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Working Memory Performance in Spanish-English Bilinguals' First and Second Languages

Jordan Allyssabeth Orozco
University of Texas at El Paso

WORKING MEMORY PERFORMANCE IN SPANISH-ENGLISH BILINGUALS' FIRST AND SECOND LANGUAGES

JORDAN ALLYSSABETH OROZCO

Master's Program in Speech-Language Pathology

APPROVED:

Patricia Lara, Ph.D., CCC-SLP Chair

Jamie L. Desjardins, Ph.D., CCC-A

Deena G. Peterson, M.S., CCC-SLP

Cecilia Fierro, OTD, OTR

Stephen L. Crites, Jr., Ph.D.
Dean of the Graduate School

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JORDAN ALLYSSABETH OROZCO, BA

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ABSTRACT

Background: Working memory is important for speech understanding in that speech recognition requires the processing, temporary storage, and manipulation of information during complex cognitive tasks. Previous research has shown contradictory findings on whether bilinguals have an advantage in working memory capacity compared to their monolingual counterparts. Differences in findings have been attributed to various factors to include task-dependent effects and poorly matched samples. Therefore, the existence of a bilingual advantage in working memory remains unclear.

Purpose: The purpose of this study was to examine the working memory performance of Spanish/English bilingual individuals compared to English monolingual individuals using a linguistically demanding working memory task.

Methods: A group of 20 Spanish-English bilinguals aged 18-33 and 20 English monolinguals aged 18-25 participated in the study. Working memory performance was measured using a modified version of the Listening Span (LSPAN) Test in quiet and in background noise.

Results: All participants performed significantly better on the 2-span condition compared to the 4- and 6-span conditions [F (2,76) =323.45; *p* = <.001; η_{p2} = 1.00] and participants' working memory performance was significantly better in quiet compared to background noise [F (1,38) =22.25; *p* = <.001; η_{p2} = .996]. Bilingual participants performed significantly better than monolinguals in quiet and noise on the 4-span condition, and in quiet on the 6-span condition [F (2,76) =3.114; *p* =.05; η_{p2} = .583]. Bilingual participants also performed significantly better in English than in Spanish [F (1,19) =17.89; *p* =<.001; η_{p2} = .980].

Conclusions: Spanish-English bilinguals have better auditory verbal working memory performance than English monolinguals. Results from this study suggest that the constant management of two language systems may enhance auditory working memory performance in bilingual individuals.

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CHAPTER 1: LITERATURE REVIEW

1.1 Introduction

Language comprehension, spoken and written, is heavily dependent on working memory, in that it requires the processing, temporary storage, and manipulation of information in the presence of complex cognitive tasks (Baddeley, 2003; Buchsbaum, 2016; Grundy & Timmer, 2017). Bilinguals have been shown to have an advantage in working memory capacity as compared to their monolingual peers (Grundy & Timmer, 2017). The bilingual advantage for working memory has largely been attributed to a domain-general executive control advantage due to the lifelong management of their two language systems (Hilchey and Klein, 2011). However, the bilingual advantage for working memory has not been evidenced in all studies (Grundy & Timmer, 2017). In fact, some researchers contend that differences in findings are due to task-dependent effects and poorly matched participant samples (Antón, Carreiras, & Duñabeitia, 2019). Differences in socioeconomic status, immigration status, and level of bilingualism have been shown to affect executive functions such as working memory (Antón et al., 2019; Grundy & Timmer, 2017). Moreover, many researchers have investigated the bilingual advantage using working memory tasks that may not require the same complex cognitive control processes involved in the management of two language systems (Antón et al., 2019). However, given the relationship between working memory, language comprehension, and bilingualism, it seems likely that the bilingual advantage may be enhanced during linguistically demanding tasks in the auditory domain.

1.2 Working Memory

Working memory is a cognitive system involved in the processing, temporary storage, and manipulation of information during complex cognitive tasks like the recognition and comprehension of speech and language (Baddeley, 2003; Buchsbaum, 2016). According to Baddeley and Hitch (1974), the working memory system can be broken down into three separate components, the central executive, the phonological loop, and the visuospatial sketchpad, all of which are thought to work together as a single system when performing complex cognitive tasks. The "central executive" is conceptualized as the system of limited attentional capacity for controlling and coordinating two subsystems, a phonological loop and a visuospatial sketchpad (Buchsbaum, 2016). The visuospatial sketchpad is responsible for the storage and maintenance of visuospatial information, while the phonological loop is dedicated to the storage and maintenance of verbal information, and thus, is the primary component involved in working memory for verbal material.

