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Comparing Verbal And Spatial Working Memory In Monolingual And Bilingual Speakers

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41 Pages

The bilingual advantage has been demonstrated in different domains of cognitive functioning, especially executive functioning. Compared to other domains of executive functioning, the impact of bilingualism on working memory in children and adults has received relatively little attention. Moreover, research on the bilingual advantage in young adults has produced mix results in tasks where working memory is required. The present study examined whether bilingual expertise yielded different results depending on the working memory task. The present study included 54 participants, 44 identified as female and 10 identified as male. Spatial working memory was measured using the computerized spatial span task (C-SST). Verbal working memory was measured using the backward digit span. It was hypothesized that bilingual speakers would outperform monolingual participants in the verbal and spatial span tasks. The results of the present study did not support the hypothesis. There were no differences between bilingual and monolingual speakers in the verbal or spatial task. There was a small correlation between performance in the verbal and spatial working memory tasks. This relation was attributed to similar cognitive processes associated with working memory tasks (Miyake et al., 2000).

KEYWORDS: Bilingualism, working memory, spatial working memory, verbal working memory

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CONTENTS

TABLES

CHAPTER I: INTRODUCTION

Background

The beginning of the research in the field of bilingualism was plagued by bias and inadequate tasks (Gould & Goodenough, 1926; Saer, 1923). The erroneous belief that learning a second language led to intellectual disabilities (Gould et al., 1926) and confusion (Saer, 1923) can explain some of the negative connotations associated with bilingualism. When Saer (1923) published his findings, it was already assumed that having two languages created a cognitive disadvantage. His findings indicated that bilingual children were less intelligent than monolingual children. These conclusions increased the existing negative stereotypes of being bilingual (Saer, 1923).

However, the assumption that bilingual children were less intelligent than monolingual children was flawed. Saer (1923) used an IQ test as a measure of intelligence, and linguistic ability was not measured. Bilingual status was measured based on participants' last names. Socioeconomic status (SES) variables were not controlled. His participant pool included immigrant children with low SES and high SES monolingual children, creating a confound (Morton & Harper, 2007). Pearl and Lambert (1962) tested monolingual and bilingual children using nonlinguistic tests. It was found that bilingual children outperformed monolingual children on the majority of the tests. Pearl and Lambert concluded that bilingual children demonstrated mental flexibility. This flexibility was due to bilingual participants switching between the first and second language. This was one of the first studies to contradict the previous views on bilingualism. This study is the source of the idea of a bilingual advantage. The bilingual advantage is defined as enhanced capabilities in executive functions associated with speaking two languages. Contrary to the belief that learning more than one language may cause cognitive confusion (Goodenough, 1926), it has been revealed that exposure to two languages enriches the experience of each language (Bialystok, Peets, & Moreno, 2014). Currently, the benefits of second language acquisition have been further investigated.

CHAPTER II: LITERATURE REVIEW

Executive Functions and Bilingualism

Executive functions constitute a number of metal operations required for goal-directed behavior. One component is cognitive flexibility, which is the capability to switch between mental sets in order to complete a mental operation (Rogers & Monsell, 1995). The ability to switch between tasks appears to be related to cognitive control. The bilingual advantage in the cognitive flexibility domain is well documented in children and adults (Bialystok et al 2005; Costa, Hernández, & Sebastián-Gallés, 2008; Moreno et al 2014). The advantage in this domain extends past linguistic abilities: Switching between Language 1 (L1) and Language 2 (L2) creates an advantage attributed to mental control of stimuli, broadly construed.

Mental switching is created by the necessity to switch between two mental domains (Prior & MacWhinney, 2010). Regardless of the type of stimuli presented, cognitive control is required in order to switch between mental tasks to perform the task at hand (Monsell, 1996). Similar to bilingual experience, one must disassociate the unintended task and switch involvement to the intended task. When individuals are asked to switch from a prior mental rule to a new mental rule, they must select the correct rule in order to appropriately perform at the mental task at hand (Miyake et al., 2000). To perform the new operation, individuals must overcome the interference created by preforming based on the prior rule and perform based on a new rule instead (Bialystok, 2017). Hence, individuals must be able to perform the operation in the face of the interference of contradicting commands. Bilingual speakers must be able to speak based on the environment-intended language and disengage the unintended language. In order to do so, bilingual speakers must be able to prevent linguistic interference between L1 and L2. Prior et al. (2010) examined the ability of college students to switch between mental tasks. Using a non-linguistic paradigm, participants completed two mental switching tasks which measured local and global costs. It was found that bilingual speakers demonstrated reduced switching costs compared to monolingual speakers. To this extent, bilingual speakers avoided proactive inference created by the previous response in the cued-switching task. Most importantly, bilingual speakers were able to resist interference between conflicting responses due to interlacing rules. Hence, the findings supported the notion that switching between two languages is similar to switching between two mental sets, and bilingual experience enhanced cognitive flexibility abilities in bilingual speakers. This recent work in the bilingual field has expanded the mental flexibility advantage to young adults as well as children.

Another component of executive functioning is inhibition, which is the ability to suppress an automatic response in order to respond to a different characteristic of the stimulus (Miyake et al., 2000). Green (1998) proposed that bilingual speakers inhibit competing non-target language using inhibitory control. When bilingual speakers are using language systems, the unintended language must be inhibited in order to avoid linguistic interference. Inhibitory control allows speakers to select and use the target language without being influenced by representations of the non-target language. Inhibitory control of the non-target language is one of the most dominant aspects of the bilingual advantage (Bialystok et al., 2009; Bialystok, 2017). Miyake et al. (2000) proposed a model of executive functions that included an inhibition model that deliberately controls the levels of activation of competing responses. The ability of bilingual children to inhibit irrelevant information was observed in the Computerized Dimension Change Card Sort (CDCC). By the age 3 and 4 years, children can distinguish between two languages, which enhances inhibitory control, ignoring irrelevant information and focusing attention on the target (Bialystok & Shapero, 2005).

A third component of executive functioning is working memory. It is important to remember relevant information about any task. Subsequently, the significance of working memory and bilingual experience is another component of understanding the bilingual advantage. In order to complete a task with conflicting responses, individuals must update information related to the task while also monitoring information about the task at hand (Morris & Jones, 1990). Relevant information about the task must be held in working memory (Miyake et al., 2000). In tasks where participants must remember more than one rule, bilingual speakers have demonstrated better performance compared to monolingual speakers. For example, Hansen et al. (2017) examined how experience impacted working memory in monolingual children engaged in an immersion program. It was found that emergent bilingual participants outperformed monolingual participants in memory and reasoning tasks. Similarly, college students taking a second language over an 8-week period had different neurological imagining results compared to their monolingual counterparts. Hence, bilingual experience, even for brief periods of time, results in differences when asked to hold information to provide the correct responses in a go-no go task.

