Bilingual/Multilingual Advantage: Is Early Bilingualism/Multilingualism Associated with an Advantage in Working Memory in Adults.

Niall Flavin

15039111

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Supervisor: Dr Caoimhe Hannigan

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Abstract

The study aimed to determine whether early bilingual/multilingual adults with high levels of second language proficiency outperform monolingual adults on tasks of working memory. A bilingual advantage has been found previously in working memory however, less is known about an advantage in adults. Nineteen bilingual/multilingual and eighteen monolingual adults completed a battery of working memory tasks, corsi block task (test of visio-spatial working memory), n-back task (test of working memory capacity) and the letter number sequencing task (test of phonological working memory). Independent T tests were used to compare the two language groups on the n-back task and the letter number sequencing task. A Mann- Whitney U test was used to compare the language groups on the corsi block task. The data showed that there was no difference in scores between bilinguals/multilinguals and monolinguals on any of the three measures of working memory. The study indicates that a working memory advantage is not evident in adults who acquired a second language before the age of seven and who have high proficiency in their second language. This finding may be a result of high reported education levels and high socio- economic levels of participants, indicating that future researchers need to control for these variables. Longitudinal research is warranted that investigates the bilingual advantage and working memory across the lifespan. The present study was limited by the cross-sectional design of the study, the sample size and the inability to generalize the results across the population.

Keywords: bilingual advantage, working memory, visio-spatial working memory, phonological working memory, working memory capacity

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Bilingual/Multilingual Advantage: Is Early Bilingualism/Multilingualism Associated with an Advantage in Working Memory in Adults.

The 'bilingual advantage' refers to a hypothesised benefit of bilingualism for cognitive performance across domains including attention, working memory (WM) and cognitive control (Van Den Noort et al., 2019). The bilingual advantage is currently one of the most controversial topics in the field of psychology; there is considerable debate within the literature as to whether a cognitive advantage exists for those who speak two or more languages (Antón, Carreiras, & Duñabeitia, 2019). When a bilingual speaks there is competition between the two languages even when conversing monolingually as both languages are triggered, this competition is known as joint activation (Bialystok, 2017; Bialystok & DePape, 2009). Joint activation is demonstrated in studies that use both neuroimaging and EEG techniques as they have shown a bilingual language crossover, highlighting that both languages are activated at any given time (Timmer, Ganushchak, Ceusters, & Schiller, 2014; Wu & Thierry, 2010). The core premise of the bilingual advantage (BA) is that due to the joint activation of multiple languages, bilinguals/multilinguals must resist the urge to engage in the non-target language(s). When bilinguals/multilinguals speak they must suppress the non-target language, control the switching between different languages and also decipher correct grammar usage. This requires more cognitive effort then monolinguals (Schweizer, Ware, Fischer, Craik, & Bialystok, 2012; Antón et al., 2019; Bak, Nissan, Allerhand, & Deary, 2014). This continuing competition between languages may lead to greater cognitive advantages that are not language-specific but include a range of cognitive functions such as executive functioning (Woumans, Ceuleers, Van der Linden, Szmalec, & Duyck, 2015).

Executive functions (EF) describes a number of top down mentally demanding cognitive processes (Diamond, 2013). The three core EFs are inhibition (the ability to intentionally suppress internal and external distractions) cognitive flexibility (Changing thought processes or switching between tasks) and working memory (the ability to temporary store, manipulate and process information) (Hartanto & Yang, 2019; Diamond, 2013; Morales, Calvo, & Bialystok, 2013; Miyake et al., 2000). A bilingual advantage (BA) has been demonstrated in various aspects of EF such as cognitive flexibility (Bergman Nutley et al., 2011; Prior & MacWhinney, 2010; Adi-Japha, Berberich-Artzi, & Libnawi, 2010) and inhibition (Bialystok, Craik, & Luk, 2008; Bialystok, Craik, Klein, & Viswanathan, 2004). According to Diamond (2013) inhibition relies heavily on WM with some researchers suggesting that inhibition is actually a behavioural product of working memory and not actually a separate cognitive skill (Diamond, 2013). This is evident as one has to hold information in the mind to decipher what is important, appropriate and what needs to be inhibited (Diamond, 2013; Namazi & Thordardottir, 2010). This might suggest that a BA in tasks of inhibition may be mediated by WM. Research, also emphasises the importance of both verbal WM and the visio-spatial WM in language processing (Kidd, Donnelly, & Christiansen, 2018). Trevisol and Tomitch (2017) describe working memory as a key complex cognition whereby language processing and second language acquisition are facilitated. The verbal aspect of WM is important in verbal processing, this is evident when words that sound similar are mixed up on tests of verbal fluency (Rudner & Rönnberg, 2008). As a result of this dependent relationship with other EFs and its role in language processing it is both likely and logical to assume that second language acquisition would increase WM capacity (the maximum amount of information a person can keep in their mind) (Grundy & Timmer, 2017; Conway, Getz, Macnamara, & Engel de Abreu, 2011).

Many models of WM have been proposed, however the model proposed by Baddeley and Hitch (1974) is recognised as the most influential (Antón et al., 2019). Baddeley and Hitch propose that there are two main systems of WM: a phonological loop (PL) and a visual spatial sketchpad (VSS). These two systems are governed by the central executive which coordinates and manages incoming information (Baddeley, 1992; Baddeley, Watts, & Wilson, 1996). The PL is made up of an acoustic store and specialises in holding and processing verbal information, whereas the VSS is responsible for retaining and manipulating visual information (Baddeley et al., 1996). Later an episodic buffer was introduced into the model this acts as an interface between the VSS and the PL slave systems (Baddeley, 2000). The PL is important in speech based language processing with Baddeley (2000) suggesting that it may have formed as a means of perceiving and producing speech as well as a means of learning new vocabulary. Baddeley (2003) hypothesised that the VSS is important when structuring grammar in language, particularly when the words have spatial components such as above or below. As both the PL and VSS are responsible for processing different components of language the effects of multilingualism/bilingualism on WM may also differ, highlighting the need to study these two systems separately.

