meta-Analytic Review. *Psychology and Aging*, 19(3), 482-494. http://doi.org/10.1037/0882-7974.19.3.482

Roivainen, E. (2011). Gender differences in processing speed: A review of recent research. *Learning and Individual Differences*, *21*(2), 145–149. http://doi.org/10.1016/j.lindif.2010.11.021

Salthouse, T. A. (1996). The Processing-Speed Theory of Adult Age Differences in Cognition. *Psychological Review*, *103*(3), 403–428.

Salthouse, T. A. (2009). Decomposing age correlations on neuropsychological and cognitive variables. *Journal of the International Neuropsychological Society : JINS*, *15*(5), 650–661.

http://doi.org/10.1017/S1355617709990385

Salthouse, T. A. (2010). Selective review of cognitive aging. *Journal of the International Neuropsychological Society : JINS*, *16*(5), 754–760. http://doi.org/10.1017/S1355617710000706

Sattler, C., Toro, P., Schönknecht, P., & Schröder, J. (2012). Cognitive activity, education and socioeconomic status as preventive factors for mild cognitive impairment and Alzheimer's disease. *Psychiatry Research*, *196*(1), 90–95. http://doi.org/10.1016/j.psychres.2011.11.012

Scarmeas, N., & Stern, Y. (2003). Cognitive Reserve and Lifestyle. *Journal of Clinical and Experimental Neuropsychology*. http://doi.org/10.1076/jcen.25.5.625.14576

Schweizer, T. A., Craik, F. I. M., & Bialystok, E. (2013). Bilingualism, not immigration status, is associated with maintained cognitive level in Alzheimer's disease. *Cortex*. http://doi.org/10.1016/j.cortex.2012.10.012

Schweizer, T. A., Ware, J., Fischer, C. E., Craik, F. I. M., & Bialystok, E. (2012). Bilingualism as a contributor to cognitive reserve: Evidence from brain atrophy in Alzheimer's disease. *Cortex*, *48*(8), 991–996. http://doi.org/10.1016/j.cortex.2011.04.009

Shanmugan, S., & Epperson, C. N. (2014). Estrogen and the prefrontal cortex: Towards a new understanding of estrogen's effects on executive functions in the menopause transition. *Human Brain Mapping, 35*(3), 847-865. http://doi.org/10.1002/hbm.22218

Sherwin, B. B. (1996). Hormones, mood, and cognitive functioning in postmenopausal women. *Obstetrics and Gynecology, 87*(2), 20S-26S. http://doi.org/10.1016/0029-7844(95)00431-9

Sherwin, B. B., & Henry, J. F. (2008). Brain aging modulates the neuroprotective effects of estrogen on selective aspects of cognition in women: A critical review. *Frontiers in Neuroendocrinology, 29*(1), 88-113. http://doi.org/10.1016/j.yfrne.2007.08.002

Singh-Manoux, A., Kivimaki, M., Glymour, M. M., Elbaz, A., Berr, C., Ebmeier, K. P., Ferrie, J.E., & Dugravot, A. (2012). Timing of onset of cognitive decline: results from Whitehall II prospective cohort study. *BMJ (Clinical Research Ed.)*, *344*(5570), d7622. http://doi.org/10.1136/bmj.d7622

Stern, Y. (2002). What is cognitive reserve? Theory and research application of the reserve concept. *Journal of the International Neuropsychological Society*, *8*(3), 448–460. http://doi.org/10.1017/S1355617702813248

Stern, Y. (2009). Cognitive reserve. *Neuropsychologia, 47*(10), 2015-2028. http://doi.org/10.1016/j.neuropsychologia.2009.03.004

Stern, Y. (2012). Cognitive reserve in ageing and Alzheimer's disease. *The Lancet Neurology, 11*(11), 1006-1012. http://doi.org/10.1016/S1474-4422(12)70191-6

Stern, Y., Gurland, B., Tatemichi, T. K., Tang, M. X., Wilder, D., & Mayeux, R. (1994). Influence of education and occupation on the incidence of Alzheimer's disease. *JAMA : The Journal of the American Medical Association*, *271*(13), 1004–1010. http://doi.org/10.1001/jama.271.13.1004

Stoet, G. (2010). Sex differences in the processing of flankers. *Quarterly Journal of Experimental Psychology (2006)*, *63*(4), 633–8. http://doi.org/10.1080/17470210903464253

