The Relationship between Cognitive Function and Bilingualism in Young Adults

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The study of bilingualism presents itself as a complex one. Within various disciplines, such as linguistics, the investigation of bilingualism has demonstrated societal benefits in academia, the workforce, and cultural relations. When identifying advantages in terms of cognitive function, a small body of research has been produced in the field of neuroscience. The current study aims to determine whether bilingual participants demonstrate higher cognitive functioning by result of their performance on neuropsychological working memory tasks. Thirty-two undergraduate students from the University of Minnesota-Duluth enrolled in the study. Participants were asked to complete various neuropsychological working memory tasks. In conjunction with the tasks, EEG technology was utilized to record the live neural activity of participants by use of facial electrodes and a specialized brain cap. Of the 32 participants enrolled in the study, 14 presented as bilingual and 18 as monolingual. Effectively, results indicate differences in cognitive performance and mental health variables between monolingual and bilingual participants.

Keywords: bilingual, cognitive function, electroencephalogram, neuropsychological

Language is the most significant mode of communication and expression among human beings. With there being over 6,000 distinct languages identified by linguists, it is estimated that 235 million people of the global population are raised in bilingual environments (Anderson, 2010; Crystal, 1997, as cited in Bialystok et al., 2009). Bilingualism offers several benefits in a societal context. Namely, an analysis of published research from 2012 to 2019 illustrates the benefits of foreign language skills relating to individual and community achievements by proposing potential impacts in the development of cross-cultural awareness and communicative competence (Fox et al., 2019). As for the context of benefits in cognitive ability, the advantages of the bilingual mind have been well documented. However, not much research has been conducted on the different levels of language proficiency of acquired bilingualism (Yang, 2017), as these are individuals who learn an initial language and then an additional language later in life. Previously published literature on this topic contributes to the advantages of bilingualism; however, whether there is a definitive difference in cognitive function remains debated among researchers.

Distinctions between Bilingualism and Monolingualism

Differences between bilingual and monolingual individuals are distinct; the number of languages they speak determines their classification. While monolingualism is easily described as the practice of having or using only one language (Khan, 2011), bilingualism is considered subjective within the linguistic research community. No standard definition of bilingualism has been established, thus making it difficult to directly compare the results of different studies (Anderson et al., 2019). According to Javan and Ghonsooly (2000), bilingualism can be best categorized into two groups: *natural*, when a language is learned from speakers around an individual, and *acquired* when a second language is learned within a classroom context with little chance to practice outside of the said environment. Meanwhile, Hamers & Blanc (2000) contribute to the categorization of bilingualism by suggesting that it holds dimensionality in its meaning as there is no clear nor agreed-upon definition. They refer to bilingualism as the state of a linguistic community in which two languages are in contact and can be used in the same interaction. Both Javan and Ghonsooly (2000) and Hamers and Blanc (2000) allude to the

understanding that bilingualism occurs in the usage of a language in societal contexts. Additionally, it must be understood that within bilingualism lies the concept of *bilinguality*, the psychological state of an individual who has access to more than one linguistic code as a means of social communication (Hamers & Blanc, 2000). The authors made a distinction between the two by referring to the effect of language contact on an individual as *bilinguality* and the effect on society as a whole as *bilingualism* (Hamers & Blanc, 1983; as cited in Hamer & Blanc, 2000). Per the previously mentioned definitions of bilingualism, the current study determined the bilingualism of participants using a measure that considers the frequency of language use and overall use in social contexts. The overall goal of this measure is to determine the bilinguality of participants through the effects that bilingualism had on their cognitive function.