The current literature that examines the effects of bilingualism on WM has provided conflicting findings, with some finding a BA for WM tasks and others finding no such advantage. A systematic review of 63 studies by Adesope, Lavin, Thompson, and Ungerleider (2010), found that bilingualism was associated with a moderate advantage on working memory measures. However, the review did not specify whether this BA occurred for both verbal and visio-spatial WM tasks, or whether the effects of bilingualism varied between these two domains. Similarly, a meta-analysis of 27 studies which investigated the effect of bilingualism on WM capacity demonstrated a small BA, the greatest benefits of bilingualism were observed in children (Grundy & Timmer, 2017). Similarly, Morales et al.

(2013) found a WM advantage in bilingual children who underwent the corsi block tapping task (test of visio-spatial WM). Neuroimaging studies have also demonstrated a BA in WM, Morrison, Kamal, and Taler (2019) found that bilinguals demonstrated larger P300 amplitudes in EEG readings when compared to monolinguals, indicating that bilinguals had more cognitive resources to manage WM load. However, a meta-analysis of 152 articles that examined cognitive experiments using a range of WM measures found no BA in WM (Lehtonen et al., 2018). These studies indicate that there is mixed support for an enhanced WM advantage in bilinguals and highlights the need for further research.

An important methodological consideration that may contribute to the mixed findings in the current literature relates to the measures used to assess WM performance. Lehtonen et al. (2018) divided WM tasks into three groups, simple span tasks (participants report a series of stimuli previously presented), transformational tasks (require the reorganisation of items such as letters or numbers) and finally complex span tasks (measures both the processing and storage of information and is a more dynamic measurement of WM capacity) (Lehtonen et al., 2018; Redick et al., 2012; Conway et al., 2005). Research suggests that high processing WM tasks should be utilised when examining the BA, especially in adults who are in their cognitive prime (Bialystok et al., 2004; Jiao, Liu, Wang, & Chen, 2019). Complex span tasks are not only required to store and control information in memory but are also required to simultaneously process additional complex information, both the n-back and the LNST have been identified as complex WM tasks (Morrison et al., 2019; Mielicki, Koppel, Valencia, & Wiley, 2018; Conway et al., 2005). Of the 251 WM tasks that were included in Lehtonen et al. (2018) meta-analysis 176 were simple span tasks such as the digit span. The over reliance on simple span tasks may have contributed to the insignificant findings. This indicates that there is a need to study WM with more complex WM measures.

Another important consideration when evaluating existing evidence for bilingualism and WM is the possibility of differential effects across WM domains. Research suggests that bilingualism may impede the phonological aspect of WM (Lukasik et al., 2018; Ratiu & Azuma, 2015; Namazi & Thordardottir, 2010; Fernandes, Craik, Bialystok, & Kreuger, 2007; Bialystok et al., 2004). This has been identified in verbal WM tasks such as the Alpha span task (remembering a list of 2 to 8 words) and the sequencing span task (recall a list of numbers from 10 to 99) (Bialystok et al., 2004). One explanation for this finding is that the competition between the vocabulary of two languages slows the lexical retrieval of information from memory (Bialystok, Craik, Green, & Gollan, 2009; Luo, Craik, Moreno, & Bialystok, 2013; Ivanova & Costa, 2008; Ratiu & Azuma, 2015). Another explanation is that bilinguals use each language less often then monolinguals and this leads to weaker neurological connections between the semantic and phonological wiring (Ratiu & Azuma, 2015). These results are inconsistent with some researchers finding no difference between monolinguals and bilinguals (Bonifacci, Giombini, Bellocchi, & Contento, 2011) and others finding a BA in verbal WM (Warmington, Kandru-Pothineni, & Hitch, 2019).

When considering the BA both the age of acquisition (AoA) of the second language (L2) and the proficiency in L2 are important considerations (Luk, De Sa, & Bialystok, 2011; Lehtonen et al., 2018; Yang, Hartanto, & Yang, 2016; Soveri, Rodriguez-Fornells , & Laine, 2011). The critical period hypothesis suggests that there is a certain timeframe in child development that is optimal for L2 acquisition, this window period for learning is not fully understood but may be a result of advanced neural plasticity in children (Hartshorne, Tenenbaum, & Pinker, 2018; Rahman, Pandian, Karim, & Shahed, 2017). There is conflicting evidence as to what ages the critical period encompasses (Mayberry & Kluender, 2018). Kousaie, Sheppard, Lemieux, Monetta, and Taler (2014) found no BA in adults who rated proficiency in L2 as high by the age of 13, however simple digit span was used to

measure WM which may have impacted findings. Luk et al. (2011) found that those with AoA under 10 years perform quicker on the incongruent targets of the flanker task indicating that they were more proficient at suppressing conflicting information (participants are asked to respond to the direction of an arrow these can be congruent when the arrow is facing the same direction and incongruent when facing the opposite direction). Interestingly, both monolinguals and bilinguals that acquired L2 after the age of 10 performed similarly on the flanker task emphasising that the EF advantages might dissipate with age. Luk et al. (2011) suggest that the critical period occurs before puberty and proposed that age 10 is a sufficient cut off age to ensure subjects are prepubescent. However an AoA of below 10 has not always yielded significant results (Lehtonen et al., 2018). Interestingly, Johnson and Newport (1989) paper suggests that the ability to acquire an L2 declines after the age of seven. Similarly, Pelham and Abrams (2014) and Warmington et al. (2019) considered early bilinguals as people who had acquired fluency in L2 before the age of seven. Some researchers suggest that L2 proficiency needs to be similar to the first language for there to be cognitive benefits associated with bilingualism, as it increases the competition between the two languages (Blom, Küntay, Messer, Verhagen, & Leseman, 2014; Pelham & Abrams, 2014; Bialystok et al., 2009; Fernandes et al., 2007). According Yow and Li (2015) the more proficient a bilingual is in their languages the more effort they need to use to control and suppress their non target language, thus enhancing their cognitive functions. Not all studies consider early AoA and L2 proficiency highlighting a need to examine the BA when considering these factors.

