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Extensive Experience with Multiple Languages May Not Buffer Age-Related Declines in Executive Function

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EXTENSIVE EXPERIENCE WITH MULTIPLE LANGUAGES MAY NOT BUFFER AGE-RELATED DECLINES IN EXECUTIVE FUNCTION

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By

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I dedicate this thesis to my parents, Ray and Sandy Weyman, who supported me through all of my crazy endeavors and continue to inspire me on a daily basis. I also decidate this study to Dr. Matthew Shake, who kept me sane and showed me that anything can be accomplished with some patience and good humor.

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ABSTRACT

The question of whether bilingualism can improve aspects of cognitive function is a hotly debated topic, with evidence on both sides. A few recent studies have reported that bilingualism may provide a limited buffer against some age-related cognitive decline. This study aimed to test that hypothesis by analyzing the combinatorial effects of age and language experience upon executive function (i.e., general cognitive control mechanisms that regulate cognition and behavior). Amazon Mechanical Turk was used to recruit an international sample of younger (YA) and older adults (OA) from 24 countries. A total of 81 participants were monolingual (ML; *N*(YA) = 37, *N*(OA) = 44), and 82 participants were bilingual/multilingual (BL; *N*(YA) = 43, *N*(OA) = 39). Executive function components of inhibition, memory updating, and attention switching were measured using Stop Signal, Letter Memory, and Color Shape tasks, respectively. YAs performed better than OAs on both the Stop Signal and Letter Memory tasks, indicating that YAs had better control of inhibition and updating processes. The Color Shape task revealed that a greater switch cost occurred if a person had less time to process a stimulus cue. Notably, no effects of language (i.e., bilingualism) were significant. Thus, YAs and OAs performed as expected regarding normal cognitive aging; however, no main effects or interactions of language experience were found. This study provides data that challenge the claim that extensive experience with multiple languages can be a reliably protective factor against some normative age-related declines in executive function.

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Weyman, K.M., & Shake, M.C. (Under Review). *Extensive experience with multiple languages may not buffer age-related declines in executive function.* Poster Presentation at the 2018 Gerontological Society of America Annual Scientific Meeting. Boston, MA.

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Language is an essential component of human communication. Consequently, intercultural communication can be difficult if both individuals are not fluent in the same language. It should not be surprising, then, that human history is replete with examples of individuals and cultures that have become proficient in more than one language. In recent years, the nature and consequences of bilingualism have become an especially strong focal point in psychological research. Some of this was due to fascinating studies reporting that bilinguals (BLs) had advantages over monolinguals (MLs) in various cognitive domains, such as interrepresentational flexibility in children (Adi-Japha, Berberich-Artzi, & Libnawi, 2010), convergent and divergent thinking (Hommel, Colzato, Fischer, & Christoffels, 2011), and the delay of symptoms of Alzheimer's disease (Schweizer, Ware, Fischer, Craik, & Bialystok, 2011).

The findings that appear to have attracted the most attention, however, are those that indicated its beneficial role in executive function (EF), defined as the control processes of the brain that oversee an individual's thoughts and behaviors. Executive function can be difficult to measure because it involves many different and interdependent cognitive processes, though one seminal framework has been used by Miyake to conceptualize EF. (Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000; Miyake & Friedman, 2012). Miyake and Friedman (2012) distinguish between three core components of EF: inhibition of preponent responses, updating of working memory, and switching attention between tasks. Their "unity/diversity" framework has offered a compelling model on which to study distinct effects of unique components of

EF in various cognitive psychology disciplines. Their evaluation offered more encompassing descriptions of the studied EF components. Inhibition was understood to be the act of intentionally hindering responses that were automatic or were trained to be automatic. Updating was linked closely with working memory, though different than passive storage of new information. Instead, updating involved purposeful manipulation of what was in the working memory to include relevant information while simultaneously forgetting irrelevant information. Finally, shifting was closely associated with proactive engagement of attention. In other words, it was defined as actively engaging in one aspect of a task while at the same time suppressing any distractions that would cause interference. With these definitions in mind, several studies have suggested that bilingualism may engender advantages in some aspects of EF (e.g., Bialystok, Craik, & Luk, 2008; Bialystok, Poarch, Luo, & Craik, 2014; Carlson & Meltzoff, 2008).

Evidence For a Bilingual Advantage in EF

It has been suggested that bilingual advantages could be due to the observation that fluency in multiple languages requires frequent engagement of components of EF (e.g., switching rapidly between languages, inhibiting one language while activating the other, etc.). This is consistent with the evidence of parallel activation of both languages during lexical processing (Costa, 2005), which would arguably induce more cognitive effort from the BLs when using both languages. This increased bilingual language activation could benefit the degree of cognitive control that a person has, particularly pertaining to the major components of EF (i.e., inhibition, updating of working memory, and switching of attention). It should be noted, though, that when engaging in strictly domain-specific, i.e. *linguistic* tasks, the parallel activation of both languages causes competition that slows the mental processes of BLs in comparison to MLs (Bialystok, Craik & Luk, 2008). In contrast, *advantages* of bilingualism have been observed in multiple domain-general, i.e., non-linguistic measures of EF (Bialystok et al., 2008; Bialystok et al., 2014; Carlson & Meltzoff, 2008).

The potentially domain-general nature of bilingual cognitive processes may thus be a concomitant reason for BL advantages on various cognitive tasks. In support of this, researchers found that overcoming the cognitive strain of competing languages in a lexicon is not localized to language areas of the brain. Instead, the ample BL language activity requires non-lexical processes that are affected in congruence with the lexical interference of dual-activation (Kroll, Dussias, Bogulski, & Valdes Kroff, 2012). Strictly speaking, BLs spend more time using inhibitory mechanisms when focusing on one language, and they must switch between languages rather than relying only on one as MLs do. This repeated and complex process directly underlies EF. The effects of this extensive EF practice have been demonstrated in tasks that demand inhibitiory control and task switching, in which BLs outperformed MLs. For example, Bialystok et al. (2008) found a BL advantage in both the Stroop and Simon measures of cognitive control. Further, bilingual children exhibited better attentional capabilities when managing conflicting demands (Carlson & Meltzoff, 2008). The source of these benefits was attributed to the increased development of control that BLs have to exercise each time they engage in lexical communication, thereby strengthening their general EF abilities. Similar results have been found in comparisons of the EF of younger and older ML and BL adults and observing possible interactions between the two variables of age and language ability, with a larger BL benefit for older adults (Bialystok, Poarch, Luo, & Craik, 2014).