Specifically, the phonological loop is composed of two interacting components; the phonological store and the articulatory rehearsal process. The phonological store acts as a passive buffer which allows for information to be briefly stored (approximately 2 seconds). The articulatory rehearsal, an active process, works to refresh the verbal material from the store, which ultimately allows the maintenance of verbal sequences in memory over intervals of time (Bachsbaum, 2016). The original model was updated to include a fourth subsystem, the episodic buffer, which is a temporary storage system in which information from the phonological loop and visuospatial sketchpad can be combined to interact with long-term memory (Baddeley, 2003). This memory system is thought to have a limited capacity that needs to be disbursed between the work (processing demands) and the memory (storage demands) (Yumba, 2017).

1.3 Language Comprehension and Working Memory

Language comprehension is a skilled task that involves more than simply comprehending single words. A primary component of skilled comprehension is a listener's ability to process the semantic and syntactic relations of incoming words, phrases, and sentences, while creating logical and meaningful representations of the information (Daneman & Merikle, 1996). Additionally, temporary storage is an important component of language comprehension as verbal input may take place over an interval of time and sections of the input must be related to one another for the message to be properly understood (Caplan & Waters, 2005). For this reason, working memory has been shown to be related to language comprehension (Rönnberg, Rudner, Foo, & Lunner, 2009). Ronnberg (2003) proposed a comprehensive model, the Ease of Language Understanding

(ELU) model, to explain the relationship between working memory and language comprehension. The ELU states that when incoming linguistic signals consist of phonological, syntactic prosodic, and semantic information, it is bound together at the cognitive level to create a phonological stream of information (Rönnberg et al., 2009). As long as the speech signal input is not degraded or under suboptimum conditions (e.g., noisy conditions), the phonological information can rapidly match the acoustic input to phonological representation stored in long-term memory (Rönnberg et al., 2009). However, if listening conditions are sub optimal, the probability that the phonological information will be matched correctly, decreases.

Just and Carpenter (1992) also proposed the capacity constrained theory, which states that individuals have a working memory capacity that constrains language comprehension, and this constraint may be greater for some individuals than for others. Differences in the component processes of language comprehension (e.g., syntactic, semantic, and referential processes), vocabulary size, and motivation are all thought to affect an individual's working memory capacity (Just & Carpenter, 1992). In this theory, two functions (storage and processing) of working memory are said to occur during language comprehension (Just & Carpenter, 1992). These two functions are fueled by activation and therefore, an individual's working memory capacity can be thought of as their maximum available activation. Moreover, working memory capacity can be manipulated when the maintenance of an extrinsic load (e.g., series of words or digits that are to be remembered for later recall) is required (Just & Carpenter, 1992). In sum, increased task demands (noisy conditions and extrinsic load) as well as individual differences can significantly impact individuals' working memory capacity and overall language comprehension (Just & Carpenter, 1992; Desjardins & Doherty, 2013).

The capacity constrained theory has been explored in research through the investigation of these effects of increased task demands and group differences on language comprehension. Desjardins and Doherty (2013) aimed to investigate the effects of noisy conditions on speech recognition performance (language comprehension) in younger and older individuals. The authors found all listeners performed better in quiet than in background noise and that older adults performed more poorly than younger adults. This finding was attributed to the increased level of cognitive resources (e.g., working memory and processing-speed ability) that older individuals must exert in order to maintain a similar listening performance as younger individuals in the presence of background noise.

1.4 Bilingualism and Working Memory

Bilingualism, the practice of speaking two languages, has been thought to enhance various executive functions such as task-switching and cognitive flexibility (Desjardins, Barraza & Orozco, 2019; Grundy & Timmer, 2017). This enhancement in cognitive functioning is thought to be attributed to the constant management of two language systems that compete for selection during day-to-day situations. This competition is said to require higher-order executive control processes, which may ultimately enhance generalized executive functioning (Grundy & Timmer, 2017). Given that language comprehension is heavily dependent on working memory, and that a positive relationship exists between working memory and executive functions, it is reasonable to assume that bilinguals would likely demonstrate greater working memory capacity than their monolingual counterparts (Grundy & Timmer, 2017).