Potential confounding variables should be considered when investing the BA and WM. Both socio-economic status (SES) and education have been identified as possible confounding variables (Cockcroft, Wigdorowitz, & Liversage, 2019; Van Den Noort et al., 2019; Bialystok, 2017; Qu, Low, Zhang, Li, & Zelazo 2016; Zhou & Krott, 2016; Goral,

Campanelli, & Spiro, 2015; Valian, 2015; Prior & Gollan, 2011). Research has shown that people from higher SES groups outperform those of lower SES groups independent of bilingualism (Namazi & Thordardottir, 2010). Previous studies indicate that SES needs to be matched between groups, as comparing monolinguals of lower SES to bilinguals of higher SES status would create uncertainty as to whether an advantage in EF was associated with bilingualism or SES (Cockcroft et al., 2019; Paap, Johnson, & Sawi, 2015; Namazi & Thordardottir, 2010). According to Van Den Noort et al. (2019) education level is often not considered when studying the BA, they emphasise that a higher education level may enhance cognitive functioning and minimize the effect of bilingualism. When education level is collected it is often used as a proxy of SES (Von Bastian, Souza, & Gade, 2016; Tao, Marzecová, Taft, Asanowicz, & Wodniecka, 2011). Goral et al. (2015) demonstrated the importance of controlling for education as they found education level impacted performance in verbal WM tasks in bilinguals. These studies suggest that both SES and education can impact the advantages associated with bilingualism, they also suggest that there is a gap in the literature that screens participants for both SES and education.

While many studies have found a BA advantage for WM the research findings have been mixed. Research is needed that investigates the effects of early bilingualism on WM, while controlling for factors such as proficiency in languages spoken and potential confounding variables such as SES and education. As previously mentioned many studies have not used complex tasks when investigating the BA and WM, this not only highlights a gap in the research available but emphasises the need for more research that uses complex WM tasks. According to Bialystok and Craik (2010) if there are cognitive benefits to bilingualism the advantages should be seen throughout one's lifetime, however the majority of research to date has focused on children and older adults (Blom et al., 2014; Bialystok, Poarch, Luo, & Craik, 2014; Engel de Abreu, Cruz-Santos, Tourinho, Martin & Bialystok,

2012; Bialystok et al., 2004; Park, Ellis Weismer, & Kaushanskaya, 2018) further studies are needed to explore the effects of bilingualism across the lifespan, which the current study plans on doing. While some studies exist which have explored the BA in a general adult population, the majority of these studies have typically recruited university students and therefore are not representative of the general population (Bialystok et al., 2008; Ratiu & Azuma, 2015; Wodniecka, Craik, Luo, & Bialystok, 2010). It is still poorly understood whether there is a BA in WM in the general adult population, the present study will attempt to fill this gap in the research.

The aim of this study is to get a greater understanding of whether early bilingualism/ multilingualism enhances working memory performance on a battery of complex working memory tasks (n -back task, corsi block task and the letter numbering sequencing task) in adults aged 18-65. Specifically, the study was interested in determining whether early L2 acquisition (before the age of seven) and a high level of L2 proficiency was associated with BA in WM once SES and education level are accounted for. From the review of the literature three hypothesis have been developed.

- Early bilinguals/multilinguals will demonstrate an advantage in working memory capacity when compared to monolinguals.
- Early bilinguals/multilinguals will demonstrate a WM bilingual advantage in visio-spatial working memory when compared to monolinguals.
- Monolinguals will score higher in phonological working memory when compared to the early bilingual/multilinguals.

Method

Participants

Participants were recruited via leaflets distributed in the National College Ireland and The National Blood center. Of the 37 participants that were included 48.6% of the sample were male (n = 18) and 51.4% were females (n = 19). Of these, 51.4% (n = 19) of the sample were bilingual/multilingual with 47.4% (n = 9) males and 52.6% females (n = 10). The monolinguals were equally matched on gender (males = 9, females = 9). Participants age in the study ranged from 19-65 (*M* = 35.97, *SD = 11.41*). For differences in ages between monolinguals and bilinguals/multilinguals refer to Table 1. Any participant aged over 65 were excluded as research has suggested that 10 - 15% of adults may demonstrate mild cognitive impairment over 65 years of age (Kirova, Bays, & Lagalwar, 2015).

To participate monolinguals first language had to be English. For bilingual participants a 70% proficiency in English was required if it was not their L1, this ensured that they understood the consent as well as the tasks. A proficiency of 70% in their L2/L3 was also needed to be considered bilingual/multilingual (Stocco & Prat, 2014). AoA was also accounted for and participants needed to have acquired their L2 before the age of 7 as recommended by Johnson and Newport (1989). Both proficiency and AoA were self-reported. Bilinguals that acquired their L2 after the age of seven were not included. No incentives were offered for participation. For frequencies of languages spoken see table 2. A non- probability convenience sampling method was used to recruit participants. Snowball-sampling was also utilized by asking participants to inform people that might be interested in partaking in the research.

Design

This is a cross-sectional quantitative study. This study examined between group differences in WM performance between monolinguals and bilingual/multilinguals. When

addressing the three hypotheses the participants language ability (being monolingual vs being bilingual/ multilingual) are the independent variables. The dependent variables were the outcome WM scores on the corsi block task, n-back task and the Letter Number Sequencing Task. Between group performance was measured for each of the three tasks, the monolinguals WM scores was compared to the bilingual/multilingual scores. A pilot study of two participants was also carried out prior to experimentation. This was done to assess the data collection method. No changes were made to the methodology post pilot.

Materials

The demographic and language ability questionnaire.

This was a self-report questionnaire that was issued to participants prior to task engagement. It was completed in pen. The questionnaire initially asked people to indicate their age in years followed by their gender. The language aspect of the questionnaire consisted of 5 questions and was adapted from LEAP-Q questionnaire (Marian, Blumenfeld, & Kaushanskaya, 2007). The questionnaire assessed participants language ability and examined dominance in language spoken, acquisition of languages spoken, age they acquired their languages, proficiency in languages spoken and percentage of time speaking each language (appendix 1). The questionnaire is widely used in research investigating the BA and factor analysis has revealed alpha levels between 0.24-0.92 (Cockcroft et al., 2019; Marian et al., 2007).

The second aspect of the questionnaire examined SES and education. These items were adapted from the Growing up in Ireland (1998) wave 1, primary caregiver main questionnaire. SES was measured by a Likert type scale which assessed one's ability to make ends meet at the end of each week and ranged from with great difficulty to very easily. Participants were asked to tick the box that best described their current situation. Education was measured by documenting both the number of years engaged in formal education and the

highest level of education achieved, once again participants were asked to tick the box that best described their situation (see Appendix A for demographic and language ability questionnaire).