Evidence Against a Bilingual Advantage in EF

Until recently, many researchers agreed that BLs had a cognitive advantage over MLs. Indeed, even undergraduate textbooks in psychology espoused the importance of learning a second language for cognition. However, de Bruin, Treccani, and Della Sala (2015) as well as Lehtonen, Soveri, Laine, Järvenpää, de Bruin, & Antfolk (2018) indicated that this may be due to publication bias, wherein papers showing null effects (or a bilingual *dis*advantage) may be significantly less likely to be published in a scientific journal as compared to a study presenting a bilingual advantage. Additionally, small sample sizes in BL advantage studies tended to be overrepresented in the literature. The Lehtonen et al. (2018) meta-analysis revealed that studies challenging the bilingual advantage were less likely to be published before 2014 (also see Sanchez-Azanza, López-Penadés, Buil-Legaz, Aguilar-Mediavilla, & Adrover-Roig, 2017). Furthermore, effect size bias relating to standard error (SE) measures has been found in studies supporting a BL advantage. Once corrected for using a method to estimate unbiased effect sizes, no significant differences between MLs and BLs were found. The meta-analyses revealing these patterns examined effects of bilingualism on monitoring, attention, and verbal fluency, as well as the EF domains that are the focus of this study (i.e., inhibition, updating, and shifting) (Lehtonin et al., 2018).

Specific studies challenging the BL advantage claim reported no language group differences on indicators of monitoring and switching, and in some cases even a slight BL disadvantage for inhibitory responses (Paap & Greenberg, 2013). In Paap and

Greengerg's study, college students were categorized as monolingual, bilingual, or neither (i.e., their ability in English was not rated as highly proficient). They completed various EF tasks with specific emphasis on inhibition for three of the tasks. Excluding a small significant BL disadvantage on two of the three inhibitory tasks, no significant effects of bilingualism were found in any condition. Further comparison of highly fluent BLs who used both of their languages equally as often (i.e., balanced BLs) yielded similar results. Paap and Greenberg (2013) explained their results in light of the effect of language experience on EF that Bialystok et al. (2008, 2014) cited as a reason for a BL benefit. Paap and Greenberg argued that MLs experience a similar degree of practice in regards to control of switching between and inhibiting of the connotative meanings of words and syntax that must be contended within one language. Additionally, every person must engage in EF processes throughout their daily behaviors, including conversations and monitoring of one's own performance on an activity.

Another recent study also found no difference between ML and BL performance on working memory, inhibition, updating, and shifting tasks. Shulley and Shake (2016) reported that people who mind wander less are more likely to perform better on cognitive tasks; therefore, perhaps some BL advantage is explained by lower rates of mind wandering. The researchers' analyses of college students' performances, however, found no significant differences between MLs and BLs in the time spent on- versus off-task. Moreover, there was no EF advantage for BLs. Shulley and Shake's results therefore provided more evidence to the argument against a BL advantage in EF.

Bilingualism and Aging

Though more research has been published showing a BL advantage than no advantage (de Bruin et al., 2015), the contradictory evidence and question of publication bias have fueled a heated debate. In response to Paap and Greenberg's (2013) strong refuting a bilingualism advantage, Bialystok, Poarch, Luo, and Craik (2014) claimed that the lack of any significant difference between MLs and BLs was due to the participant sample of the prior study. In particular, they suggested that the BL benefit is most likely to be found in older adults because EF in younger adults (regardless of language) is already optimized and has more limited variance. In support of this, Bialystok et al. (2014) found that older participants had slower reaction times on a Stroop task, but older MLs were slower than older BLs. In comparison, younger adults showed no difference in performance on the Stroop task with regard to language proficiency (Bialystok et al., 2014). Thus, an age-related confound could have led to the lack of any BL effect in previous studies.

It is commonly understood that aging is correlated with natural declines in various aspects of cognition. These effects extend to measures of EF, especially switching and inhibition, in adults ages 55 and older (Goh, An, & Resnick, 2012). Older adults also tend to be less involved in cognitively engaging activities compared to younger adults, especially participant pools of college students that dominate the research literature (e.g., Paap & Greenberg, 2013; Shulley & Shake, 2016). This observation strengthens the claim by pro-BL benefit researchers who have stated that studies that counter the BL advantage have found null evidence because they did not recruit older adults as a comparison group. Among younger adults, it is more common to find no difference in EF performance between MLs and BLs (Valian, 2015), possibly due to a higher prevalence of cognitively engaging activities. Similar to the bias found in sample size, however, evidence of a publication bias as it relates to aging and bilingualism leaves substantial doubt. In contrast to Bialystok's claims, a recent meta-analysis revealed that age group did not moderate differences in performance of MLs and BLs on EF tasks (Lehtonin et al., 2018).

Another possible factor that may moderate the impact of bilingualism on cognitive aging involves prevalence of language use in older adults. Dominant BLs, who have an obvious prominent language, may experience more interference when switching to the secondary language. This could relate to more exercise of a BL individual's EF capacities. On the other hand, balanced BLs experience more ease in using both languages, for they are equally proficient in each language. Therefore, the balanced BL experiences less strain when communicating, and the effect of bilingualism is not as efficacious at strengthening a BL participant's EF domains. In one study examining these two groups' performances on EF tasks, the dominant BLs showed little age-related decline in comparison to the balanced BLs on a task measuring inhibitory control (Goral, Campanelli, & Spiro III, 2015).