Bilingualism and Cognitive Flexibility

Bilingual speakers switch between L1 and L2 frequently, creating an advantage in the task switching domain, sometimes called cognitive flexibility. An advantage in this domain reflects benefits that extends past linguistic abilities. Cognitive flexibility is created by the necessity to switch between two mental domains (Bialystok et al., 2005; Costa, Hernández, & Sebastián-Gallés, 2008; Prior & MacWhinney 2010). Bialystok and Shapero (2005) examined the ability of children to reverse mental pictures of ambiguous figures. Children were presented with figure-ground and content meaning figures. The task required children to point out differences in the figures presented. Also, flexibility was examined using the Computerized Dimension Change Card Sort (CDCC). Children sorted cards based on separate dimensions (color or shape). Children classified the cards according to one dimension and later classified the cards using another dimension. First, the card was presented in the middle of the screen and the children had two choices that were located at the bottom of the screen. In the pre-switch condition, all the cards were matched to one dimension. For instance, the red heart appeared with the red heart (color game). In the shape game, the green stars appeared with the green stars. In the post-switch dimension, the red stars appeared with green stars (shape game). Bilingual participants outperformed monolingual in the post-switch condition, demonstrating superior cognitive flexibility. Bilingual children also were better at pointing out the differences of the figure-ground figures. This ability was attributed to the capability to reverse the features of the figure-ground figures. Such ability requires participants to switch between mental sets. During the CDCC, sorting the cards during the post-switch phase required the children to switch to the other dimension, activating the new criteria and inhibiting the previous criteria. Bilingual participants' performance in both tasks demonstrated that managing two language systems enhanced cognitive flexibility abilities.

Likewise, Moreno et al. (2014) investigated brain signaling and engagement during task switching by comparing brain functionality among monolingual speakers, bilingual speakers, and musicians. Using a go-no go task, it was demonstrated that bilingual speakers and musicians exhibited an advantage when presented with conflict. Similar to bilinguals, music training also engages working memory, inhibitory control, selective attention, and task switching. The experiment involved scalp recording of event-related potentials (ERPs). Participants completed a task-switching assessment. The go-no go task involved answering to pictures under specific rules. Participants responded to shapes based on color (white or purple). Due to the conflicting choices in the no go section of the task, researchers hypothesized that these trials would increase the N2 and P2 amplitudes. The importance of the N2 and P2 amplitudes are related to top-down influence of the predispositions. Greater P2 amplitudes were associated with neural representations of the stimuli. Greater N2 amplitudes were associated with the registration of the conflicting responses. Hence, N2 amplitudes were related to complexity of the task, whereas P2 amplitudes were related to latency of the task.

The behavioral responses of the go-no go task for the three groups (musicians, bilinguals, and control) were equivalent. However, different neural responses were evident. More specifically, bilinguals produced larger N2 amplitudes than the control or musician group. On the other hand, musicians produced much smaller amplitudes of N2 than the control group. Musicians also demonstrated larger amplitudes in P2 responses. This demonstrated musicians' ability to create representations in relation to the content of the task at hand. The large amplitudes of N2 in bilingual participants also manifested the conflict between possible responses (L1 and L2 language systems). There were no differences in increases of P3 amplitudes, suggesting a lack of specificity in the inhibitory control of bilingual speakers.

The expertise related to bilingualism and musical training activated different brains networks in relation to conflict in the go-no go task. This indicated that bilingual speakers were more skilled in detecting the possible answers between the two language systems and then resolving the issue at hand. Musicians, compared to the other two groups, demonstrated the biggest differences at the early part of performance. In contrast, bilingual participants, compared to the other two groups, demonstrated the biggest differences at the later part of the task. Musicians' performance in the go-no go task was associated to enhanced representations by visual, auditory, and motor systems due to musical training. Bilinguals' performance in the go-no go task was associated with life experiences of two active language systems, which created greater expertise of inhibiting non-target responses. Their bilingual experience allowed bilingual participants to detect interference. Subsequently, inhibitory control allowed a resolution when faced with conflict. Therefore, the unique experience created by musical training and bilingualism can be traced to functional brain organization.

Bilingualism and Inhibitory Control

Bilinguals' usage of Language one (L1) and Language two (L2) creates skilled inhibitory control. When bilinguals employ L1, they must ignore the demands of L2 (Gollan & Kroll, 2001). To this extent, language processing influences a high level inhibitory control. Since both L1 and L2 are constantly active, bilinguals become experts at selecting the intended language when there is an alternative system available. This system known as language control allows for inhibition as well as task-switching. Inhibition of L1 or L2 is due to the intent of the target language. Early bilinguals have more life experience with inhibiting the non-target language, whereas late bilingual need to strongly inhibit L2 due to dominance of the previously mastered L1 (Bak, Vega-Mendoza, & Sorace, 2014). Bialystok and Shapero (2005) investigated the relation between bilingualism and of inhibitory control using the Opposite World Task. In this task, children counted the times a pig or a cow appeared on a farm road-strip. In the first condition, the cow and pig were named as soon as they appeared. In the second condition, the farm was turned upside-down, and the children named the animals with the opposite name (pig was a cow and vice versa). Children inhibited the previous and logical animal-name relation to answer the new paradigm. Bilingual children outperformed monolingual children in this task. The authors interpreted the findings by noting that bilingual children were demonstrating inhibitory control when there were two possible answers (pig as a pig or pig as a cow). Bilingual children's ability to switch between L1 and L2 depending on circumstances and intent of speech strengthens the ability to name items in the pig-cow paradigm. Therefore, the ability to inhibit distracting information and focus on the target in this the task was enhanced by bilingual experience.

The domain-general characteristics of language activation in two systems may also facilitate the ability to direct attention to the target language. Bilingual speakers must select the correct language based on the target language of a particular environment, demonstrating attentional control. Bak et al. (2014) conducted a study where they examined attentional control using auditory stimuli in late bilingual young adults. In addition, late bilinguals' level of expertise in L1 introduced new complexities compared to previous studies with early bilingual speakers as a sample. The Elevator Task 2 was used to examine selective attention, and the Elevator Task 3 to examine attentional switching. In the Elevator Task 2, participants heard an array of low and high tones. Participants needed to ignore the high tones and only count the number of low tones. In the Elevator Task 3, participants listened to three tones (low, medium, high). Participants only counted the middle tone according to the prior tone, when the previous tone was a high tone, the participants counted up, and when it was a low tone, the participants counted down. In this instance, they had to use selective attention as well as attentional switching. It was found that early bilinguals outperformed monolinguals in the Elevator 2 Task. Early bilinguals, who learned L1 and L2 before the age of 6, have extensive experience switching between the two language systems. This skill is exercised in selective attention tasks such as the Elevator 2 Task. Late bilinguals, who learned L1 and L2 between 15 and 19 years old, outperformed monolinguals in the Elevator 3 Task. Late bilinguals needed to control irrelevant information, inhibiting L1 when using L2 and the other way around. Moreover, since late bilinguals consolidated L1 before learning L2, they must demonstrate stronger inhibition control of the more recently acquired L2. This causes greater inhibitory control in late bilinguals. The performance of early and late bilinguals exhibited different cognitive advantages due to inhibition and attentional switching. To this extent, the experiences fostered as a bilingual speaker in late bilinguals enhanced their cognitive abilities.