Corsi Block Task

The corsi block task was based on Kessels, Van Zandvoort, Postma, Kappelle, and De Haan (2000) paper and was run on Inquisit software using a laptop. The corsi block task is a measure of visio-spatial WM (Kessels et al., 2000). It has previously been used to measure visio-spatial WM and the bilingual advantage in numerous studies and is considered a reliable measure of visio-spatial WM (Cheng, 2017; Luo et al., 2013; Morales et al.,2013). Participants were given verbal instructions prior to task commencement. Inquisit software also gave a written description of what the task entailed. No practice run was provided but participants were given ample time to ask questions. Participants are presented with nine blue squares on a black background. In each trial a number of squares change colour from blue to yellow in a sequence. Participants must recall this sequence by clicking on the blocks with a mouse in the order that they changed colour. The task starts simple with 2 squares changing colour, with each sequence running twice. For each round the person makes a correct response an additional square will change colour. The task ends when participants fail to remember the same block sequence twice. Participants were asked to wait until the sequence was finished lighting up before engaging in the task. On completion participants are then provided with a block span score (number of blocks recalled correctly) and a total score which is calculated by multiplying block span (max score 9) by number of correct sequences (max score=16) with a total max score of 144, this is the dependent variable.

N-Back Task

The n-back task measures how WM updates but also is a measure of WM capacity (Soveri, Antfolk, Karlsson, Salo, & Laine, 2017). This task was run on a laptop using

Inquisit software as described by Jaeggi et al. (2010). During this task participants were presented with a sequence of visual stimuli, participants were asked to respond by clicking the 'A' key each time the current stimulus was the same as the stimulus shown n positions back. Participants were asked not to respond if they thought it was not a match. The stimulus were eight different yellow shapes and appeared on a black background. Participants underwent 2, 3, and 4 - back tasks with each of these blocks running twice. This amounted to six blocks in total. Each n- back block consisted of 20 visual stimulus, with six of the shapes of each block being a target shape. The block sequence ran chronologically with 2-back first followed by 3-back and finished with the 4-back. Participants were informed at the start of each block which n – back task they were expected to complete. Each visual stimulus was presented on screen for 500ms and waits 2500ms before presenting the next stimulus. A practice session was run for each of the three n -back blocks. Once the task was completed a total score was calculated, this was calculated by (Total Hits – Total false alarms)/number of experimental blocks). This score represents the WM score and is the dependent variable. The n- back task has been found to be highly correlated with other tasks of working memory with an r=0.67 (Schmiedek, Lövdén, & Lindenberger, 2014). It has also been used in studies that measured the BA and WM (Morrison et al., 2019).

Letter Numbering Sequencing Task

The Letter Numbering Sequencing Task (LNST) is a task of verbal working memory and was adapted from the Wechsler Adult Intelligence scale (Wechsler, 2008). During this task participants hear a string of numbers and letters in random order. They are then asked to rearrange this string and repeat it back to the researcher, participants need to reorganize the string numerically in ascending numerical order and alphabetically in ascending alphabetical order. Numbers should be repeated first followed by letters. A template was read to the participant that provided instructions on the task prior to commencement (see Appendix B for

instructions on how to administer LNST). The test was administered orally in English with the stimuli being read from a test sheet, this test sheet provided the researcher with the trials to be read out and the correct responses (see Appendix C for LNST test sheet). For each correct response a participant gets a score of one (max score= 21). The task has 7 blocks in total with each block containing three alphanumeric sequences of equal string length. The task starts off simple with 2 alphanumeric characters in the string however this gets progressively more difficult with a max of 8 alphanumeric characters to be recalled. If a participant gets all three string lengths of the same block incorrect the task is discontinued. Alphanumeric characters were read at one number/letter per second. A practice session was administered prior to commencement, this was also provided on the test sheet. The total number of correct responses is the dependent variable and represents phonological WM. Shelton, Elliott, Hill, Calamia and Gouvier (2009) found the LNST to be a reliable measure of WM.

Procedure

Participants contacted the researcher via e- mail which was provided on the recruitment poster (see Appendix D for recruitment poster), then a date and location for the session was agreed. Participants were also e-mailed a copy of the information leaflet, which gave an overview of why the study was being conducted, what it entailed, some exclusion criteria and participants rights if participating (see Appendix E for information leaflet). The study took place in either a quiet interview room in the National Blood Center or in the psychology lab in the National College of Ireland at the participants convenience. Once participants were greeted, they were provided with the Information leaflet to read again. A verbal explanation of what the study entails was also provided. Two copies of the Informed consent were signed and dated by both the researcher and participant (see Appendix F for consent form). The participant kept one copy and the researcher the other. An ID number

was issued on the bottom of the consent form this number would allow the participant to withdraw their results at a later stage if required. The language and demographic questionnaire were then completed in pen. Once informed consent and the language and demographic questionnaire were completed the cognitive study began. The three tasks were administered in a counter balanced order to ensure fatigue did not impact results. Breaks were offered between each task. Once cognitive tasks were complete participants were debriefed and a debriefing leaflet was provided (see Appendix G for debriefing form). The study took about 25 minutes to complete.

The current study was approved by National College of Irelands ethics committee. Informed consent was obtained from all participants in both written and verbal form. Participants were given to opportunity to withdraw from the research at any stage. Participation was pseudo- anonymous. All participant data was stored under a unique ID. The researcher maintained a separate 'key' file linking the ID to code to name for the purpose of reidentification. Data was stored under password protected file.

Table 1

Age differences between monolinguals and bilingual/multilinguals

	Number of participants	Mean	SD	Range
Age				
Age total	37	36	11.41	19-65
Age Monolingual	18	37.17	13.92	19-65
Age Bilingual/Multi	19	34.84	8.64	26-59

Table 2

Frequency and percentage of languages spoken (n=37)

Variable	Frequency	Valid Percentage
Number of languages spoken		
Monolingual	18	48.6%
Bilingual	15	40.5%
Multilingual (speaks 3 languages)	3	8.1%
Multilingual (speaks 4 languages)	0	0%
Multilingual (speaks 5 languages)	1	2.7%

Results

Descriptive statistics

Descriptive results for variable relating to language use can be found in Table 3 and Table 4, frequencies of SES and education level can be found in Table 5. The mean years of education was 17.35 years (*SD* = 2.95) and ranged from 11 to 22 years, with monolinguals having a slightly higher mean (*M* = 17.65, *SD* = 2.81*)* then the bilingual/multilingual group (*M* = 17.16, *SD* = 3.18*)*.