Findings in Support of a Bilingual Advantage

Morales, Calvo, and Bialystok (2013) examined the performance of monolingual and bilingual children on working memory tasks of differing difficulty levels. Results revealed that bilingual participants responded more rapidly throughout the working memory tasks than monolinguals, and achieved higher scores on the more difficult working memory conditions. The authors concluded that bilingual children outperform monolingual children on working memory tasks. Results support the presence of a bilingual advantage in working memory. However, the authors noted that both tasks used in this study required low verbal requirements, which may have attributed to the presence of a bilingual advantage in comparison to previous studies that have found no bilingual advantage. Consistent with this, Blom and colleagues (2014) found that

Turkish-Dutch bilingual children show cognitive gains compared to Dutch monolingual children on visuospatial and verbal working memory tasks. Moreover, the authors stated that sequential bilingualism may place Dutch bilinguals at an advantage on working memory tasks that are less language specific and require higher level of executive control.

Ańton, Carreiras, and Duñabeitia (2019) investigated the effects of bilingualism on working memory of 90 Spanish monolinguals from Murica and 90 Basque-Spanish bilinguals from Basque Country. All participants had a mean age of 22 years, and both groups were matched on a variety of factors which included differences in age, IQ, socio-economic status (SES), educational level, and knowledge of Spanish. These factors were controlled for because many researchers have argued that evidence in favor of a bilingual advantage is due to various uncontrolled external factors (e.g. SES, education, linguistic competence) rather a true bilingual advantage. To assess working memory the authors utilized two versions (forward and backward) of the Corsi test and the digit span test. Findings revealed that bilinguals outperformed monolinguals on the inverse versions of the Corsi and digit span tasks, with no differences in the forward versions. The authors attributed this finding to the complex processing and retrieval of the backward tasks, in which the domain general working memory system is required. Domain-general working memory abilities are thought to be susceptible to improvement through the enhancement of another domain (e.g., bilingualism). The authors concluded that although there was no effect of bilingualism in the easier version of the working memory tasks, there is evidence in support of a bilingual advantage in tasks that require storing, manipulation, and retrieval. Moreover, the authors noted that their study was the first to discover a bilingual advantage in working memory in carefully matched large groups.

Yang (2017) investigated whether a difference exists in working memory between 20 Korean near-monolinguals (mean age = 24.50), 20 Korean-English intermediate bilinguals (mean age = 24.45), and 20 Korean-English high proficiency bilinguals (mean age = 23.50). The author also investigated the relationship between the bilinguals' advantage and language practices. All bilingual participants were sequential bilinguals, and the amount of language use and second language proficiency were used to distinguish between different bilingual groups. Gender, age, field of study, and socioeconomic status were all controlled for to reduce the potential of skewed results. Daily language practices were measured through semi-structured interviews with 8 bilingual participants (4 intermediate bilinguals and 4 high proficiency bilinguals). Auditory and visual digit span tasks were used to measure participants' working memory. Numeric digits were used as stimuli for the visual digit span task and Korean was selected as the auditory stimuli for the auditory digit span tasks. Forward and backward (reverse order) digit span tasks were implemented into the auditory and visual tasks.

Findings revealed that the intermediate bilingual group outperformed the monolingual group and the high proficiency bilingual group during both the visual and auditory digit span tasks. Moreover, the intermediate bilingual group also scored higher during the reversed order of digits in the auditory task. Overall, the author's findings support the idea, to some degree, that the use of two languages serves as a cognitive training. The author stated that the intermediate bilingual group might have more developed working memory because of the high demands of managing both of their languages. They contend that that this group is required to overcome their lack of language proficiency, and are continuously monitoring, memorizing, and replaying what they hear. On the other hand, the highly proficient bilinguals may not exhibit an advantage due to their high second language proficiency, which allows for instantaneous processing. Thus, it is possible that bilingualism does not guarantee a working memory advantage, and may depend more on bilinguals' unique second language practices and environment.

Lastly, Ljungberg and colleagues (2013) investigated episodic memory recall, verbal letter fluency, and categorical fluency performance of 74 Swedish-monolingual and 104 bilinguals (95% reported English as a second language) who ranged in age from 35-70 years old. Education, gender, and general fluid ability were all controlled for. All testing was performed in Swedish. Episodic memory recall was measured using three different recall tasks: the recall of actions and sentences, category cued recall of nouns, and recall focused attention. Findings revealed a bilingual advantage in episodic memory recall and letter fluency performance, and this advantage was seen across age. Moreover, there was no interaction between bilingual and monolingual performance and age, meaning bilinguals outperformed monolinguals similarly across all ages. Overall, the authors of this study concluded that their evidence is in support of the fact that bilingualism may optimize memory performance across age.