Additional aging studies have placed emphasis on BL benefits for individuals with Alzheimer's disease or other forms of dementia. Interestingly, bilingualism has been shown to affect behavior that is correlated with neuropathological regions associated with Alzheimer's disease (Schweizer et al., 2011). Multiple mental status evaluations of ML and BL Alzheimer's disease patients showed that the two language groups had equal levels of cognition. Later CT scans of these patients showed that BLs had higher degeneration in their medial temporal lobes (a region where Alzheimer's disease has been linked to brain atrophy) than MLs. The equal cognitive status of BLs to MLs, therefore, indicated that the BL participants experienced greater “cognitive reserve” despite higher levels of degeneration. Additionally, BLs experienced an age of onset of Alzheimer’s disease over four years later on average than ML patients. For other types of dementia, age of onset was also delayed with a difference of over three years on average, with the significantly larger delay benefitting BL patients (Bialystok, Craik, & Freedman, 2007).

Purpose of the Present Study

In light of this contentious bilingualism and cognition debate, the present study aimed to investigate whether a buffering effect occurred for BLs, in which BL older adults would perform significantly better than ML older adults. To do so, a large participant sample of both younger (ages 18-30) and older adults (ages 55+) was included. These groups were either ML or BL in a diverse variety of languages. Previous studies of these variables had notable weaknesses, including small sample sizes and/or fairly homogenous demographics. The present study recruited a large participant pool of international participants from all over the world, including from countries where bilingualism is more common. In light of the aforementioned literature, the present study implemented tasks that measured the three most highly stressed components of EF: inhibition, updating, and shifting. It was hypothesized that no benefit of bilingualism would be found on any of the cognitive tasks between groups of young adults. On the other hand, a second hypothesis was made regarding age-related effects and bilingualism. If the studies finding an age-related BL advantage were correct, it was expected that a significant buffer effect of bilingualism among older adults would be found, with a greater difference between older BLs and MLs.

Method

Participants

All participants were recruited through Amazon Mechanical Turk (MTurk), a web service that is used to reach individuals around the world. There were 167 individuals who signed up for the study; four either did not meet demographic requirements or did not complete the study. The 163 completed participants consisted of younger (N = 80) and older (N = 83) adults from 24 countries who were monolingual or bilingual (see Figure 1). In an attempt to control for cross-cultural comparisons, both ML and BL younger adults were from countries other than the United States, while a majority (87%) of the older adults were United States citizens. The mean age of younger adults was 24.4 years of age (*SD* = 3.25 years), and the older participants averaged 62.0 years (*SD* = 4.31 years).

Table 1 contains participant demographics. Participants were systematically recruited to create a fairly even distribution among age and language proficiency. This was accomplished by utilizing participant restrictions on MTurk to maintain similar group sizes across the between-subjects factors. There were 38 younger adults who were ML and 42 were BL; 43 older adults were ML and 40 were BL. There was also nearly equal representation of males and females, with 53% male and 47% female participation. Moreover, almost all of the participants had some form of higher education. The other 6.1% had a high school degree or equivalent. Finally, additional MTurk restrictions included a Human Intelligence Task (HIT) approval rate greater or equal to 95% and at least 100 HITs completed previously.

All ML participants' primary language was English. BL participants were fluent in English and at least one of 33 other languages: Arabic, Bosnian, Bulgarian, Catalan, Chinese, Croatian, Dutch, Farsi, French, Galician, German, Greek, Hebrew, Hungarian, Indonesian, Italian, Japanese, Latvian, Lithuanian, Pashto, Persian, Polish, Portuguese, Romanian, Russian, American Sign Language, Slovenian, Spanish, Tagalog, Tamil, Turkish, Ukrainian, or Welsh. Table 2 shows mean self-reported ratings of familiarity and proficiency for all participants.

Measures

Demographic restrictions for age, language proficiency, and geographic location were used both through MTurk and an initial screening/informed consent questionnaire on Qualtrics. The Qualtrics Experience Management Platform was used for both the screening/informed consent questionnaire and the final demographic questionnaire.

Inquisit Lab, downloadable software that runs online scripts of cognitive tasks, was used to run the three tasks for this study. All tasks were compatible with both Windows and Apple computers. Participants completed three tasks, which were derived from previous studies as adequate measures of each aspect of EF. The first task was Stop Signal, used to measure inhibition of the developed automatic response of pressing corresponding arrow keys (Verbruggen, Logan, & Stevens, 2008). The second was the Letter Memory task that was chosen to measure updating of participants' working memory by presenting a varied sequence of letters (Friedman, Miyake, Young, DeFries, Corley, & Hewitt, 2008). The final task was the Color Shape task that measured switching of attention between characteristics of superimposed stimuli (Miyake, Emerson, Padilla, & Ahn, 2004). All three tasks have been studied to be mostly pure measures of their corresponding EF measures, meaning that they involved only one aspect of EF for participants to complete the task.

Inhibition. Participants completed the Stop Signal task (Verbruggen, Logan, & Stevens, 2008). Each trial started with a fixation circle on a black screen, which would produce an arrow that pointed either to the right or to the left. Participants were to indicate which direction the arrow was pointing by pressing either the corresponding right or left response key. In this task, participants pressed D for an arrow pointing to the left and K for an arrow pointing to the right. In random trials, a stop signal tone would be given. If the stop signal is heard, then participants waited for the arrow to disappear without pressing a key. Participants completed 32 practice trials, followed by 64 test trials. In the practice block, a stop signal was given in eight trials. In the test block, 16 stop signals were given. The trials were randomly dispersed in each block.

The time between the presentation of the stimulus and the stop signal depended on the participant's performance on the task. The first signal tone occurred 250 ms after the arrow. This delay would then be either lengthened or reduced by 50 ms, depending on the participant's performance: successful inhibition further delays the stop signal (up to 1150 ms), while failed inhibition results in a smaller delay (down to 50 ms) for the next stop trial. This variable was defined as the covert stop signal reaction time.