Bilingualism and Working Memory

To further examine the impact of bilingualism and working memory, Morales, Calvo, and Bialystok (2013) studied working memory in elementary school children using two experiments. The first experiment used the Simon task. This task was designed to expose children to conflict. The conflict is created by holding two or four rules while completing the task, requiring inhibition and shifting. To reduce linguistic demands, a visuospatial task was administered. The Simon task consists of answering the target stimuli while ignoring the location where the stimuli is presented. In this version of the Simon, the stimuli consisted of a red heart and a purple flower. There were two conditions: the non-conflict and the conflict condition. In the non-conflict condition, stimuli were presented in the middle of the screen and participants answered according to the coordinate of each individual stimuli. A red heart was coordinated with the right key and the purple flower with the left key. Since the spatial location of the stimuli was consistent, there was no conflict between stimulus and response. The conflict condition required participants to remember the type of stimuli presented while ignoring the location. The red heart and the purple flower were presented on the right or left side of the screen. A red heart located on the right side of the screen and the key to press was located in the right side constituted a congruent trial. A red heart located on the left side and the key to press is located in the right side constituted an incongruent trial. Participants ignored where the stimuli were presented and answered according to the coordinates previously learned. Participants needed to inhibit the non-target rule (lateral location) in order to focus on the rule presented at each trial.

The second experiment examined visuospatial working memory measured by a span task. The span task consisted of a Corsi block task. In this version, the stimuli were frogs presented on a touch screen. There were two conditions: sequential and simultaneous. The sequential condition presented more complex demands because the child needed to remember the order the frogs were presented as well as the location of each individual frog. In the simultaneous condition, a group of animated frogs were presented at the same time, and the child recalled the spatial locations. In the easiest condition, younger bilingual children performed at the level of older monolingual children. However, the interesting result was regarding the most difficult conditions. Bilingual children outperformed monolingual children in the conditions where other executive functions, such as inhibition and shifting, were also required. In the Simon task, bilingual children outperformed monolingual children in conflict and non-conflict conditions. In the Corsi block task, bilingual children outperformed monolingual children in the sequential and simultaneous conditions. The main effect of language group in both tasks demonstrated that the bilingual enhancement advantage is independent of other task demands. Bilingual children outperformed monolingual children in the Corsi Tapping Task and Simon task. Thus, bilingual children demonstrated an advantage on visual spatial working memory based on the performance of the Corsi tapping task.

The bilingual advantage was observed in elementary aged children, therefore if the same language systems remain in place throughout adulthood, the same advantage should be observed in adulthood. Wodniecka, Craik, Luo, and Bialystok (2010) investigated the impact of bilingualism on memory among young and older adults. Two studies were designed to examine differences by age (young adults and older adults), bilingual and monolingual groups, and verbal and spatial working memory tasks. In the first study, the Corsi Block test and digit span task were administered to examine visual-spatial and verbal working memory, respectively. Two recognition tasks also were administered to examine verbal and non-verbal memory.

The Corsi Block test measured visual-spatial working memory. Blocks were spatially arranged on a board located between the experimenter and the participants. There were two trials per set size of blocks. The researcher tapped the blocks starting with two blocks then the participants repeated the sequence. Set sizes increased until participants failed at one of the two trials. There were two conditions, forward and backward. In the forward condition, the participant repeated the sequence in the same order as the researcher. In the backward condition, the participant repeated the sequence in the opposite order of the researcher. Verbal working memory also was measured using the forward and backward digit span task (Wodniecka et al., 2010).

The results for the Corsi Block test demonstrated no significant differences between monolingual and bilingual participants; however, there was a significant difference between age groups: young adults had higher memory span scores in both conditions compared to older adults. In the digit span task, young adults had higher memory span scores than older adults. Older monolingual speakers had higher span scores in the forward digit span than older bilingual speakers. This bilingual disadvantage may be a result of lower proficiency in L2. In the backward condition of the digit span, there were no significant differences between bilingual and monolingual speakers. Higher demands associated to the backward condition could be an explanation for the equivalent performance between bilingual and monolingual speakers in the backward condition. Bilingual speakers compensated the demands required in this condition by depleting executive control abilities required when speaking L1 and controlling the demands of L2 or vice versa (Wodniecka et al., 2010).

The verbal memory task consisted of a recognition task. In this task, participants were asked to recall whether they recognized the word presented as seen before during the task by answering “yes” or as a new by answering “no.” A total of 120 words were used during the study phase and 140 in the test phase. Presentation of words was counterbalanced between conditions by repeating the new items at different distances (lags) between lists. In this task, the lags consisted of 3, 12, 24 and 48. The non-verbal task consisted of a recognition task using face stimuli. Participants were presented a total of 220 pictures with lags of 1, 2, 4 and 12. Similar to the verbal memory task, the non-verbal task entailed a study phase and a testing phase (Wodniecka et al., 2010).

The results of the of verbal memory task demonstrated that older bilingual speakers demonstrated lower accuracy scores on lag 12 compared to older monolingual speakers. In the non-verbal task, there was a trend regarding bilingual speaker’s memory scores. Older bilingual speakers had significantly higher recollection scores for lag 12 compared to older monolingual speakers. The bilingual disadvantage in the verbal memory task is attributed to verbal responses required in this task. The results of non-verbal memory task support a bilingual advantage in the most difficult (lag 12) memory condition for older bilingual speakers (Wodniecka et al., 2010).

The second study was designed to further investigate the more prominent advantage in the non-verbal memory task and bilingual drawback due to verbal material in the verbal memory task. In this study, the number of items between the testing and the study phase was decreased, and for the non-verbal task, abstract stimuli were presented instead of faces. To measure spatial working memory, a matrix span task was administered. The stimuli consisted of dots presented sequentially in a 5 x 5 matrix, and participants were asked to recall the spatial location of the dots. Trials began by presenting two dots and gradually increased to 7 dots. There were 2 sequences per trial for a total of 12 trials. Working memory was measured by the number of correct sequences the participants recalled measured by obtaining at least one correct sequence per trial. Results of the matrix span task demonstrated higher scores for young adults but no differences between language groups (Wodniecka et al., 2010).

In the verbal memory task, during the study phase participants observed 60 words and 40 new words. Words were presented during four lags of 1, 2, 4, and 12. During non-verbal memory task, participants were asked to remember abstract items. Participants were asked to determine whether the abstract item presented was studied before or the item was new. A total of 62 items was presented, including 18 critical items studied beforehand and 8 fillers. New items were categorized intro 3 groups and presented in three lags of 1, 2, and 4 (Wodniecka et al., 2010).