Regarding bilingualism and monolingualism, both possess advantages over the other. For instance, the ability to direct one's attention despite distractions, results from practices in controlling and switching between two activated languages among bilinguals, thus strengthening cognitive flexibility (Yang, 2017). Meanwhile, findings from numerous child-language studies indicate that monolingual children possess a larger vocabulary learned in a single language in comparison to bilingual children, who typically possess smaller vocabularies in each language (Bialystock, 2009). Additionally, researchers suggest linguistic and nonlinguistic processes as consequences of bilingualism (Bialystock et al., 2012; Kroll et al., 2012). Bialystock and colleagues (2012) recognize the consequences of linguistic processes as a product of attention problems created by joint activation, which is not seen in monolinguals. The attention problems present in bilinguals include linguistic dimensions of register, collocation, and synonymy of their target language (Bialystock et al., 2012). As for consequences in non-linguistic processes, Kroll and colleagues (2012) recognize the presence of cross-language interactions from the parallel activation of the native and secondary language. Uncommonly, these interactions are observed in the influences made by a secondary language on a native language (Kroll et al., 2012). The investigation of differences between the two language groups is of popular interest, specifically in terms of cognitive ability. Although consequences of bilingualism may be present, bilinguals appear to gain high levels of skill, associated with executive functions recruited during language selection, through cross-language competition resolution (Kroll et al., 2012).

Understanding Cognitive Function

When investigating cognitive abilities of mental processes, it is important to be specific about which cognitive abilities are being investigated as there is not one single pattern of intellectual functioning (Schaie, 1994). Cognitive function refers to the performance of mental processes including perception, learning, memory, understanding, awareness, reasoning, judgment, intuition, and language (American Psychological Association, 2023). Originally, psychometrics addressed how well cognitive information processing measures individual differences through measurements of reaction time tasks assessing cognitive ability (Roznowski, 1993). However, Roznowski and colleagues (2000) note that these measurements of human cognitive ability have dramatically evolved over decades of research on individual differences. Advancements in psychometrics today consider factors like intellectual ability and cognitive attributes such as perception, memory, and reasoning (Roznowski et al., 2000). Findings from studies assessing cognitive function with neuroimaging tools have indicated that increases in neural signal complexity are associated with greater information processing capacity and knowledge representations (Grundy et al., 2017a). This heightened information processing capacity could suggest advantages amongst individuals who have greater cognitive ability performance. Additional studies discussed by Grundy and colleagues (2017a) have indicated that bilingualism has led to brain reorganization that delays cognitive decline in the elderly, including Alzheimer's disease. As mentioned previously, the bilingual mind has been well documented in several different areas of focus, from social interpersonal interactions to differences and similarities between language groups regarding cognitive abilities. However, research is limited on how bilingualism truly affects cognitive function.

The relationship between levels of neural activity and cognitive functioning implores further

investigation into a possible connection with bilingualism. Research has shown a greater cognitive efficacy among bilinguals regarding increased brain signal complexity, disengagement ability during switch tasks, and high working memory capacity (Grundy et al., 2017a; Javan & Ghonsooly, 2018; Yang, 2017a). In addition, the need to process and manage two languages simultaneously requires a high function of the brain that holds, manipulates, and processes temporary information needed to accomplish various tasks at any given moment, effectively supporting bilingual advantages (Yang, 2017). Learning and regularly using a second language is an intense experience that has the potential to lead to a domain-general cognitive adaptation, suggesting that the linguistic conflict could enhance executive control (review in Bialystok, 2017; Grundy et al., 2017c).

Interactions between Bilingualism and Cognitive Function

The cognitive benefits of the bilingualism are outstanding regarding various areas of problem-solving, metacognitive awareness, divergent thinking, and attention control (Bialystok et al., 2017; Grundy et al., 2017a, b, c; Javan & Ghonsooly, 2018; Yang, 2017). In a study conducted by Javan & Ghonsooly (2018), the constant engagement of the bilingual experience was shown through the management of two languages and the concentration required to communicate efficiently. The authors suggest that with two simultaneously active language systems at their disposal and communicating efficiently, bilingual individuals need to concentrate on the target language system and inhibit the interference of the non-target one. Similarly, Grundy et al. (2017c) found that the ability to manage two languages simultaneously produces constant activity to some degree by creating a situation in which bilinguals must continually manage their attention to the target language and avoid interference from the other. Results from a separate study further support the existence of disengagement between languages, as the bilingual participants possessed a greater ability to disengage their attention from a previous trial to focus their attention on a current trial (Grundy et al., 2017b). Their research has found that bilingual individuals generally appear better equipped to modulate functional connectivity as compared to their monolingual counterparts, specifically during task-evoked brain activity in brain regions involved in error detection, attention, shifting, and focus (Grundy et al., 2017b). In a culmination of the mentioned literature, the collation between Javan & Ghonsooly (2018) and Grundy et al. (2017 b & c) emphasize and define both the experience and necessity of disengagement that bilinguals demonstrate.