Stuss, D. T. (2011). Functions of the frontal lobes: relation to executive functions. *Journal of the International Neuropsychological Society : JINS*, *17*(5), 759–65. http://doi.org/10.1017/S1355617711000695

Titone, D., & Baum, S. (2014). The future of bilingualism research: Insufferably optimistic and replete with new questions. *Applied Psycholinguistics*, *35*(5), 933–942. http://doi.org/10.1017/S0142716414000289

Titone, D., Gullifer, J., Subramaniapillai, S., Rajah, N., Baum, S. (in press). History-Inspired Reflections On The Bilingual Advantages Hypothesis. *Linguistic Approaches to Bilingualism.*

Tucker, A. M., & Stern, Y. (2011). Cognitive reserve in aging. *Current Alzheimer Research*, *8*(4), 354–60. http://doi.org/10.2174/156721112225912050

Tun, P. a., & Lachman, M. E. (2009). Age Differences in Reaction time and Attention in a National Telephone Sample of Adults: Education, Sex, and Task Complexity Matter. *Developmental Psychology*, *44*(5), 1421–1429. http://doi.org/10.1037/a0012845.Age

Valian, V. (2015). Bilingualism and cognition. *Bilingualism: Language and Cognition*, *18*(1), 3–24. http://doi.org/10.1017/S1366728914000522

Valian, V. (2016). Putting together bilingualism and executive function. *Linguistic Approaches to Bilingualism*, 1–10. http://doi.org/10.1075/lab.15044.val

van der Linden, D., Frese, M., & Meijman, T. F. (2003). Mental fatigue and the control of cognitive processes: effects on perseveration and planning. *Acta Psychologica*, *113*(1), 45–65. http://doi.org/10.1016/S0001-6918(02)00150-6

Vaughan, L., & Giovanello, K. (2010). Executive function in daily life: Age-related influences of executive processes on instrumental activities of daily living. *Psychology and Aging*, *25*(2), 343–355. http://doi.org/10.1037/a0017729

Venables, W. N. & Ripley, B. D. (2002) Modern Applied Statistics with S. Fourth Edition. Springer, New York. ISBN 0-387-95457-0

Verhaeghen, P., & Cerella, J. (2002). Aging, executive control, and attention: a review of meta-analyses. *Neuroscience & Biobehavioral Reviews*, *26*(7), 849–857. http://doi.org/http://dx.doi.org/10.1016/S0149-7634(02)00071-4 von Studnitz, R. E., & Green, D. W. (2002). The cost of switching language in a semantic categorization task. *Bilingualism: Language and Cognition, 5*(3), 241-251. doi:10.1017/s1366728902003036

Voyer, D., Voyer, S., & Bryden, M. P.(1995). Magnitude of Sex Differences in Spatial Abilities: A Meta-Analysis and Consideration of Critical Variables. *Psychological Bulletin*, *117*(2), 250–270. http://doi.org/10.1037/0033-2909.117.2.250

Watson, C. W.-M., Manly, J. J., & Zahodne, L. B. (2016). Does bilingualism protect against cognitive aging?: Methodological issues in research on bilingualism, cognitive reserve, and dementia incidence. *Linguistic Approaches to Bilingualism*, *5*(2016), 590–604. http://doi.org/10.1075/lab.15043.wat

Wiederholt, W. C., Cahn, D., Butters, N. M., Salmon, D. P., Kritz-Silverstein, D., & Barrett-Connor, E. (1993). Effects of age, gender and education on selected neuropsychological tests in an elderly community cohort. *Journal of the American Geriatrics Society, 41*(6), 639-647..

Wilson, R. S., Beckett, L. A., Barnes, L. L., Schneider, J. A., Bach, J., Evans, D. A., & Bennett, D. A. (2002). Individual differences in rates of change in cognitive abilities of older persons. *Psychology and Aging, 17*(2), 179-193. http://doi.org/10.1037/0882-7974.17.2.179

Yudes, C., Macizo, P., & Bajo, T. (2011). The influence of expertise in simultaneous interpreting on non-verbal executive processes. *Frontiers in Psychology*, *2*(309). http://doi.org/10.3389/fpsyg.2011.00309

Zahodne, L. B., Schofield, P. W., Farrell, M. T., Stern, Y., & Manly, J. J. (2014). Bilingualism Does Not Alter Cognitive Decline or Dementia Risk among Spanish-Speaking Immigrants. *Neuropsychology*, *28*(2), 238–246. http://doi.org/10.1037/neu0000014