The analysis of memory scores revealed a significant three-way interaction of age group, lag, and language group. In order to further explore this effect, an ANOVA test was conducted, which indicated a significant main effect of lag type. For the older bilingual speakers, there was a significant main effect of lag, demonstrating a bilingual advantage on lag 12. Furthermore, older bilingual speakers exhibited an enhanced recollection ability on the most demanding lag. In the non-verbal task, there was a trend for the young and older bilinguals to effectively identify new items.

Together, Study 1 and 2 suggested a bilingual advantage in various tasks. The advantage of older bilinguals compared to older monolinguals was evident in high demand conditions, perhaps due to executive function demands. Older bilingual speakers demonstrated a bilingual advantage in both tasks of Study 2 and in the non-verbal task of Study 1. Young adults demonstrated a slight advantage in the spatial task of Study 2. As such, the advantage in working memory was associated with recollection components that required executive control. In addition to these effects of language experience, the spatial working memory tasks used in Study 1 and 2 demonstrated an age group advantage with younger adults outperforming older adults (Wodniecka et al., 2010).

Similar to Wodniecka et al. (2010), Luo et al. (2013) investigated the impact of bilingualism on working memory in young and older adult monolingual and bilingual speakers. The Corsi Tapping block task was used to measure spatial working memory, and the word span task was used to examine verbal working memory. Both tasks consisted of simple and complex conditions. The verbal working memory task consisted of a word span task (simple condition) and an alpha task (complex condition). The sequence for word span started with two words, increasing one word at the time until the list reached eight words. Participants recalled the list in the same ordered read by the experimenter. The alpha task was similar to the word span; however, participants recalled the words in alphabetical order. There were two trials per list length, and participants obtained one point per correct list recalled. Verbal working memory scores were obtained by adding all the points from the lists correctly recalled.

The Corsi-block task was used to measure spatial memory. In this study, the blocks were colored blue and consisted of the forward (simple) and backward (complex) conditions. The sequence started with two blocks and increased one block at a time until it reached nine blocks. There were two trials per sequence, and spatial span was determined using the last set size in which participants correctly recalled the sequence on at least one trial. In the forward condition, participants were asked to repeat the sequence in the same order the researcher tapped the blocks.

In the backward condition, participants were asked to repeat the sequence in the opposite pattern the researcher tapped the blocks (Luo et al., 2013). Comparable to other studies (Wodniecka et al., 2010), in this study, bilingual speakers had lower scores in the verbal working memory tasks compared to monolingual speakers. This time, young and older bilingual speakers outperformed monolingual speakers in the spatial working memory tasks, suggesting that the executive control benefits associated with bilingualism may be related to the performance of bilingual speakers in the Corsi Tapping task. The complexity of the verbal task was analyzed, and it was found that the effect of complexity was lower for older speakers. Another important finding was that advantages related to bilingualism were observed in both age groups, indicating that the benefits of speaking two languages do not decrease with age across adulthood. The researchers concluded that the general enhanced abilities of bilingual participants allowed for the advantage with the spatial working memory task (Luo et al., 2013).

Current Study

The bilingual advantage has been demonstrated in different domains of cognitive functioning. Compared to other domains of executive functioning, the impact of bilingualism on working memory in children and adults has received relatively little attention (Blom et al., 2014; Hansen et al., 2017). Moreover, research on the bilingual advantage in young adults has produced mixed results in tasks where spatial or verbal working memory are required. The verbal demands associated with the verbal working tasks (Calvo, Ibáñez, & García, 2016) seem to yield a bilingual disadvantage (Wodniecka et al., 2010; Luo et al., 2013), but in other cases a bilingual advantage can be observed (Bialystok, Poarch, Luo, & Craik, 2014; Wodniecka et al., 2010).

Even when similar tasks are implemented, the results for bilingual speakers in the spatial and verbal working domain remain unclear. In the first part of Wodniecka et al.'s (2010) study, bilingual participants performed worse than monolingual in the verbal working memory tasks. In comparison, during the second part of Wodniecka's study, bilingual participants outperformed monolingual participants in verbal working memory. Luo et al. (2013) found that bilingual speakers had lower memory scores in the verbal task than monolingual speakers. The Luo et al. (2013) study also found a bilingual advantage in spatial working memory tasks, whereas the Wodniecka et al. (2010) study found a significant trend for young bilingual speakers and a marked advantage for older bilingual speakers in the spatial working memory task. Luo et al. (2013) found a bilingual advantage in the working memory task for both young and older adults. The intricacy of the results of different studies examining verbal and spatial working memory in monolingual and bilingual participants demands further examination. As such, this study examined whether college students demonstrate a bilingual advantage in verbal and spatial working memory using well established tasks.

The goal of this research study was to examine whether bilingual expertise yielded different results depending on working memory modality. Spatial working memory was measured using a computerized version of the Corsi block tapping task, and verbal working memory was measured using the backwards digit span task. It was hypothesized that bilingual participants would outperform monolingual participants in the spatial working memory task and the verbal working memory task. Additional correlational analyses focused on whether level of second language expertise was related to working memory performance. It was predicted that bilingual proficiency would be positively correlated with spatial and verbal working memory performance. This study sought to add new information to the body of literature in working memory and bilingualism.

CHAPTER III: METHOD

Participants

A power analysis using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007) revealed that a minimum of 50 participants was needed to have a 95% chance of obtaining a medium effect size at the 0.05 alpha level. A second analysis revealed that a minimum of 44 participants was needed to have a 72% chance of obtaining a small effect size at the 0.05 alpha level. Wodniecka et al. (2010) had 50 participants--24 bilinguals and 26 monolinguals--and 44 participants—22 bilinguals and 22 monolinguals--in Study one and two, respectively. Given these details, this study sought to analyze data from 44 participants.

Demographics

The study included 54 participants. Data collection was ended earlier than anticipated due to the Covid-19 pandemic. Participants were 18 years or older. Participants were recruited through the Illinois State University (ISU) Department of Psychology SONA system and received course credit for participation. All participants were college students from Illinois State University between the ages of 18 and 27. The average education years for bilingual speakers was 15.83 and 13.45 for monolingual speakers. The average age for bilingual speakers was 21.83 years and the average age for monolingual was 20.91 years. The study included 44 female participants and 10 male participants. In the bilingual group, 4 participants identified as female and 2 identified as male. In the monolingual group, 40 participants identified as female and 8 as male. I had begun to distribute recruitment materials via courses and registered student organizations related to languages, literatures, and cultures but was unable to invite any of the potential participants to the laboratory due to the pandemic. Ethics approval was obtained from the ISU Institutional Review Board (IRB). Participants provided informed consent before participating.