Updating. Participants then completed the Letter Memory task (Friedman et al., 2008). Participants were presented with a fixation point for one second, followed by a series of letters, each presented for 2500 ms. The letters were randomly selected from the 21 consonants in the English alphabet. Each set included five, seven, or nine letters. The order of the sets was random, though each size (five, seven, or nine letters) occurred once every three trials so no consecutive sets were of equal number. Once a set was complete, a screen with all 21 possible letters was shown. In order to successfully complete a trial, participants had to identify the last three letters of the series in the correct order on the final screen. Participants completed a practice round that included three trials, one of each set number of letters. Participants then completed 12 test trials, with four trials per set size.

Shifting. The final cognitive task was Color Shape (Miyake et al., 2004). This task involved two types of stimuli: shape and color. The stimulus was either a circle or a triangle that was superimposed on a red or green square. Participants first assismilated to each characteristic by completing separate practice trials for both shape and color. For shape indication, participants were instructed to press the A key for a triangle or the L key for a circle. To identify the color, participants pressed the A key for a red square or the L key for a green square. The shapes were then randomly superimposed on the colored squares before testing in a blocked condition. After the blocked test trials were complete, a one-minute break was given before completing trials in the mixed condition. In a blocked condition, participants were cued before completing a series of trials. In a mixed condition, participants were given a cue before each stimulus appeared that identified which characteristic to indicate (color vs. shape) and had either a long or short cue-stimulus-interval (CSI). The characteristics were randomly distributed throughout the task, with even representation of the four features (red or green vs. circle or triangle). Accuracy percentages were provided at the end of each set of test trials.

The blocked condition involved five practice blocks of 32 trials each, with each stimuli characteristic randomly occurring eight times per block without replacement. The order of the training blocks was fixed: 1) only shape presented; 2) only color presented; 3) mixed presentation of separate color patches and shapes; 4 and 5) shapes superimposed on color patches. Error feedback was given for one second after a wrong answer was selected during these practice trials. A one-minute break was given after the five practice blocks. Two test blocks of 64 trials each were then given in which the stimuli looked similar to those presented in the fourth and fifth practice sessions. Participants indicated the shape of the superimposed stimulus in one block; in the other, they identified the color. Error feedback was not given between each stimulus; instead, accuracy was displayed on the screen at the end of each test block.

A 2 (word vs. letter) x 2 (long CSI vs. short CSI) design was implemented in the mixed trials, where the cue was either a word ("COLOR" vs. "SHAPE") or a letter ("C" vs. "S"), and the interval between the cue and the stimulus was either long (1200 ms) or short (200 ms). Similar to the blocked condition, participants were cued with which feature of the stimulus to attend to. Unlike the blocked condition, participants were cued before each individual stimulus. A total of 48 practice trials were first presented through two training blocks (word vs. letter cue) in random order. Error feedback was given for one second after each stimulus during the practice trials. A one-minute break ended the set of practice trials. Four test blocks followed, with random distributiton of two word-cued sets and two letter-cued sets of 25 trials each. Half of the trials were switch trials, in which the participant attended to the opposite characteristic of the stimulus in two subsequent trials (i.e., attending to color, followed by attending to shape, or vice versa). As an additional variable, the time between the cue and the stimulus was randomly distributed. The four possible conditions (word vs. letter and long vs. short CSI) were given equal weight throughout the task. Instead of error feeback after each stimulus, participants were given a percentage score of correctly-attended-to stimuli at the end of each block.

Procedure

Before beginning the study, participants completed a primary questionnaire that provided additional screening to the participant restrictions included in the HIT on MTurk regarding age and language ability (see Appendix A). On the second page of the questionnaire, participants electronically signed an informed consent document that was approved by the Institutional Review Board (IRB) at Western Kentucky University (see Appendix B). Participants then completed the Stop Signal, Letter Memory, and Color Shape tasks, in that order. At the termination of the cognitive tasks, participants answered the demographic questionnaire (see Appendix C) that was derived from the Language History Questionnaire (Li, Zhang, Tsai, & Puls, 2014). Participants were paid $7.50 through MTurk once all of the tasks and questionnaires were completed.

Results

Design and Statistical Analysis

Before completing any data analysis, the summary data within each age group were screened for any outliers beyond 2.5 standard deviations above or below the mean values. This resulted in removing a small number of participants' data for the Letter Memory (2 younger, 3 older), Stop Signal (2 younger, 1 older), and Color Shape (5 older, 1 younger) tasks. Younger adults are hereafter referred to as YAs, and older adults are OAs. A series of 2 (Age Group: YA vs. OA) x 2 (Language Group: BL vs. ML) between-subjects Analyses of Variance (ANOVAs) were used to test for any significant differences, with *p*-values set to .05. Means and standard errors for each of the following three tasks can be found in Table 3.

Stop Signal

The key dependent variable for this task was covert stop signal reaction time (SSRT). Figure 2 shows the mean SSRTs for younger and older MLs and BLs. As expected, YAs had shorter SSRTs than OAs, $F(1, 151) = 14.51$, $p < .001$. No significant effect of Language Group was found, $F(1, 151) = .000$, $p > .99$. The interaction of Age and Language Group was not significant, $F(1, 151) = .130$, $p > .70$.

Letter Memory

The dependent variable for this task was the proportion of letters correctly recalled on the final screen. Figure 3 shows the mean values of the proportion of letters chosen correctly for all between-subjects comparisons. A significant effect of Age was found, with YAs correctly recalling more letters than OAs, $F(1, 158) = 7.65$, $p < .01$. No difference as a function of Language Group was found, $F(1, 158) = 1.88$, $p > .10$. Additionally, there was no significant interaction between Age and Language Group, $F(1, 158)$, $p > .60$.