Zelinski, E. M., Gilewski, M. J., & Schaie, K. W. (1993). Individual differences in cross-sectional and 3-year longitudinal memory performance across the adult life span. *Psychology and Aging, 8*(2), 176-186. http://doi.org/10.1037/0882-7974.8.2.176

APPENDIX

Table 1. *Effect sizes (β), standard errors (SE), t values for Model 1, which examines the interaction between Age, Age of L2 Acquisition, and Sex.*

	Perseverative Errors (PE)			**Non-Perseverative Errors (NPE)**			**Categories Completed (CC)**		
Fixed effects	*β*	*SE*	*t value*	*β*	*SE*	*t value*	*β*	*SE*	*t value*
–Age	1.52	.63	2.39*	2.00	.53	3.75***	-.76	.18	-4.15***
–L2 AoA	-.02	.62	-.04	.01	.52	.02	.06	.18	.31
–Sex	2.50	1.26	1.99*	1.89	1.06	1.78	-.93	.36	-2.57*
–Age * L2 AoA	-.33	.60	-.54	-.02	.51	-.05	.02	.17	.09
–Age * Sex	3.13	1.28	2.43*	1.27	1.08	1.17	-1.15	.37	-3.11**
–L2 AoA * Sex	.12	1.27	.09	3.78	1.07	3.54***	-.62	.37	-1.68
–Age * L2 AoA * Sex	.50	1.17	.43	2.06	.99	2.08*	-.47	.34	-1.39
Control Predictors	*β*	*SE*	*t value*	*β*	*SE*	*t value*	*β*	*SE*	*t value*
Languages Known	-.65	.66	-.97	-1.33	.56	-2.39**	.37	.19	1.94
Non-Native Usage	-.79	.68	-1.16	.78	.58	1.35	-.11	.20	-.57
Education Level	.06	.59	.10	-.10	.50	-.19	.34	.17	2.03*
(Intercept)	16.46	.63	26.26***	10.08	.53	19.11***	7.22	.18	40.00***

* *p or Pr (>|z|) < .05* ; ** *p or Pr (>|z|) < .01*; *** *p or Pr (>|z|) < .001*

Table 2. *Effect sizes (β), standard errors (SE), t values for Model 2, which examines the interaction between Age, Number of Languages Known, and Sex.*

	Perseverative Errors (PE)			**Non-Perseverative Errors (NPE)**			**Categories Completed (CC)**		
Fixed effects	*β*	*SE*	*t value*	*β*	*SE*	*t value*	*β*	*SE*	*t value*
–Age	1.54	.61	2.51*	1.55	.56	2.76**	-.69	.19	-3.59***
– Languages Known	-.69	.68	-1.02	-1.05	.62	-1.69	.33	.21	1.54
–Sex	2.50	1.21	2.07*	3.03	1.11	2.72**	-1.05	.38	-2.74**
–Age * Languages Known	.48	.62	.77	.28	.57	.50	-.09	.19	-.47
–Age * Sex	3.20	1.19	2.69*	2.50	1.09	2.29*	-1.29	.38	-3.45***
–Languages Known * Sex	.03	1.26	.03	.15	1.16	.13	.01	.40	.03
–Age * Languages Known * Sex	-.30	1.24	-.24	.23	1.14	.20	.20	.39	.52
Control Predictors	*β*	*SE*	*t value*	*β*	*SE*	*t value*	*β*	*SE*	*t value*
L2 AoA	-.12	.59	-.20	.04	.55	.08	.06	.19	.34
Non-Native Usage	-.75	.65	-1.15	.59	.60	.99	-.11	.20	-.55
Education Level	.14	.57	.24	-.40	.53	-.76	.41	.18	2.23*
(Intercept)	16.43	.60	27.56***	9.66	.55	17.65***	7.23	.19	38.41***

* *p or Pr (>|z|) < .05* ; ** *p or Pr (>|z|) < .01*; *** *p or Pr (>|z|) < .001*

Table 3. *Effect sizes (β), standard errors (SE), t values for Model 3, which examines the interaction between Age, Non-Native Usage, and Sex.*