Instruments

Demographic Survey

The Language Experience and Proficiency Questionnaire (LEAP-Q; Marian, Blumenfeld, & Kaushanskaya, 2007) was used to measure language proficiency. It was administered via Qualtrics. The LEAP-Q is a self-report questionnaire of Language One (L1) and Language Two (L2) proficiency; participants specified age of language acquisition, language use, and preference of language in different modalities. The purpose of the LEAP-Q was to gather information about language history and acquisition, for example, "Please list what percentage of the time you are currently and on average exposed to each language." Questions range from fill-in options, percentage of language use, and drop-down menu options. The LEAP-Q was used to collect general demographic information, such as gender and age, used to describe the sample. Kirk et al (2014) used the LEAP-Q to examine language proficiency and daily language usage. Researchers used the self-reported proficiency as well as age of acquisition question for each language group. In other studies, bilingual proficiency was determined by calculating self-reported expertise in speaking, understanding, and reading (Krizman, Bradlow, Lam, & Kraus, 2017). Participants in the monolingual group scored less than 3 in the understanding and proficiency in the self-report questions. Participants in the bilingual group scored 7 or higher in the understand and proficiency self-report questions (Krizman et al., 2017). Marian et al (2014) categorized bilingual participants with a score of 7 or higher, whereas monolingual participants did not report proficiency in any second language. Similar to previous studies, this study examined language proficiency by establishing mean levels of speaking, understanding, and reading. Specifically, the question regarding proficiency was used determine language membership. Using 0-10 Likert scale, the language proficiency question asks participants to report their level of proficiency in speaking, understanding spoken language, and reading. In this scale 0 represents none, whereas 10 presents perfect. Bilingual status was defined as a mean proficiency in speaking, understanding, and reading in a second language of 7 or higher; whereas monolingual status was defined as a mean proficiency of 3 or lower. Based on this definition, 6 participants were included in the bilingual group, and 32 participants were included in the monolingual group in analyses comparing the performance of the two groups. The majority of the bilingual speakers shared English as L1 and others spoke a language other than English as L1, see Table 1. Sixteen participants scored in the intermediate range. Figure 1 provides the age of acquisition of L1 for monolingual and bilingual speakers, see Appendix A. Figure 2 provides the age of acquisition of L2 for the bilingual speakers, see Appendix B.

Table 1

First and Second Languages for Bilingual Speakers (N = 6)

L1	L2
English	Spanish
English	Spanish
English	Spanish
English	Spanish
French	English
Spanish	English

Computerized Spatial Span Test

The Computerized Spatial Span Test (C-SST) (Woods et al., 2016) was used to measure visuospatial working memory. Similar to a Corsi task, the C-SST presented participants with a range of block sequences, and participants repeated the pattern sequence in the same order in which it was presented. The C-SST has stronger reliability compared to the standard Corsi-tapping block task (Woods et al., 2016). The C-SST presented participants with ten blocks randomly located on the screen in each trial for each participant. Participants watched a sequence of blocks highlighted on the screen, and using the computer mouse, participants indicated the pattern of the blocks by tapping the blocks on the screen (by clicking the mouse) in the same order presented. The sequence started with 2 blocks and continued to add one block after each correctly reproduced sequence. Each sequence was presented twice. The longest possible sequence was 9 blocks. Once participants failed one set size, the task ended. The C-SST recorded three scores: maximal span, mean span, and traditional span. The maximal span was the longest trial achieved in the task. The mean span was the average span for the last five sequences. The last span measured reaction times across all 14 trials. This study used the maximal span because it is most similar to the traditional scoring of the backward digit span. In addition, maximal span was most similar to the way verbal working memory span was calculated in the digit span task utilized here. That is, both measurements, backward digit span and C-SST maximal span, examined the highest possible memory capacity for verbal and spatial spans, respectively.

Backward Digit Span

To measure verbal working memory, the backward digit span was administered using audio recordings presented via computer speakers (Naveh-Benjamin & Ayres, 1986). Digit span demonstrated suitable reliability and validity (Schroeder, et al., 2012). In the digit span, the list of digits started with two digits and went up to 9 digits. Each set size was presented twice. The participant repeated the list in the opposite order the researcher read it. The digit span was determined by the last (largest) span correctly recalled.

Procedure

Participants were tested individually in a university laboratory by trained research assistants. Participants read the consent document and indicated consent. They completed the LEAP-Q questionnaire, followed by the working memory tasks, digit-span and C-SST. The order of working memory tasks was counterbalanced across participants. Participants were debriefed at the end of the study. Participants received psychology course credit through the SONA system.

Data Analysis

To analyze and interpret the data, the Statistical Package for Social Science (SPSS) 25.0 software was used. The goal of this study was to examine the impact of bilingual expertise on working memory modality by comparing working memory spans of participants identified as bilingual and monolingual. Data collected by the LEAP-Q was used to determine language group membership. As noted above, monolingual status was defined as a L2 proficiency mean of 3 or lower ($n = 32$). Bilingual status was defined as a L2 proficiency mean of 7 or higher ($n = 6$). Sixteen participants were omitted from the analyses based on language group because their proficiency was intermediate.

Two one-way ANOVAs were conducted to determine the effect of language group (monolingual, bilingual) on verbal and spatial working memory performance. The quasi-independent variable was language group, whereas the dependent variable was the spatial working memory scores. The one-way ANOVA for spatial working memory included the maximal span. I predicted a significant main effect of language group on spatial working memory, such that bilingual participants would demonstrate higher spatial spans than monolingual participants. The second ANOVA compared verbal working memory for the language groups, using backward digit span scores. I predicted a significant main effect of language group on verbal working memory, indicating that bilingual participants would demonstrate higher verbal working memory spans than the monolingual participants.

To further explore the relation between language proficiency and working memory, the extent of self-report proficiency was further explored. Specifically, Pearson correlations were analyzed. The same proficiency scores from the LEAP-Q were used; however, the full distribution of second-language proficiency scores were included (not only those greater than 7 and less than 3). It was predicted that bilingual proficiency would be significantly positively correlated with spatial and verbal working memory scores, suggesting that bilingual proficiency is related to working memory in a continuous fashion.

CHAPTER IV: RESULTS

Spatial Working Memory

Two one-way ANOVAs were conducted to determine the effect of language group (monolingual, bilingual) on verbal and spatial working memory performance. In the first analysis, the quasi-independent variable was language group, whereas the dependent variable was spatial working memory scores (i.e., the maximal span). The results indicated no significant difference between monolingual ($M = 6.56$, $SD = .95$) and bilingual speakers ($M = 6.50$, $SD = 1.04$) in the spatial task, $F(1, 36) = .021$, $p = .885$, see Appendix C.

Verbal Working Memory

The second ANOVA compared verbal working memory for the language groups, using backward digit span scores. The results indicated no significant difference between the monolingual ($M = 5.28$, $SD = 1.40$) and bilingual speakers ($M = 4.83$, $SD = 1.47$) in the verbal task, $F(1, 36) = .512$, $p = .479$, see Appendix D.

Correlations

To further explore the relation between language proficiency and working memory, the extent of self-reported proficiency was examined. Specifically, Pearson correlations of language proficiency and working memory scores were analyzed. The same proficiency scores from the LEAP-Q were used; however, the full distribution of second-language proficiency scores was included ($n = 54$). Contrary to predictions, language proficiency was not correlated with spatial or verbal working memory. The spatial task and the verbal task were found to be moderately correlated, $r(54) = .318$, $p = .019$. The results from the correlational analyses can be seen in Table 2.