The Current Study

The primary goal of this study is to further contribute to the literature in this area of research, while simultaneously expanding upon the connections between cognitive function and bilingualism. As the literature has shown the performance of bilingual children and older adults in cognitive functioning tasks, this study aims to investigate this relationship in young adults. With an investigation of the cognitive abilities of monolingual and bilingual individuals, the cognitive performance of participants during memory tasks was examined by factors of speed, accuracy, and electrophysiology. Three hypotheses were tested with the expectation that the bilingual participants will demonstrate a greater performance of cognitive function as compared to the monolingual participants:

1. Differences between monolingual and bilingual participants will exist in cognitive performance.
2. Monolingual and bilingual participants will differ in measures of neurophysiology recordings.
3. Monolingual and bilingual participants will exhibit a difference in mental health variables.

Methods

Participants

The participants were 32 (20 male and 12 female) undergraduate students from the University of Minnesota Duluth (UMD). Of the 32 participants in the current sample, 43.8% were classified as bilingual. Classification of the experimental group was calculated using the *Language Social Background Questionnaire* (Anderson et al., 2019). The demographics of participants were primarily Caucasian (78.1%). Other ethnicities represented in the study include Hispanic (12.5%) and a

combination of multiple ethnicities (9.4%). The age range of those enrolled in the study was 18-24 years old. The sample was composed of 37.5% first-year students, 34.4% second-year students, 15.6% third-year students, and 12.5% fourth-year students who were all undergraduate students attending the University of Minnesota-Duluth. All participants were recruited for the experiment via SONA, an online research recruitment tool, approved IRB flyers on the university's campus, and word of mouth. Experimental procedures were conducted in fulfillment of an Undergraduate Research Opportunity Program (UROP) award and approved by the Institutional Review Board (IRB) at the University of Minnesota.

Design and Materials

Prior to the in-lab session, participants were invited to take part in a screening interview to determine eligibility for the study. During the 5–10-minute screening interview, participants were asked various demographic questions as well as several health-related questions. Eligibility to participate in the study were as follows: 18-24 years of age, 11-17 years of education, and the proficient ability to read and speak English, regardless of assigned group. Once screening interviews were completed, eligible participants were read the consent form to inform them of the study details and their rights as a participant. After participants were Given the chance to read through the consent form themselves, those who continued with participation signed the document along with the research, claiming responsibility. Participants were then instructed to complete several questionnaires and tasks during the lab session:

Language and Social Background Questionnaire (LSBQ): The LSBQ was used to determine which group participants would be assigned. The LSBQ assesses the degree of bilingualism of an individual through the following three sections: Social Background, Language Background, and Community Language Use Behavior.

Mental Health Inventory (MHI): This questionnaire measures several domains of mental health including anxiety, depression, behavioral control, positive affect, and general distress. In addition, the MHI provides necessary data to determine whether the participants are, or are not, sample representatives of our target population.

Digit Symbol Substitution Test: This visual task was administered as a measure of cognitive range and working memory. The participants of this study were instructed to match symbols to numbers according to a key located at the top of their paper. They would then copy the symbols into spaces below, matching them with their coordinating number.

Trail Making Test A & B: A neuropsychological test involving the visual scanning and working memory of participants, the TMT requires participants to draw a line between 24 consecutive circles that are arranged on a page, randomly. The TMT-A uses only numbers, while the TMT-B alternates between both numbers and letters. The performance of participants is scored by their speed and accuracy. This measure provides an assessment of complex attention.

Shipley Institute of Living Scale-Revised: This test assesses mental processes through the comparison of vocabulary and abstract thinking. The SILS-V consists of 40 questions asking participants to circle one word out of four that is most synonymous with the target word. The SILS-A consists of 20 items instructing participants to fill each blank at the end of a line with either a letter or number to complete the presented pattern.