Color Shape

The major dependent variable for this task was the switch cost, defined as the mean reaction time difference between alternating switch trials and consecutive consistent trials. Since this task included some within-subjects task manipulations, a 2 (YA vs. OA) x 2 (ML vs. BL) x 2 (word vs. letter) x 2 (long CSI vs. short CSI) mixed factorial ANOVA was conducted. Figure 4 shows the mean switch costs with distinction between long and short CSI, Age, and Language Group. There were no significant effects of Age, $F(1, 155) = 3.50$, $p > .06$. Consistent with the other tasks, no significant effect of Language Group was found, $F(1, 155) = .264$, $p > .60$. The interaction of Age and Language Group was not significant, $F(1, 155) = .158$, $p > .60$. There was a significant effect of CSI, with shorter CSI leading to a greater switch cost, $F(1, 155) = 83.87$, $p < .001$. The interaction of CSI and Age was not significant, $F(1, 155) = 1.21$, $p > .20$. There were no significant CSI-Language Group interactions, $F(1, 155) = .000$, $p > .90$. Finally, no 3-way or 4-way interactions reached significance, all $p > .05$.

Discussion

This study aimed to offer more insight into the debate concerning whether or not bilingualism offers any cognitive benefit. We implemented three measures of distinct components of executive function, corresponding to the Miyake and Friedman (2012) framework: inhibition measured by Stop Signal, updating measured by Letter Memory, and shifting measured by Color Shape. To investigate the claim offered by Bialystok et al. (2014) that an EF advantage is most consistently found in older BLs, the impact of age was also investigated. Finally, the diversity of the sample was improved by recruiting international participants through MTurk.

Our results do not support a BL advantage, either in younger or older adults. As expected, age-related deficits were found in two of the tasks (i.e., Stop Signal and Letter Memory), while no significant effect of age was found in the Color Shape task. Across each of the three tasks, no effect of bilingualism was found within either Age Group. These findings thus do not support the argument of Bialystok et al. (2014) that the clearest benefits of bilingualism should emerge with advancing age. Instead, these results support the conclusions of Lehtonen et al. (2018) that a bilingual benefit of EF is unlikely in either YA or OA.

Before conducting the study, we hypothesized that there would be no significant interaction of age and language for the younger participants, due to the extraneous cognitive practice that YAs have been observed to undergo, in combination with the possibility of a publication bias. This hypothesis was supported. We also hypothesized that there would be an obvious difference in performance by OAs in comparison to YAs, with YAs performing significantly better on all three tasks, which was also supported. Finally, we expected to find a bilingual benefit for BL OAs that was discernable as a buffering effect of normative age-related cognitive decline, but our results did not support this hypothesis.

Strengths, Limitations, and Future Directions

The most notable strength of the present study is its the international component. All but two of the YAs were from countries outside of the United States, with a majority (71%) of YAs from European countries. We recruited participants from a variety of countries for two reasons: the first, most European countries have similar ideals and economic development as the United States; and second, bilingualism is more common because the European continent consists of many small, adjoining countries. This was possible through the utilization of MTurk. However, since MTurk is still new and increasing its international reach, it proved difficult to reach older participants outside of the United States. Therefore, approximately 87% of the OAs were from the United States. Nevertheless, our sample was more representative than any of the previous literature, which strengthens the generalizability of our results. In addition to the diversity of the sample, the large sample size enhanced the reliability of our data, especially considering that small sample size is a point of dispute in the bilingualism-EF debate.

We also reduced self-selection bias through two approaches. First, MTurk provided constraints based on geographic location and age. Second, the initial questionnaire screened participants for age and language proficiency. If the person did not meet the requirements, then he or she would not be permitted to participate in the study. This strategy prevented participants from knowing that the purpose of the study was to study bilingualism and aging. Therefore, the participants' performances on the tasks were unlikely to stem from a feeling of needing to excel due to activating socio-cognitive cues regarding aging or language proficiency.

Perhaps the most evident limitation in our study relates to the subjective nature of the demographic questionnaire. No tests of language proficiency were given because there was no restriction on language type. Rather, participants rated their own linguistic abilities in the demographic questionnaire on aspects such as speaking, listening, reading, and writing. Due to the absence of any language tests, the demographic data relies on trust that each participant carefully followed the instructions and was honest in their answers. Subjective age of acquisition (AoA) data was also collected, though there is evidence that AoA does not affect language proficiency in BLs (see De Carli et al., 2014; Lehtonen et al., 2018). There is also a possibility that the participants were distracted while completing the tasks because a researcher was not there to directly monitor each participant. However, we excluded certain extreme outliers and participants for whom total task time made it clear that they were not following instructions, in an effort to prevent inattentiveness from impacting our results.

Future studies should implement controls to effectively manage these potential confounds. If possible, a more objective measure of bilingualism should be used. The present study's use of the demographic questionnaire was intended to be a short review of participants' major demographic information and exposure to one or more languages. Because the study was online, it was important to keep the duration of the entire study – from informed consent to the final questionnaire – under one hour. The three executive function tasks themselves lasted approximately 55 minutes, so an objective language test was impractical. Further, the questionnaire in place could not be too specific, for over thirty languages were reported between the participants.

In order to increase the external validity of both sides of the BL argument, more international studies should be implemented. MTurk is an excellent tool for large-scale research that is also cost efficient. However, older adults are less likely to use MTurk, as demonstrated by the present study. This could simply be a result of the novelty of the online source. As MTurk continues to develop and gain impact outside of the United States, psychologists should take advantage of the much more representative pool of participants in comparison to recruiting on a university campus.

Conclusion

In conclusion, this study aimed to test whether bilingualism would act like a mental buffer in normal age-related declines in executive function by comparing an international sample of ML and BL younger and older adults on three EF tasks. Bilingualism had no effect on EF, and there were no interactions between language ability and age. These results support the argument that bilingualism does not offer any cognitive advantages in EF. On the other hand, the results disputed the argument that contradictory evidence to a bilingual benefit was due to the lack of age variability among participants. Improvements can be made, specifically concerning more objective measures of language ability, though the results lead to one true supposition: the debate on bilingualism is not over, and there are many more aspects that need attention before a definite answer can be given.