Table 2

Pearson Correlations for Second Language Proficiency and Spatial and Verbal Working Memory

Measurements	L2 Proficiency	Spatial Span	Verbal Span
L2 Proficiency	---	.067	-.061
Spatial Span		---	.318*
Verbal Span			---

Note. N = 54. *p < .05.

CHAPTER V: DISCUSSION

The purpose of this study was to examine verbal working memory and spatial working differences in monolingual and bilingual adult speakers. It was hypothesized that bilingual participants would outperform monolingual participants in the verbal working memory task and the spatial working memory task. Additionally, it was predicted that bilingual proficiency would positively correlate with spatial and verbal working memory performance. The analysis comparing backward digit span for monolingual and bilingual participants did not reveal any statistically significant differences, thereby failing to support the first part of the hypothesis. Secondly, the results of the spatial span test demonstrated no differences in the maximal span between monolingual and bilingual speakers. Thus, the second part of the hypothesis was not supported.

These group-level comparisons did not yield differences in verbal working memory based on bilingual expertise. The digit span measured the capacity to remember numbers and repeat them aloud. The bilingual advantage has been demonstrated differences when asked to hold information (Wodniecka et al., 2010). Similar to the findings of the present study, Wodniecka et al.'s (2010) first study found an equivalent performance in backward digit span between monolingual and bilingual speakers. Also, similar to the present finding of the backward digit span, Luo et al. (2013) examined the bilingualism and verbal working memory and found no significant advantage for bilingual speakers. Interestingly, Luo et al. (2013) found a disadvantage for bilingual speakers, scoring lower than monolingual in the verbal task. Costa et al. (2004) examined whether lexical access creates a disadvantage for bilingual speakers compared to their monolingual counterparts. Language production requires a central system which allows the speakers to retrieve words from the lexicon to match the desired intention in speech. The ability to retrieve information in order complete a cognitive task involves cognitive demands that could be impacted by the information available in each language system. Lexical representations of the language involved in the task can impact the performance of bilingual speakers depending on their proficiency. Therefore, the proficiency of the bilingual speakers that participated in the present study could be a detrimental aspect to the findings of the present study.

Costa at el. (2004) conducted serval studies to examine the lexical demands of L2 leaners, bilingual speakers and high proficient bilinguals. The results demonstrated that for non-high proficient bilinguals, it was more difficult to switch from L1 to L2. However, high proficient bilinguals did not experience unequal switching costs. Regardless of the language of the task, the performance of high proficient bilingual speakers was independent of the proficiency in each language. Thus, the proficiency of the bilingual speakers involved in the present could have impacted the results of the backward digit span test. If non-high proficient bilinguals experience a disadvantage in tasks where information involves lexical processing, the digit span is not the appropriate task to test the verbal working memory abilities of bilingual speakers.

The process deficits in verbal tasks exhibited by bilingual speakers in Bialystok et al. (2008b) further supports the notion that verbal processing places bilingual speakers at a cognitive disadvantage compared to their monolingual counterparts. Bialystok et al. (2008b) examined parallel activation between language groups and its relation to receptive vocabulary. Bilingual speakers scored higher than monolingual in naming vocabulary task but monolingual speakers scored higher in receptive vocabulary in the PPVT. Bialystok found that bilingual speakers did not outperform monolinguals speakers in the verbal task, supporting the notion that lexical access involved in the verbal tasks creates a disadvantage for bilingual speakers in tasks where naming and verbal fluency are involved. The impact of the receptive vocabulary of the bilingual participant in the present study is unknown. Therefore, depending on the proficiency of the bilingual speakers in the present study, the ability to repeat the numbers aloud for the backward digit span could have presented a disadvantage for bilingual speakers. When generating the items, bilingual speakers must inhibit any representation of that item in the non-target language. Furthermore, regardless of proficiency levels, the ability to inhibit lexical representations of the non-target system generates a complication for bilingual speakers (Costa et al. 2004). Theoretically, activation in one language system requires activation in the other system in order to retrieve the information to be recalled (Green, 1998). According to Green (1998), the more dominant language (L1) the information in this system is more readily available than the non-dominant language (L2). However, in some cases lexical presentation of L2 are needed to retrieve information form L1, bilingual speakers are susceptible to a lexical disadvantage whether the materials and tasks are presented in L1 or L2 (Green, 1998). Bialystok et al. (2008) suggested that managing two language systems leads to different outcomes for cognitive and linguistic functions. Perhaps, the lexical differences between monolingual and bilingual speakers prompted the lack of differences in working memory spans between the two language groups.

The second part of the hypothesis examined the impact of bilingualism on spatial working memory. The results of the present study did not support the prediction that bilingual speakers would outperform monolingual speakers in the spatial working memory task. The maximal spatial span did not differ between bilingual and monolingual speakers. Wodniecka et al. (2010) found similar results. They used the Corsi block task and 5x5 matrix for the second study and did not find a bilingual advantage. Similar to the present study, Luo et al (2013) used the maximal span to measure spatial memory. However, contrary to the present study, Luo et al. (2013) found that bilingual speakers outperformed their monolingual counterparts in the spatial task. Wodniecka et al. (2010) and Luo et al. (2013) used young adults as part of their sample, therefore I might expect results of the present study to be comparable to the prior findings. However, results varied widely depending on the study. McLeay (2010) found a relation between bilingual processing and spatial abilities in spatial tasks. In this study, bilingual young adult speakers completed verbal spatial tasks, such as comparison of diagrams. Participants verbal answered questions regarding spatial figure, such as diagrams. McLeay (2010) also found that higher proficiency helped bilingual speakers when performing complex tasks. Thus, non-verbal (Luo et al., 2013) and verbal (McLeay, 2010) spatial span yielded significant differences in the performance of bilingual and monolingual speakers, whereas Wodniecka et al. (2010) found no significant differences in the spatial span those groups. The different results in this field do not create a clear picture regarding the connection between the cognitive advantages related to bilingualism and the underlying similarities of such abilities to working memory.

Another interesting finding of the present study is the relation between spatial and verbal working memory tasks. Similar underlining processes for verbal and spatial working memory tasks likely contributed to the correlation between the spatial and verbal performance found in the present study. Information related to the tasks must be held in working memory for the Corsi task and backward digit span (Miyake et al., 2000). The correlation between the two tasks can be attributed to the similar cognitive processes when completing the tasks. Both tasks measured the highest span obtained by participants. Although the modality of the tasks was different, the underlining cognitive processed needed were similar. Studies investigating bilingualism and working memory should take into consideration tasks that do not correlate in order to examine the specific cognitive advantage associated with bilingualism.