	Perseverative Errors (PE)			**Non-Perseverative Errors (NPE)**			**Categories Completed (CC)**		
Fixed effects	*β*	*SE*	*t value*	*β*	*SE*	*t value*	*β*	*SE*	*t value*
–Age	2.08	.63	3.28**	1.48	.61	2.42*	-.79	.20	-4.01***
–Non-Native Usage	.27	.86	.32	.53	.84	.64	-.29	.27	-1.06
–Sex	1.86	1.27	1.46	3.05	1.23	2.48*	-.99	.40	-2.50*
–Age * Non-Native Usage	.39	.70	.55	.14	.68	.21	-.09	.22	-.40
–Age * Sex	2.25	1.25	1.81	2.62	1.20	2.18*	-1.10	.39	-2.84**
–Non-Native Usage * Sex	-3.26	1.64	-1.99*	.57	1.59	.36	.66	.51	1.29
–Age * Non-Native Usage * Sex	-1.93	1.43	-1.35	-.02	1.38	-.02	.37	.44	.84
Control Predictors	*β*	*SE*	*t value*	*β*	*SE*	*t value*	*β*	*SE*	*t value*
Languages Known	-.70	.61	-1.15	-1.00	.59	-1.71	.32	.19	1.67
L2 AoA	-.24	.58	-.41	.15	.56	.27	.05	.18	.30
Education Level	-.19	.56	-.33	-.41	.55	-.75	.46	.18	2.63**
(Intercept)	16.83	.63	26.82***	9.71	.61	16.01***	7.22	.19	37.07***

* *p or Pr (>|z|) < .05* ; ** *p or Pr (>|z|) < .01*; *** *p or Pr (>|z|) < .001*

Figure 1. Partial effects plot demonstrating the Age x Sex interaction on the number of Perseverative Errors (Model 1).

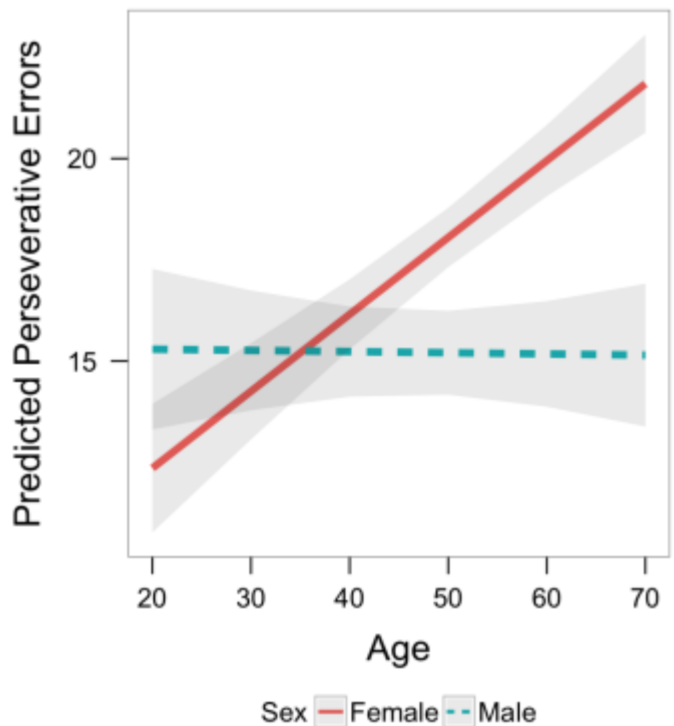

Figure 2. Partial effects plot demonstrating the Non-native Language Usage x Sex interaction on the number of Perseverative Errors (Model 3).