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Table 1

Participant Characteristics

Measure	Younger Adults *N*		Older Adults *N*	
Sex				
Male	49	(30.1)	38	(23.3)
Female	31	(19.0)	45	(27.6)
Education				
Less Than H.S.	0	(0.0)	0	(0.0)
H.S. Graduate	6	(3.7)	4	(2.5)
Some College	17	(10.4)	23	(14.1)
2-year Degree	14	(8.6)	14	(8.6)
4-year Degree	28	(17.2)	29	(17.8)
Master's Degree	13	(8.0)	11	(6.7)
Doctorate	2	(1.2)	2	(1.2)
Language Proficiency				
Monolingual	38	(23.3)	43	(26.4)
Bilingual	42	(25.8)	40	(24.5)

Note. Percentages are shown in parentheses.

Table 2

Language Proficiency Frequencies and Self Ratings of Proficiency

	Younger Adults			Older Adults		
Number of Proficient Languages	N			N		
One (L1)	80			83		
Two (L2)	42			40		
Three (L3)	20			10		
Four (L4)	4			4		

Number of Familiar Languages*	N	M	SD	N	M	SD
Reading						
L1	80	4.91	0.36	83	4.75	0.75
L2	56	4.18	1.25	48	3.44	1.43
L3	32	3.72	1.40	18	3.00	1.33
L4	13	2.77	1.79	8	3.50	1.51
Writing						
L1	80	4.79	0.72	83	4.61	0.93
L2	56	3.59	1.47	48	3.15	1.52
L3	32	3.38	1.45	18	2.44	1.50
L4	13	2.31	1.60	8	2.50	1.41
Speaking						
L1	80	4.81	0.64	83	4.69	0.89
L2	56	3.76	1.35	47	3.54	1.46
L3	31	3.30	1.47	20	2.45	1.43
L4	12	2.33	1.44	8	2.63	1.69
Listening						
L1	80	4.94	0.29	83	4.71	0.86
L2	56	3.89	1.52	47	3.62	1.45
L3	31	3.43	1.59	20	2.50	1.32
L4	12	2.83	1.70	8	2.50	1.31

Note. *Familiar languages refers to all languages that participants reported having exposure to, regardless of fluency. Scale was as follows: 1 – Poor; 2 – Fair; 3 – Neutral; 4 – Good; 5 – Very Good.

Table 3

Means and Standard Errors for Executive Function Tasks

	Younger Adults				Older Adults			
	Monolingual		Bilingual		Monolingual		Bilingual	
Measure	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Stop Signal Reaction Time (SSRT)	253	14	248	12	298	13	303	13
Letter Memory (Prop. Correctly Recalled)	0.94	0.02	0.92	0.02	0.89	0.02	0.86	0.02
Color Shape								
Word, Long CSI	58	26	58	22	48	22	31	25
Word, Short CSI	159	23	156	20	128	20	112	22
Letter, Long CSI	83	37	53	33	39	33	49	36
Letter, Short CSI	208	27	176	24	132	24	147	26

Figure 1. Map of countries of participant origin, highlighted in red. Countries of participant origin included Australia, Bosnia and Herzegovnia, Bulgaria, Canada, Croatia, France, Germany, Greece, India, Iran, Ireland, Italy, Japan, Lithuania, Mexico, the Netherlands, Portugal, Romania, Spain, Turkey, Ukraine, United Kingdom, Uruguay, and the United States. Map generated using an online tool at amcharts.com.

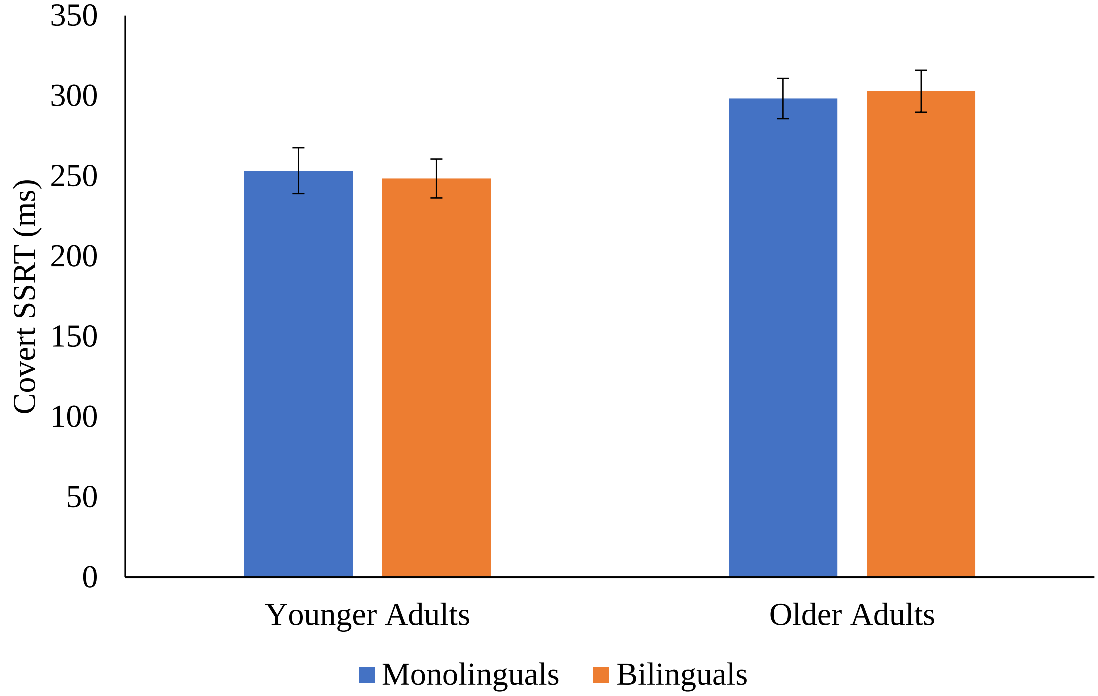

Figure 2. Mean stop signal reaction times (SSRTs) in ms for younger and older monolinguals (MLs) and bilinguals (BLs) on the Stop Signal task. Younger adults had faster SSRTs than older adults, $p < .001$, and no effect of Language Group was found, $p > .99$. Error bars display the standard error above and below the mean.