Limitations and Future Research

The findings of the present study are shaped by other limitations. In order to compare groups, the number of participants in each should represent the desired sample. The number of bilingual participants obtained in the present study was lower than the desired number of participants. Therefore, the present study could not properly compare the two groups. Another factor that could had impacted the results of the present study is the proficiency of bilingual participants. Self-report surveys might not represent a holistic representation of bilingual abilities. The bilingual speakers in the present study indicated year of acquisition and proficiency levels; however, participants' language abilities were not tested. In order to improve the findings of future studies, bilingual participants must be tested on their linguistic abilities. Furthermore, there should be equivalent number of participants for the language groups studied. Another aspect to consider is the age of acquisition and language of bilingual speakers. The non-dominant language can impact inference created when retrieving information for a specific scenario. Future studies, should group bilingual by late or early bilingual, this can also impact the proficiency of speakers. Future research also should implement multiple tasks in order to measure spatial and verbal working memory tasks to clarify conflicting findings in the field.

In conclusion, the goal of this study was to examine the impact of bilingual expertise and working memory modality. The results of the present study did not support the bilingual advantage hypothesis. Bilingual participants did not outperform their monolingual counterparts in verbal or spatial tasks. Based on the findings of the present study, it cannot be determined how development of two language systems impacts verbal and spatial working memory. Future studies should consider measures to match participants using receptive vocabulary and proficiency. Due to the inconclusive findings, much remains to be learned about the relation between bilingualism and working memory.

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APPENDIX A: AGE FREQUENCIES OF AGE ACQUISITION OF L1

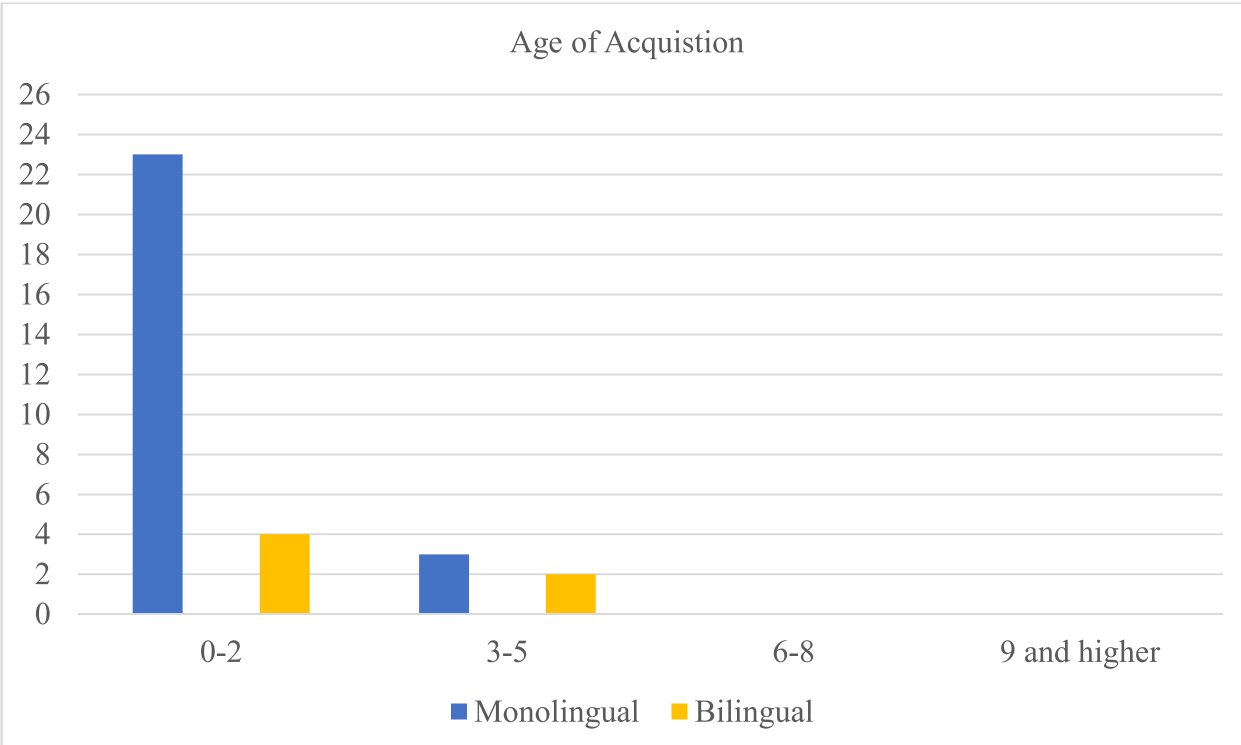

Figure 1. Age frequencies of age acquisition for bilingual and monolingual speakers (N = 28).

APPENDIX B: AGE OF ACQUISITION OF L2 FOR BILINGUAL SPEAKERS

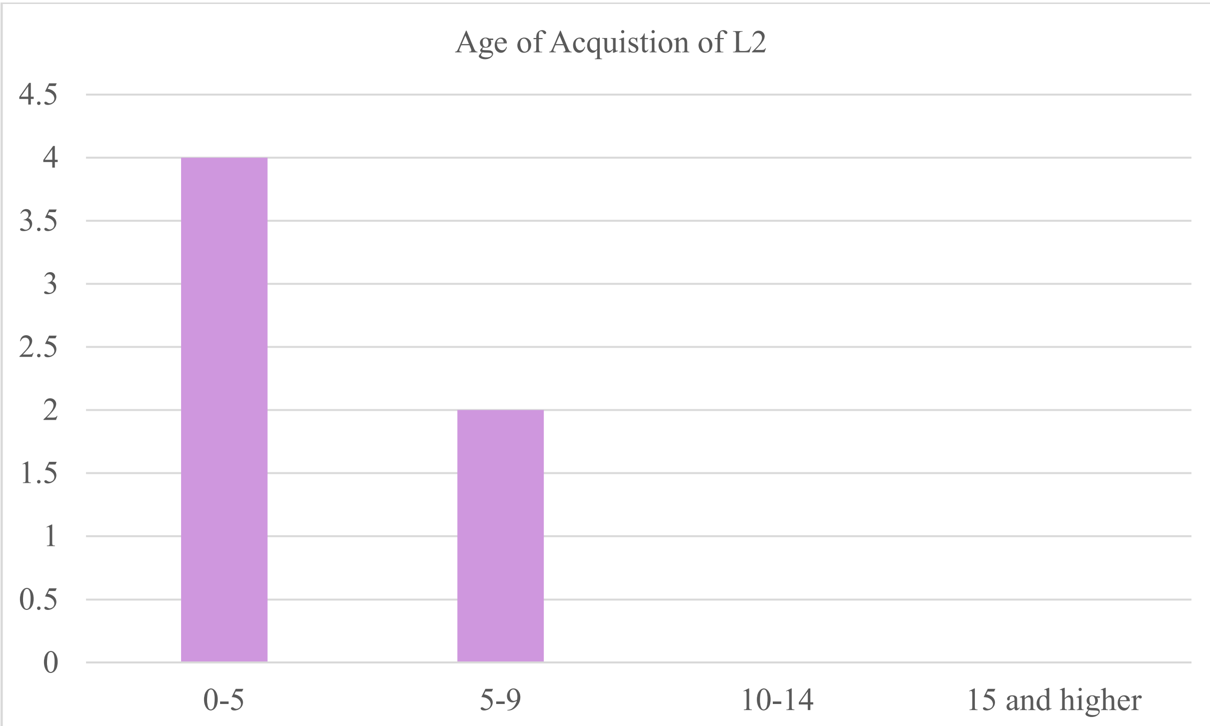

Figure 2. Age of acquisition of L2 for bilingual speakers (N = 6).