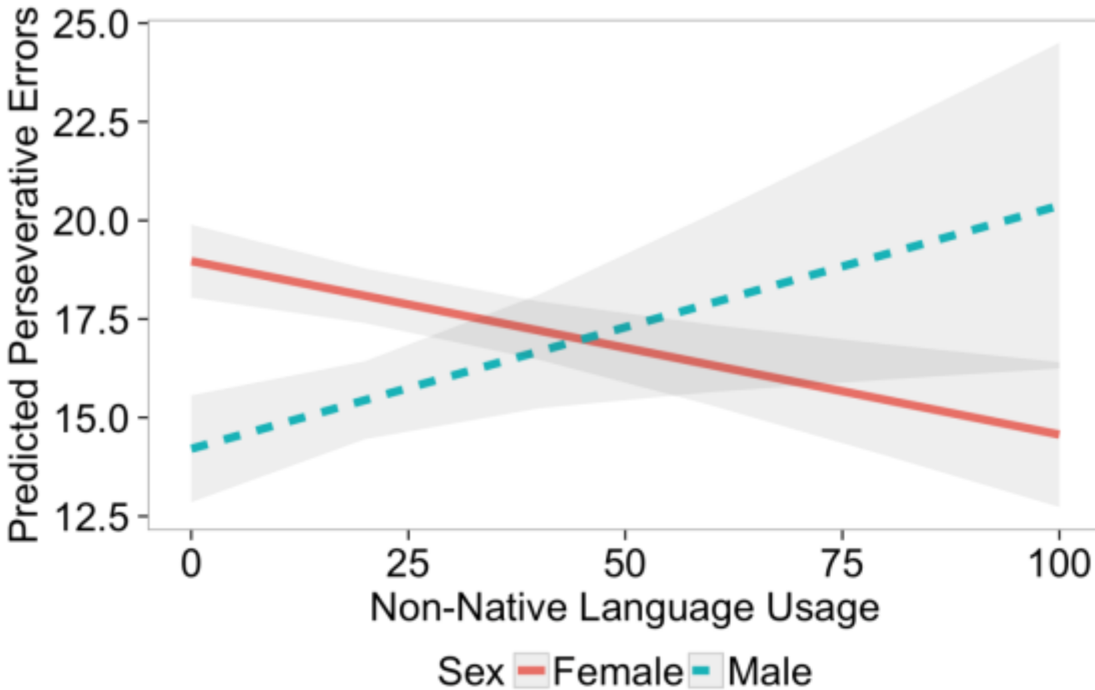

Figure 3. Partial effects plot demonstrating the three-way interaction between Age, Sex, and Age of L2 Acquisition on the Number of Non-perseverative Errors (Model 1).

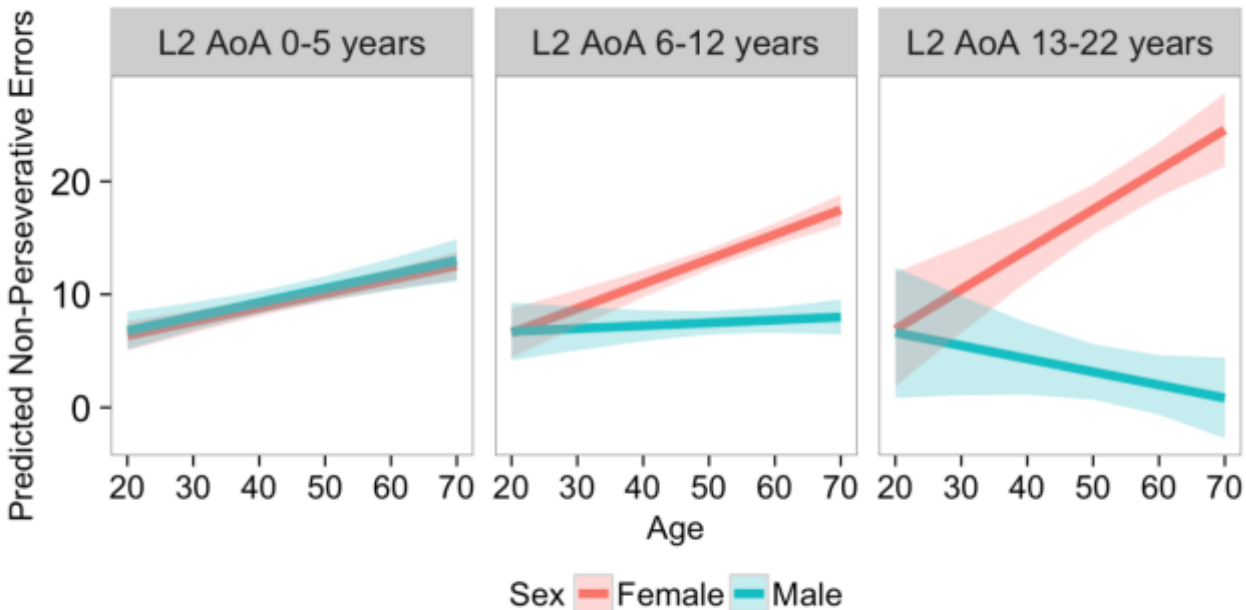

Figure 4. Partial effects plot demonstrating the Age x Sex interaction on the number of categories completed (Model 1).