EEG Visual Oddball Task: The Visual Oddball Task is a computer task that presents sequences of repetitive stimuli infrequently interrupted by a deviant stimulus. This task was used to measure speed and accuracy among participants.

Participants' neurophysiological responses were recorded with EEG technology. The data was recorded using a 32-channel ActiCHamp System (ActiCHamp Brain Products). Ag/AgCl electrodes were placed over prefrontal, frontal, temporal, central, occipital, and parietal sites (10/20 montage). Brain signals were recorded via BrainVision ActiChamp Recorder system software in response to task stimuli elicited by E-Prime software. The ground electrode (Fpz) was placed at 10% of nasion to inion measurement. Eye blinks were also recorded

by Ag/AgCl electrodes placed above and below the right eye (eye blink detection) and near the outer canthi of both eyes for horizontal eye movement (AntiCHamp, Brain Products, Inc.). Signals were processed offline using Brain Vision Analyzer software. The EEG recording and its setup took less than 30 minutes to complete. Participants were talked through the setup process and allowed to ask questions if they had them. In the hundreds of EEG recordings completed using the ActiCHamp system, participants tolerated the EEG setup and subsequent EEG recordings well. Importantly, participants viewed the Oddball paradigm (E-Prime software) on a separate computer screen. Participants did not view the EEG recording during the experimental session.

Procedure

This study utilized Electroencephalogram technology to assess the complexity of brain signals between monolingual and bilingual participants to investigate their cognitive function during memory tasks to determine whether there was a significant difference between the two groups. Before the screening visit, participants were instructed to contact the laboratory researchers via email. Participants consented via a verbal script at the beginning of the screening visit. At the end of the verbal script, participants indicated voluntary participation or indicated they are no longer interested. Screening questions were administered online via Qualtrics, and the Student Investigator read screening questions aloud. Participants typed their responses (not visible to the Student Investigator). Screening interviews (~15 minutes) were reviewed by the PI to determine participant eligibility for the study. Eligible participants were invited to participate in the laboratory session. After consent, they then were asked to complete a demographic survey, the Language and Social Background Questionnaire, and the Mental Health Inventory. Once completed, participants moved on to the working memory tasks in which brain activity was recorded via an EEG. The working memory tasks included the Digit Span Test, Trail Making Test, Shipley Institute of Living Scale-Revised (Shipley-2), and the Visual Oddball Task. After, the participants were provided a resource sheet and the session ended. Laboratory duration (~60-80 minutes). Consistent with laboratory protocol, all surfaces (e.g. table, keyboard, door handles, etc.) were cleaned before and after all participant interactions by Student Investigator. Disinfecting Clorox wipes, or disinfectant Lysol spray were used, according to the label instructions. A HEPA air-filtering unit was also used in the laboratory space.

Results

Demographics

Of the 32 participants used in the sample, 37.5% were female and 62.5% were male. The age range of participants was between 18-24, with the average age of 19.47 years (SD = 1.565, range = 18-24). Of this sample, 37.5% were first-year students, 34.4% were second-year students, 15.6% were third-year students, and 12.5% were fourth-year students.

Hypothesis 1

The hypothesis that differences between Monolingual and Bilingual participants will exist on cognitive performance, was assessed using a Pearson *r* Correlation statistical analysis. As shown in Figure I, findings indicate a greater beta spectral power in correlation with quicker reaction time, $r = -.485$, $p < .01$. In addition, an Independent Samples *t*-test was utilized to compare the performance of each group's cognitive measures. Findings suggest a non-significant difference in the performance of Monolingual participants in the TMT-B Accuracy measure, $p = 0.56$.

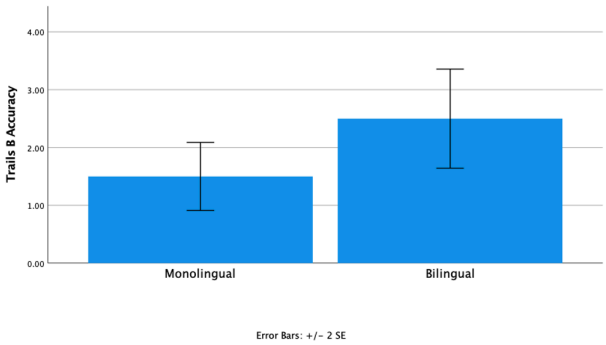

Figure I. Accuracy of TMT-B in control (monolingual) and experimental (bilingual) participants. Fewer errors made by participants equated with greater accuracy. Group differences were not significant, $p = .56$.