In order to determine whether education and SES should be controlled for in the inferential analysis, t -tests were conducted to compare means between these variables for the monolingual and bilingual/multilingual groups. For the purpose of this analysis SES was treated as a categorical variable. The results indicated that SES and years of education were not significant and therefore were not controlled for in the final analysis. A summary of the results of these t- tests is available in Table 6.

Prior to preliminary analysis data was screened for normality using histograms and outliers using Q-Q plots. No outliers were noted. Both n-back total score and the LNST were normally distributed. The corsi block task total score was not normally distributed; assumptions for the Mann Whitney U test were checked. For descriptive results on the scores of the LNST, corsi block task and the n-back task see Table 7.

Table 3

Frequency and percentages of the most dominant languages and the age in years that language was acquired

Variable	Total Number	Percentage
Most dominant language		
L1 (English)	32	86.5%
L2 (Irish)	7	18.9%
L3 (English)	3	100%
L4 (German)	1	100%
L5 (Italian)	1	100%
Age of language Acquisition		
First language		
Age 1 (birth)	37	100%
Second Language	19	51.4%
Age 1 (birth)	9	24.4%
Age 3	2	5.4%
Age 4	5	13.5%
Age 5	1	2.7%
Age 6	2	5.4%
Third Language	3	8.1%
Age 1 (birth)	2	5.4%
Age 7	1	2.7%
Fourth language	1	2.7%
Age 1 (birth)	1	2.7%
Fifth language	1	2.7%
Age 7	1	2.7%

Table 4

Proficiency in languages and percentage of time speaking languages in the bilingual/multilingual group

	Number of participants	Mean	SD	Range
Proficiency speaking languages				
Proficiency in L2	19	89.21	10.04	75-100
Proficiency in L3	3	97.50	3.54	95-100
Percentage of time speaking languages				
Percentage of time speaking L1 (bilingual/multi)	19	57.11	29.88	10-90
Percentage of time speaking L2	19	22.68	20.58	1-70
Percentage of time speaking L3	3	12.50	10.61	5-20

Table 5

Number and percentage of responses on socio-economic status and education level

Variable	Totals		Monolingual		Bilingual/multilingual	
	number	Valid percentage	number	Valid percentage	number	Valid percentage
SES						
With great difficulty	0	0%	0	0%	0	0%
With difficulty	0	0%	0	0%	0	0%
With some difficulty	4	10.8%	2	11.1%	2	10.5%
Fairly easily	13	35.1%	10	55.6%	3	15.8%
Easily	14	37.8%	3	16.7%	11	57.9%
Very easily	6	16.2%	3	16.7%	3	15.8%
Education level						
None	0	0%	0	0%	0	0%
Primary level	0	0%	0	0%	0	0%
Junior cert	0	0%	0	0%	0	0%
Leaving cert	5	13.5%	4	22.2%	1	5.3%
Diploma or cert	5	13.5%	2	11.1%	3	15.8%
Undergraduate degree	17	45.9%	10	55.6%	7	41.2%
Postgraduate degree	10	27%	2	11.1%	8	42.1%

Table 6

Language group differences in age, education and socio-economic status

	Monolinguals			Bilingual/multilingual						
	M	SD	n	M	SD	n	t	df	p	95%cl
Education in years	17.78	2.78	18	17.16	3.18	19	.63	35	.53	-1.38,2.62
SES	4.39	.92	18	4.79	.86	19	-1.38	35	.18	-.99,.19

Table 7

Descriptive statistics for the letter numbering sequencing task, Corsi block task and the n-back task

	Mean (95% Confidence Intervals)	SD	range
LNST			
Total score	10.81 (10.16-11.51)	2.09	8-16
monolingual	10.72 (9.94- 11.61)	1.84	8-15
Bilingual/multilingual	10.89 (9.89- 11.95)	2.36	8-16
Corsi block task			
Total score	41.89 (36.92-47.51)	15.96	20-96
monolingual	38.72 (33.28- 44.94)	12.59	20-63
Bilingual/multilingual	44.90 (37.84- 53.47)	18.45	24-96
n-back			
Total score	-.23(-.72-.26)	1.61	-4.16- 3
monolingual	-.04 (-.70- .69)	1.57	-2.67- 3
Bilingual/multilingual	-.41 (-1.20- .26)	1.67	-4.67- 2.33

Inferential statistics

As corsi- block task total score was not normally distributed A Mann- Whitney U test was conducted to compare means in visual spatial WM, using the corsi- block total memory score between bilinguals/multilinguals and monolinguals. There was no significant difference in scores, with monolinguals (M = 38.72, SD = 12.59) and bilinguals/multilinguals (M = 44.90, SD = 18.45) U = 211.50, p = .21. These results indicated that there was no significant difference between monolinguals and bilinguals/multilinguals visuospatial WM.

An independent samples t-test was conducted to compare Phonological WM using the LNST total score between bilinguals/multilinguals and monolinguals. There was no significant difference in scores, with monolinguals (M = 10.72, SD = 1.84) and bilinguals/multilinguals (M = 10.89, SD = 2.36), t (35) = -0.25, p = 0.81, two tailed. These results indicate that monolinguals and bilingual/multilinguals in this experiment performed similarly in the verbal WM task.

An independent samples t-test was conducted to compare WM capacity using the n-back total memory score between bilinguals/multilinguals and monolinguals. There was no significant difference in scores, with monolinguals (M = -0.04, SD = 1.57) and bilinguals/multilinguals (M = -0.41, SD = 1.67), t (35) = .69, p =.49, two tailed. These results indicate that monolinguals and bilingual/multilinguals in this experiment performed similarly in the n back task. As numerous t-tests were conducted and considering Bonferroni correction a p value of <0.01 was needed for the model to be considered significant.

Discussion

The purpose of this research was to investigate whether early bilinguals/multilinguals demonstrated a BA in various WM tasks, when compared to monolinguals. The first hypothesis was that bilinguals/multilinguals would perform better on tasks of WM capacity. The findings did not support this hypothesis. The second hypothesis was that the bilingual/multilingual group would perform better on a task of visual- spatial WM, the findings did not support this hypothesis. The final hypothesis was that monolinguals would have higher performance scores in phonological WM, once again the results did not support this hypothesis.