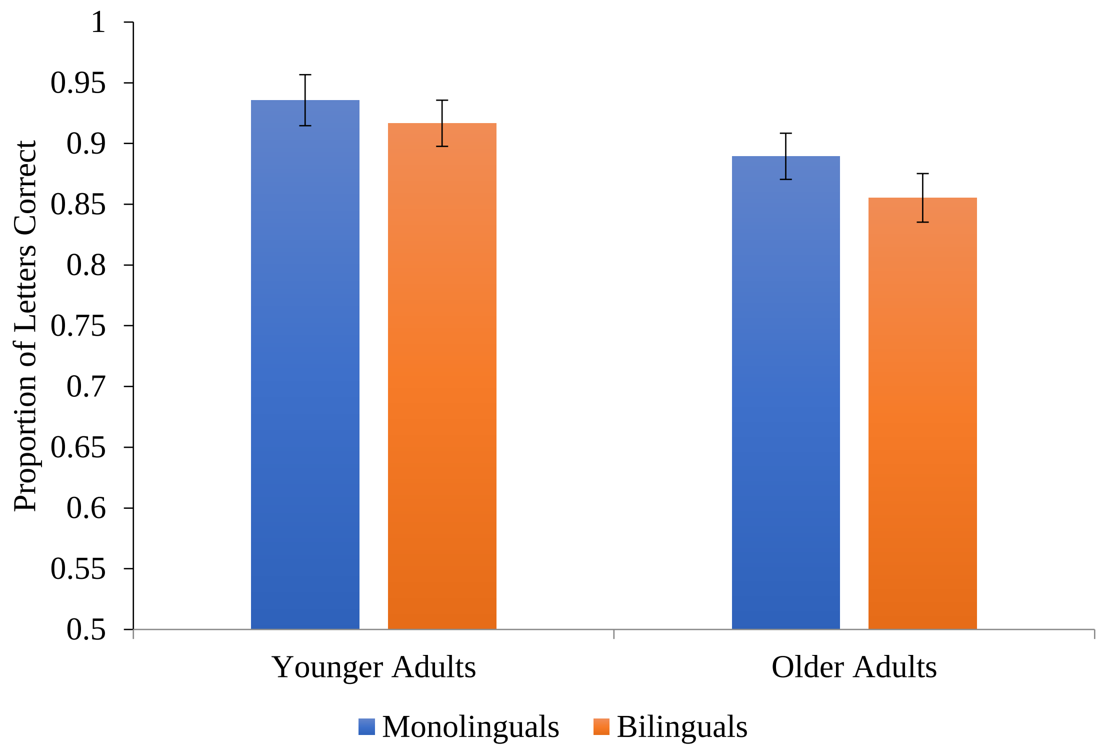

Figure 3. Mean proportion of letters correct for younger and older monolinguals (MLs) and bilinguals (BLs) on the Letter Memory task. Younger adults correctly recalled more letters than older adults, $p < .01$, and no effect of Language Group was found, $p > .10$. Error bars display the standard error above and below the mean.

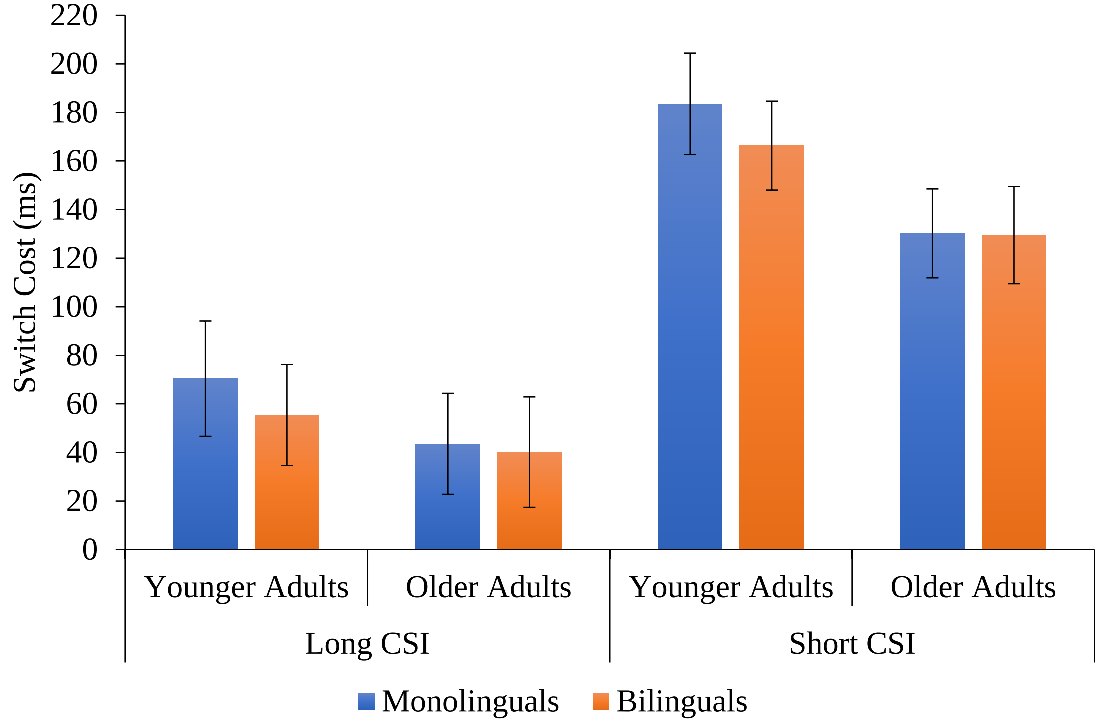

Figure 4. Mean switch costs in ms for younger and older monolinguals (MLs) and bilinguals (BLs) on the Color Shape task. A shorter cue-stimulus-interval (CSI) yielded a greater switch cost, $p < .001$. Older adults tended to have a smaller switch cost than younger adults, though the difference was not significant, $p > .06$. No effect of Language Group was found, $p > .60$. Error bars display the standard error above and below the mean.