APPENDIX C: SPATIAL SPAN AVERAGE BY LANGUAGE GROUPS

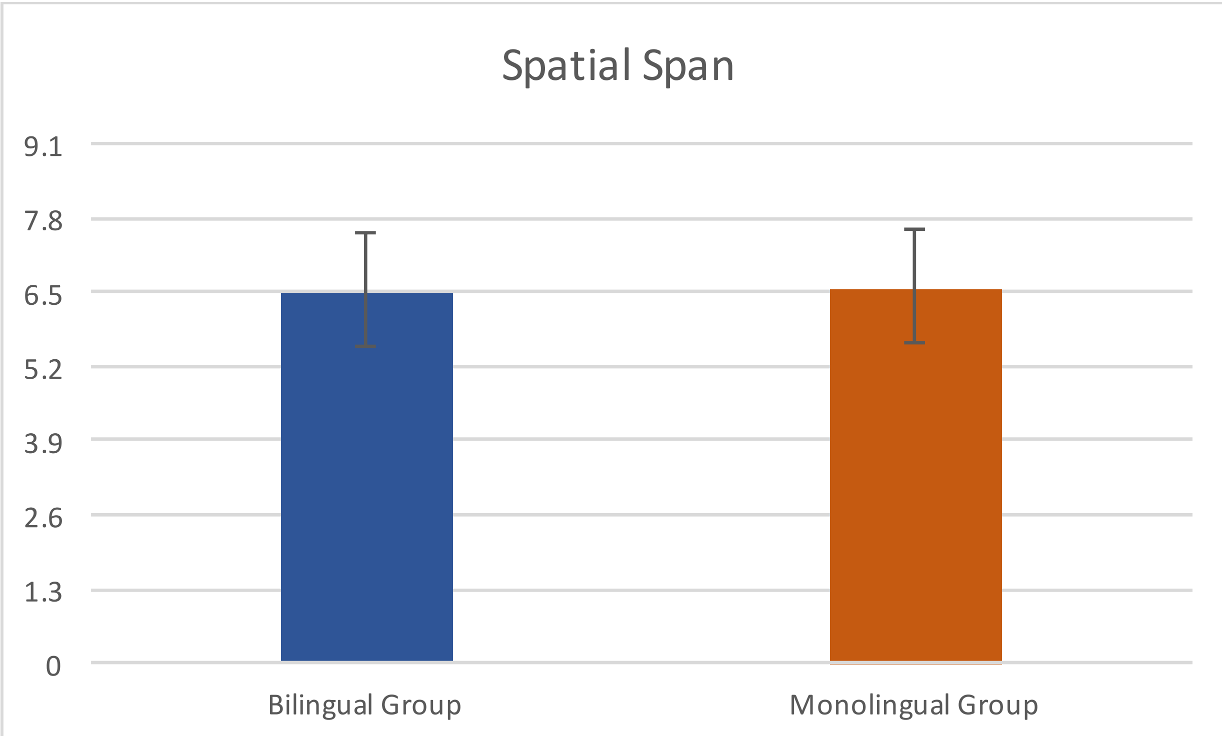

Figure 3. Mean spatial span for bilingual and monolingual participants.

APPENDIX D: VERBAL SPAN AVERAGE BY LANGUAGE GROUPS

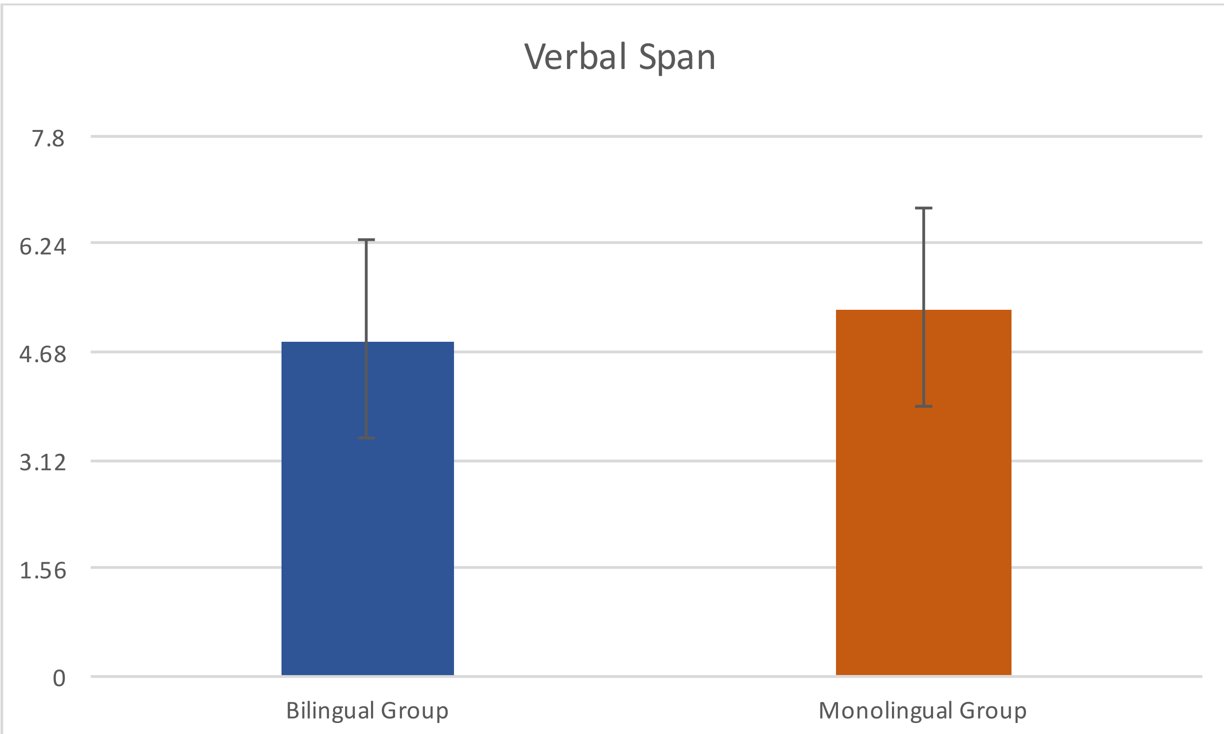

Figure 4. Mean verbal span for bilingual and monolingual participants.