Previous research that examines the BA has been controversial, with much research finding a BA in WM capacity and visio-spatial WM (Adesope et al., 2010; Morales et al., 2013; Morrison et al., 2019). In consideration of the literature, the present study supports those of Lehtonen et al. (2018) whose meta -analysis found no BA in WM tasks. One of the criticisms of Lehtonen et al. (2018) meta-analysis was that many of the WM tasks that were included in the analysis were simple digit span tasks. The present results were surprising as high capacity WM tasks such as the n- back task were utilized, as recommended by previous literature (Morrison et al., 2019; Bialystok et al., 2004; Jiao et al., 2019). The discrepancy between past findings and the current study may be due to the age range in the present study, participants were aged between 18- 65, perhaps a BA in WM is not as obvious in those in their cognitive prime and is more pronounced in children (Grundy & Timmer, 2017) or older adults (Bialystok et al., 2014). These results may suggest that people aged 18-65 might not demonstrate the same WM benefits as those in other age groups.

Previous research suggested that participants should be matched on both education and SES to see a BA (Cockcroft et al., 2019; Paap et al., 2015; Namazi & Thordardottir, 2010). The present sample had comparable education levels and SES status, this is an

important consideration when examining the results. The majority of the sample firstly, reported that they had an undergraduate degree or higher, and secondly that they made ends meet fairly easily (or above). One interpretation of this could be that as monolingual participants were highly educated, this might have enhanced their WM, mitigating the BA that would be expected from the bilingual/multilingual group (Goral et al., 2015). Secondly, as the majority of the sample had a self-reported SES that was in the higher ranges, perhaps the benefits of bilingualism in adults is more obvious in lower SES groups, as demonstrated by Cockcroft et al. (2019). When considering SES and education level these results might suggest that these factors lessen the BA in WM.

Contrary to the previous research findings, our study did not support the finding that monolinguals would outperform bilingual/multilinguals in phonological WM (Bialystok et al., 2009; Bialystok et al., 2004). Similar to Bonifacci et al. (2011) our results suggests that monolinguals and bilingual/multilinguals performed similarly in phonological WM. Like other aspects of WM perhaps phonological WM may also be enhanced by variables such as education and SES as suggested by Goral et al. (2015). This might explain some of the inconsistencies within the literature with people who are educated and from higher SES groups performing the same or better than monolinguals on verbal WM tasks (Warmington et al., 2019; Bonifacci et al., 2011). Bialystok, Majumder, and Martin (2003) have suggested that there might be a BA associated with languages with phonological similarities, such as Spanish and English. The participants in the current study spoke a multitude of different languages, as suggested it could be possible that the diversity of languages spoken may have impacted results. Future research could examine bilingualism and phonological similarities to decipher if the BA is associated with certain aspects of bilingualism.

Considering the critical period, the present study excluded bilinguals/multilinguals who acquired their L2 after the age of 7. The results of this study support those of Kousaie et

al. (2014) and Lehtonen et al. (2018) who also found no BA in EF in people who acquired fluency in L2 at a young age. Although the bilingual/multilingual participants had a high L2 proficiency many of the participants did not utilise their L2 regularly when English was their L1. English was the most dominant language used by bilinguals/multilinguals even when it was not their first language, as suggested by previous research, perhaps if participants utilised their languages more frequently the BA would be more evident (Yow & Li, 2015; Soveri et al., 2011). Future research should examine the BA in those who are regularly engaged in both languages. When considering the AoA of L2 in the current study the age ranged from birth to seven years old. This might suggest that there could be BA discrepancies even within the critical period, perhaps a BA might be obvious if someone learnt there L2 at birth, and used both languages daily as demonstrated by Morales et al. (2013).

The present study had many strengths. Firstly, it examined the BA in WM in isolation of other aspects of cognitive functioning. Many previous studies use a battery of cognitive tasks that explore various aspects of executive functioning, by focusing on WM alone this allowed for a more thorough analysis of the BA in WM. A wide battery of complex WM tasks were used in the present study, this enabled the researchers to study multiple components of WM (phonological, visio-spatial and WM capacity). This is a strength of the study as it allowed the researcher to investigate the BA across different domains of WM as opposed to looking for benefits in one component of WM, as demonstrated by previous research (Goral et al., 2015). Previous research has been criticized for failing to use complex WM tasks, this study used complex tasks, which allowed for a comprehensive comparison between the two groups, as complex tasks are required to illicit a BA for people in their cognitive prime (Bialystok et al., 2004; Jiao et al., 2019). The tasks were administered in a counter balanced order this ensured that any fatigue related to the tasks was accounted for. As previously mentioned, participants were matched on SES and

education, this suggests that these variables did not confound the results. Often studies do not measure education levels of participants or use education as a measure of SES (Namazi & Thordardottir, 2010), the present study measured both as separate factors, and therefore could account for the risk of both confounding results.

The current study was affected by numerous limitations. Firstly, the sample size was small with 37 participants, this may have subdued potential findings, however, previous research studying the BA have used similar sized samples (Linck & Weiss, 2015). Secondly, as the current study had a cross-sectional design a cause and effect relationship could not be established. As self- report measures were used to gather information on language demographics, the researchers were unable to determine how accurate factors relating to language ability actually were, however self-report measures are commonly used in studies examining the BA, with researchers finding that they are often as reliable as objective measures of language ability (Goral et al., 2015; Marian et al., 2007). As participants reported both their education level and SES level in the higher ranges the results are not generalisable to the population, however this could also be seen as a strength as less is known about the BA in those with higher levels of education (Van den Noort et al., 2019). Finally, much of the monolingual sample had been exposed to an L2 in school, however the proficiency was very low and therefore not included in the analysis, finding monolinguals who have no L2 knowledge is an ongoing issue in studying the BA (Woumans et al., 2015).