Appendix A

Informed Consent Questionnaire

BL Block

Are you bilingual (**fluent** in more than one language)?

- NO
- YES

Fluent in English Block

Are you fluent in English?

- NO
- YES

Age Block

What is your Age?

Consent Form Block

Below is a consent form for the study. Please read and click "yes" at the bottom to continue.
Please note: this study requires your full and complete attention, and will take approximately one hour to complete. If you do not think you can focus only on the study, please return the HIT and do not complete it.

Please enter your Amazon Mechanical Turk Worker ID to confirm that you have read the above document and that you are at least 18 years old.

Your worker ID: ${q://QID4/ChoiceTextEntryValue}

Thank you for consenting to complete our research study. Before we begin, please read the instructions below.

This study will take approximately one hour and includes cognitive/mental tasks that require your direct attention and memory. It is important that you pay attention and concentrate, in order to compete the HIT and have it approved.

The next part of this survey involves several automated tasks **that use Inquisit, which is an online library of mental tasks that has been used on MTurk previously.**

By hitting the next button, you will be redirected to a new page where you will complete the cognitive tasks. Once completed, you will be directed to another short post-survey where you answer some questions about your language experience and other demographic information. All your responses will remain anonymous.

NOTE: Payment for your HIT will only be processed if you complete all of the automated tasks **as well as the survey afterward.**

Appendix B

Institutional Review Board Informed Consent Document

INSTITUTIONAL REVIEW BOARD WKU APPROVED

INFORMED CONSENT DOCUMENT

Project Title: Effects of Language Diversity on Cognitive Functioning in Younger and Older Adults
Investigator: Kaitlyn Weyman; Western Kentucky University, Department of Psychological Sciences, kaitlyn.weyman177@topper.wku.edu

You are being asked to participate in a project conducted through Western Kentucky University. The University requires that you give your agreement to participate in this project.

You must be 18 years old or older to participate in this research study.

The investigator will explain to you in detail the purpose of the project, the procedures to be used, and the potential benefits and possible risks of participation. You may ask any questions you have to help you understand the project. A basic explanation of the project is written below. Please read this explanation and discuss with the researcher any questions you may have. You should keep a copy of this form for your records.

1. **Nature and Purpose of the Project:** The purpose of this project is to investigate correlations between language use and cognition. Effects of age are also being considered.

2. **Explanation of Procedures:** You will be asked to complete a short demographic questionnaire, followed by cognitive tasks that assess aspects of attention or memory, and a conclusive questionnaire. This process will last approximately one hour.

3. **Discomfort and Risks:** There is no foreseeable risk of harm or discomfort; any foreseeable risk is not more than inconvenience or those experienced from normal computer usage.

4. **Benefits:** After passing attention checks, you will receive compensation of $7.50 at the completion of the experiment. You will also get to experience what it is like to participate in a psychology study.

5. **Confidentiality:** Anonymity of the participants will be maintained at all times because personally identifying information is not asked for in the study. Anonymous results may be shared with other investigators.

6. **Refusal/Withdrawal:** Refusal to participate in this study will have no effect on any future services you may be entitled to from the University. Anyone who agrees to participate in this study is free to withdraw from the study at any time with no penalty.

You understand also that it is not possible to identify all potential risks in an experimental procedure, and you believe that reasonable safeguards have been taken to minimize both the known and potential but unknown risks.

Your continued cooperation with the following research implies your consent.

THIS PROJECT HAS BEEN REVIEWED AND APPROVED BY
THE WESTERN KENTUCKY UNIVERSITY INSTITUTIONAL REVIEW BOARD
Paul Mooney, Human Protections Administrator
TELEPHONE: (270) 745-2129

Appendix C

Demographic Questionnaire

Default Question Block

Thanks! We have just a few more questions about your experience with languages. First, please re-enter your MTurk Worker ID. (It needs to be the same one you entered at the start of the study.)

What is your age?

To which gender do you most identify?

- Male
- Female

What is your highest level of education?

Would you consider yourself to be:

- Monolingual
- Bilingual/Multilingual

What language(s) do you know well? (Please list all)

What would you consider to be your home country?

Please write in the first column each language that you are **fluent** in, *including your primary language*.
Then, write in the next three columns the **age** at which you first learned each language in terms of speaking, reading, and writing.
Finally, in the last column, write the number of years you spent learning each language.

		Age first learned the language			
	Language	Speaking	Reading	Writing	Number of years spent learning (cumulative)
1					

	Language	Age first learned the language: Speaking	Reading	Writing	Number of years spent learning (cumulative)
2					
3					
4					

Please rate your current ability in reading and writing for *all* languages **you know, are currently acquiring, or have studied previously** according to the following scale:

	Language	Reading					Writing				
		Poor	Fair	Neutral	Good	Very Good	Poor	Fair	Neutral	Good	Very Good
1		○	○	○	○	○	○	○	○	○	○
2		○	○	○	○	○	○	○	○	○	○
3		○	○	○	○	○	○	○	○	○	○
4		○	○	○	○	○	○	○	○	○	○

Please rate your current ability on speaking and listening for *all* languages **you know, are currently acquiring, or have studied previously** according to the following scale:

	Language	Speaking					Listening				
		Poor	Fair	Neutral	Good	Very Good	Poor	Fair	Neutral	Good	Very Good
1		○	○	○	○	○	○	○	○	○	○
2		○	○	○	○	○	○	○	○	○	○
3		○	○	○	○	○	○	○	○	○	○
4		○	○	○	○	○	○	○	○	○	○

In which language (among your **two best** languages) do you feel you usually do better or feel more comfortable in the following situations? Write the name of the language under each situation.

	At home	At work/school	In a social setting
Speaking			
Writing			
Reading			

Comments Block

Before finishing the HIT, do you have any comments for us based on your experience today? (Optional)