Hypothesis 2

The hypothesis that monolingual and bilingual participants will differ on measures on neurophysiology recordings, using an Independent Samples *t*-test, exhibited non-significant findings during baseline and tasks, $p = .216$.

Hypothesis 3

The hypothesis that monolingual and bilingual participants will exhibit a difference in mental health variables, using an Independent Samples *t*-test, resulted in counterintuitive findings. The bilingual participants demonstrated marginally higher anxiety scores ($M = 14.00$, $SD = 2.69$) as compared to monolingual participants ($M = 11.22$, $SD = 4.78$), $t(30) = -1.947$, $p = .061$. Looking at factors contributing to anxiety levels, a Chi-square statistical analysis was used to analyze sex differences, and no significance was found. The percentage of participants with greater anxiety scores did not differ by gender, $X2(30, N = 32) = .034$, $p = .854$.

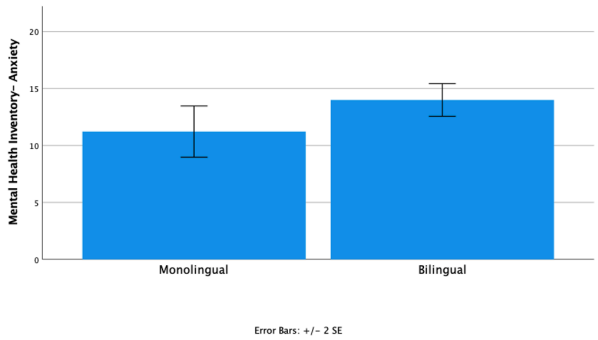

Figure II. Self-reported anxiety in control (monolingual) and experimental (bilingual) participants. Experimental participants had greater self-reported anxiety as compared to controls, $p = .061$.

Discussion

Findings

The functions and influences of the mind have been greatly explored, however still, little is known regarding its cognitive relationship with language. In this study, the prospect of higher cognitive functioning as a result of bilingualism was explored. With the use of several neuropsychological tasks and EEG recordings of brain activity, connections between cognitive function and Bilingualism were tested.

Concerning the first hypothesis, findings suggest a correlation between greater beta spectral power and quicker reaction time. Comparisons in task performance were statistically tested, and contrary to expectations, performance of monolingual participants were marginally higher than those of bilingual participants in terms of task accuracy with the TMT-B, $p=0.56$.

While looking at spectral power differences in the second hypothesis, a change in beta and alpha power during baseline recording was expected. Although, findings suggest no significant change will occur in beta and alpha from the baseline recording to tasks between bilingual participants versus controls. Statistical analysis showed a greater beta spectral power was negatively related to the TMT-B speed assessment. Effectively, the existence of covariation of spectral power was demonstrated, further suggesting that beta is linked to greater attention (Gola et al., 2013).

Earlier citations reference the difficulty of divided attention tasks for bilingual individuals (Bialystock et al., 2012). A possible explanation for this could be the result of the anxiety experienced by bilingual participants in the current study. The effects bilingualism has on anxiety was found to be counterintuitive with bilinguals exhibiting higher levels of anxiety as compared to monolinguals. Several theories could explain this finding: age, race/ethnicity, and bilingual type. More specifically concerning bilingual type, the constant disengagement between the participants' native and target language may be responsible for this influence; further research is needed in support of this theory.

Conclusion

As research has shown bilingualism to promote problem-solving, metacognitive awareness, divergent thinking, and attention control, results from the current study question the notion of bilingualism supporting cognitive function. Findings exhibited a correlational between cognitive function and language groups through cognitive performance on neuropsychological tasks and neurophysiological recordings of brain activity. Although more research is necessary, our findings contribute to the limited existing literature in hopes of further understanding the bilingual experience.

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