The current study has added to the current knowledge on the BA in WM. Firstly, it has demonstrated that those from higher SES and educational groups might not benefit from bilingualism when they are in their cognitive prime. This finding has implications for future research and indicates that when addressing the BA and WM, researchers need to be stringent in matching participants in both SES and education, as failure to measure them accurately might lead to false findings (Paap, Johnson, & Sawi, 2015). Secondly, despite using complex

WM tasks a BA was not evident in WM in people aged 18-65, this again might suggest that education and SES mediate the effects of bilingualism. Future research should examine the BA and compare different groups on education level and SES to determine whether the BA in WM is present in adults from lower SES and education backgrounds only. When accounting for AoA and language proficiency the BA may not be present in adults WM. This study also emphasises the importance of addressing language demographics of participants, although high proficiency in all spoken languages was evident in participants an WM advantage was not found. This has implications for future research as it suggests that there might be other language aspects that might contribute to a BA. Future research should examine bilinguals/multilinguals who use both of their languages frequently to determine whether the BA in WM is only associated with people who switch between languages regularly (Yow & Li, 2015). As most monolinguals have been exposed to an L2 at some stage in their life future research could compare bilinguals to multilinguals, if there is a BA perhaps one might expect it would be greater for multilinguals. As L2 learning is a complex process that is influenced by many factors (Van den Noort et al., 2019), more longitudinal research is warranted to investigate the BA, to see if there are cognitive benefits across the lifespan.

In summary, this study found no BA in adults visio-spatial WM, phonological WM or in WM capacity. These results indicate the importance of matching participants on variables such as education and SES as recommended by Van Den Noort et al. (2019), as similarly matched participants might not demonstrate a BA. The results highlight that a BA might not be evident in people in their cognitive prime, despite using complex WM tasks, which was not found by previous researchers (Morrison et al., 2019. Finally, the results highlight that high proficiency in all languages might not contribute to a BA in early bilingual/multilinguals aged 18-65, who report higher SES and education levels. However, the present results are only suggestive, considering the amount of studies that have found a BA in EF. The results

contribute to the discussion on the effects of bilingualism/multilingualism on WM, but further research is required.

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Appendix A

Is Early Bilingualism/Multilingualism Associated with an Advantage in Working Memory in Adults

The demographic and language ability questionnaire

Participant ID _____

Gender :

Male □1

Female □2

Age: _____

Language ability

1. Please list all the languages you know **in order of dominance** (*from the language you speak the most to the language you speak the least*):

   _____

   _____

   _____

   _____

2. Please list all the languages you know **in order of acquisition** (*your native language first*):

   _____

   _____

   _____

   _____

3. Please indicate the age you acquired each of your languages:

List language here:	age you acquired language here:

4. On a scale of 0-100 (100 indicates that you are very proficient) how would you rate your proficiency in each language you speak:

List language here:	List proficiency here:

5. Please list what average percentage of the time that you speak and people speak to you in each language. (*Your percentages should add up to 100%*):

List language here:	Percentage of time:

Socio-Economic Status

A household may have different sources of income and more than one household member may contribute to it. Concerning your household's total monthly or weekly income, with which degree of ease or difficulty is the household able to make ends meet?

With great difficulty □1

With difficulty □2

With some difficulty □3

Fairly easily □4

Easily □5

Very easily □6

Education

(1) How many years of formal education do you have? _____

(2) Please check your highest education level (or the approximate Irish equivalent to a degree obtained in another country):

None □1

Primary level □2

Junior cert or equivalent □3

Leaving cert or equivalent □4

Diploma or certificate □5

Undergraduate degree □6

Postgraduate degree Ph.D/M.D. □7

Appendix B

Administer the task as scripted below.

Participants are required to track letters and numbers, and then simultaneously remember and re-order the stimuli.

However, **if all 3 trials of an item are answered incorrectly, the test can be discontinued.**

"Now, I am going to say a group of numbers and letters. After I say them, I want you to tell me the numbers first, in order, starting with the lowest number. Then tell me the letters in alphabetical order."

"For example, if I say B-7, your answer should be 7-B. The number goes first, then the letter. If I say 9-C-3, then your answer should be 3-9-C, the numbers in order first, then the letters in alphabetical order. Let's practice."

Administer practice trials by reading from the practice sheet.

Say each combination at a rate of one letter/number per second.

Allow the participant ample time to respond. Correct any errors during the practice trial and repeat instructions as necessary.

Even if the participant fails all practice trials, continue to the test.

"That is the end of the practice. Are you clear on what you have to do?". If the participant is not clear, repeat the instructions again. (**"I am going to say a group of numbers and letters. After I say them, I want you to tell me the numbers first, in order, starting with the lowest number. Then tell me the letters in alphabetical order."**) **"Ready?"**

Administer the items by reading them from the record form. Record the participants' response on the record form – in the space for participant response ***underneath*** the correct response for each trial.

If the participant scores 0 on all three trials within one item, discontinue the test.

Appendix C

Participant ID: _____ **Date: _____**

Letter Number Sequencing Test

Read the letters and numbers at a rate of one letter/number per second.

PRACT CE TRIALS	
Trial	**Correct response**
6-F	(6-F)
G-4	(4-G)
3-W-5	(3-5-W)
T-7-L	(7-L-T)
1-J-A	(1-A-J)

TEST TRIALS			
	Stimulus	**Correct Response**	**Score**
1.1	**L – 2**	(2 – L)	
	Participant Response:		
1.2	**6 – P**	(6 – P)	
	Participant Response:		
1.3	**B – 5**	(5 – B)	
	Participant Response:		
2.1	**F - 7 - L**	(7 – F – L)	
	Participant Response:		
2.2	**R – 4 – D**	(4 – D - R)	
	Participant Response:		
2.3	**H – 1 - 8**	(1 – 8 – H)	
	Participant Response:		
3.1	**T – 9 – A – 3**	(3 – 9 – A – T)	

	Participant Response:		
3.2	**V – 1 – J – 5**	(1 – 5 – J – V)	
	Participant Response:		
3.3	**7 – N – 4 – L**	(4 – 7 – L – N)	
	Participant Response:		

Participant ID: _____ **Date: _____**

4.1	**8 – D – 6 – G – 1**	(1 – 6 – 8 – D – G)	
	Participant Response:		
4.2	**K – 2 – C – 7 – S**	(2 - 7 – C – K – S)	
	Participant Response:		
4.3	**5 – P – 3 – Y – 9**	(3 – 5 – 9 – P – Y)	
	Participant Response:		
5.1	**M – 4 – E – 7 – Q – 2**	(2 – 4 – 7 – E – M – Q)	
	Participant Response:		
5.2	**W – 8 – H – 5 – F – 3**	(3 – 5 – 8 – F – H – W)	
	Participant Response:		
5.3	**6 – G – 9 – A – 2 – S**	(2 – 6 – 9 – A – G – S)	
	Participant Response:		
6.1	**R – 3 – B – 4 – Z – 1 – C**	(1 – 3 – 4 – B – C – R – Z)	
	Participant Response:		
6.2	**5 – T – 9 – J – 2 – X – 7**	(2 – 5 – 7 – 9 – J – T – X)	
	Participant Response:		
6.3	**E - 1 – H – 8 – R – 4 – D**	(1 – 4 – 8 – D – E – H – R)	
	Participant Response:		
7.1	**5 – H – 9 – S – 2 – N – 6 – A**	(2 – 5 – 6 – 9 – A – H – N – S)	
	Participant Response:		
7.2	**D – 1 – R – 9 – B – 4 – K – 3**	(1 – 3 – 4 – 9 – B – D – K – R)	
	Participant Response:		
7.3	**7 – M – 2 – T – 6 – F – 1 – Z**	(1 – 2 – 6 – 7 – F - M – T – Z)	
	Participant Response:		

Appendix D

Would you be interested in taking part in a study that investigates language and working memory?

To be eligible to participate you must be

1. **Aged between 18-65**
2. **Have 2 or more languages from the age of 7 or only speak in English**

If interested please e-mail me on x15039111@student.ncirl.ie and I will provide you with further information.

Appendix E

Bilingual/Multilingual Advantage: Is Early Bilingualism/Multilingualism Associated with an Advantage in Working Memory in Adults.

Thank you for your interest in this research. You are being invited to take part in this study, which investigates memory performance and language use. Before deciding whether to take part, please read the following document carefully, which explains why the research is being done and what it would involve for you. If you have any questions about the study, you will have the opportunity to discuss these with the researcher before you decide whether to take part in the research.

I would also like to provide you with a little bit of information on who I am. My name is Niall Flavin, and I am a final year psychology student at the National College of Ireland. As part of our final year we are required to conduct a piece of research. I am conducting my research project in the area of working memory as I am hugely interested in how the brain works. My project is supervised by Dr Caoimhe Hannigan, Lecturer in Psychology at National College of Ireland.

What is this research about?

There are many different types of memory. For the purpose of this research I am interested in one aspect of memory called working memory. This is the type of memory that is used when you need to work out a problem. For example, working memory is used if you want to add two numbers together in your head, or remember sequences such as a phone number. Researchers are interested in whether different experiences and activities can have an impact on our working memory. One experience that may impact on working memory is speaking 2 or more languages (or being bilingual/multilingual). This piece of research aims

to investigate this by comparing working memory performance between individuals who speak only one language, and individuals who are bilingual or multilingual.

What will taking part involve?

If you decide to take part in this study, you will be asked to take part in one research session, which should take approximately 25 minutes to complete. This will be scheduled in a time and place that is convenient to you. During this session, you will first be asked to sign a consent form to indicate your agreement to take part in the research – if you have any questions about the study, you will have the opportunity to ask these before you decide whether to take part. You will be asked to complete a brief questionnaire to provide some basic information about you and the languages that you speak. You will then be asked to complete three brief tasks that are designed to measure working memory, as follows:

- A verbal task, where you will be asked to remember some letters and numbers that are called out by the researcher.
- Two computer-based tasks, where you will be asked to remember some sequences of shapes presented on the screen. You will be required to indicate the correct sequence by pressing some keys on the keyboard.

Who can take part?

You can take part in this research if you are:

- between the years 18-65
- You are monolingual (fluent in English only) OR you have been bilingual/multilingual from early childhood (before you were 7 years old)
- You do not have a known cognitive impairment.

Participation

Participation in this study is entirely voluntary, you do not have to take part, and a decision not to take part will have no consequences for you. You can withdraw from the study at any stage of the process without providing a reason. The study will take approximately 25 minutes to complete – you can choose to end the session at any time if you would prefer not to continue. You can also take breaks during the session if you wish. You can withdraw your data from the study after you have completed your session, up to the point that the results have been written up for submission in my thesis. If you want to withdraw your data, you can contact me using the details below.

Will taking part be confidential?

Participation in the study is strictly confidential. The information that you provide will not be shared with anyone outside of the research team – only the student researcher and their supervisor will have access to this information. Each participant will be assigned a unique ID code, and their data will be stored under their ID code, separate from their name or any other identifying information. All information collected on computer will be stored securely in a password protected folder. All paper data collected will be stored in a locked filing cabinet. Your name will not appear anywhere in the final research thesis. The data will be stored for 5 years in accordance with the NCI data retention policy. Under the Freedom of Information legislation, you are free to view your data at any time.

What will happen to the results of this study?

The results of this study will be written up and presented within my dissertation, which will be submitted to National College of Ireland as part of my final degree. The results may also be presented at conferences within the College and at a national level or may be submitted to

an academic journal for publication. The results that are presented will not contain any information that could identify participants.

Finally, I would like to thank you for taking the time in reading this document. If you have further queries, please contact me on x15039111@student.ncirl.ie or my supervisor on caoimhe.hannigan@ncirl.ie.

Appendix F

Consent

I _____ have read and understood the information sheet provided. I understand the nature of the study and my right to withdraw at any time.

I understand that the research involves taking part in one research session, during which I will be asked to complete a brief questionnaire and 3 tasks to measure working memory.
I understand that the information collected in the study will be used to in the researcher's thesis as well as college presentation and may be presented in Psychology Society of Ireland or submitted to academic journal for publication. I understand that the information provided is strictly confidential and my name will not appear in the research.
I understand that under the Freedom of Information legislation I am entitled to access the information I have provided. I understand that I am free to contact the researcher or supervisor should I have any queries or worries regarding the research.

Signature of participant: _____

Date: _____

Signature or researcher: _____

Date: _____

Participant ID: _____

Appendix G

Debriefing Sheet

I would like to take this opportunity to thank you for partaking in this research. The results of this study will be analysed to investigate whether being bilingual/multilingual from early childhood enhances working memory performance.

If you have any queries about the research or wish to withdraw your results please contact me on x15039111@student.ncirl.ie or my supervisor on caoimhe.hannigan@ncirl.ie.

If you would like to hear about the results of the study, you can also contact me using the details above.

Appendix H

Evidence of data