Findings not in Support of a Bilingual Advantage

However, a bilingual advantage in working memory has not been evidenced in all studies. For example, Engel de Abreu (2011) investigated whether bilingual children exhibit an advantage in verbal working memory performance. A total of 44, 6- to 8-year-old bilingual and monolingual children were tested over a longitudinal period of 3 years. All participants were matched on age, sex, and socioeconomic status. The 22 bilingual children were exposed from birth to two languages, one language being Luxembourgish and the other being any of the following: French, Spanish, German, Dutch, Portuguese, Czech, and Italian. The 22 monolingual children were only exposed to Luxembourgish from birth, however exposure to German began at age 7 due to scholastic instruction. All participants were tested on three different occasions within a 3-year time period. The author obtained various measurements including fluid intelligence, performance on complex span tasks, performance on simple span tasks, expressive vocabulary, and syntax. Working memory was assessed using the Counting Recall task, the Backwards Digit Recall task, and the Digit Recall task from the Luxembourgish version of the Automated Working Memory Assessment (AWMA; Alloway, Gathercole, Kirkwood, & Elliott, 2007).

Findings from this study revealed that monolinguals performed significantly better than the bilinguals on vocabulary and syntax. The authors also found that both the bilingual and monolingual groups performed equally well on all working memory tasks. The author concluded that there was no evidence to suggest that a bilingual advantage emerges across the years. The author attributed the lack of a bilingual advantage to the fact that the cognitive control processes utilized in the working memory tasks may be different due to the type of processes required for resolving conflict between competing lexical responses. Additionally, the author suggested that young simultaneous bilinguals are able to switch between languages in a highly automatic manner and may not rely on any cognitive control processes.

Lastly, Ratiu and Azuma (2015) investigated the differences between 53 English monolinguals and 52 Spanish-English bilinguals on verbal and non-verbal complex working memory span tasks. All participants had a mean age of about 19 years. The study consisted of four tasks: a backward digit span task, two operation span tasks (verbal), and a symmetry span task (non-verbal). The authors found no bilingual advantage on the verbal or non-verbal working memory span tasks or in the backward digit-span task. In the operation span task, the monolingual participants performed significantly better than the bilingual group. However, the monolingual and bilingual group performed similarly on the non-verbal symmetry span task. The authors found that individual working memory was more predictive of non-verbal simple and complex performance than bilingual status. The authors concluded a bilingual advantage may present itself when the tasks are specific to conflict resolution or switching between tasks. Moreover, the authors stated that the participants experience with bilingualism may result in improved switching ability, rather than inhibitory control.

Summary of Findings

In summary, based on findings in the literature, it remains unclear whether bilinguals have an advantage in working memory function compared with their monolingual peers. Furthermore, it remains unclear how bilinguals working memory performance may differ between their first and second languages as the majority of studies have only tested individuals' working memory performance in one of their languages. Lastly, the working memory tasks implemented in previous studies were primarily visual and required minimal linguistic demands. Since, the bilingual advantage is thought to result from managing two complex linguistic systems, it stands to reason that if bilinguals have an advantage in working memory, then the advantage would likely be more evident on linguistically demanding working memory tasks.

1.5 Tasks to Measure Working Memory

Working memory tasks vary widely across different studies; and require different procedures, stimuli, and mode of presentation (Calvo, Ibáñez, & García, 2016). Working memory is typically assessed using span tasks, such as the reading span, counting span, and operation span (Conway, Kane, Bunting, Hambrick, Wilhelm, & Engle, 2005). These tasks have gained popularity not only for their sound methodology and scientific usefulness, but also because performance on span task has been shown to be highly correlated with various complex cognitive behaviors, such as language comprehension, reasoning, and problem solving (Conway et al., 2005). Moreover, the methodology of working memory span tasks has shown to be reliable and valid measures of working memory (Conway et al. 2005). Span tasks previously were designed using Baddeley and Hitch's (1974) theory regarding working memory. This theory stresses the *functional importance* of creating a memory system that requires an individual to briefly store task-relevant information in memory while executing a complex cognitive task, rather than simply just storing and rehearsing information (Conway et al., 2005). Therefore, working memory tasks, were created to require "to-be-remembered" target stimuli, such as words, accompanied by a demanding secondary task, such as comprehending sentences. Daneman & Carpenter (1980) developed the first tasks aimed at targeting the storage and processing of working memory, the reading span task and listening span task. Both tasks resemble a simple word span task, with the addition of a secondary processing component, comprehending sentences. Participants are required to read or listen to sentences, and identify the logical accuracy of the sentences (true or false), while trying to remember the last word of each sentence (Conway et al., 2005).

Speech recognition relies heavily on an individual's ability to correctly process incoming information while creating logical meaning from it (Akeroyd, 2008). Temporary storage is an integral part of speech understanding as verbal input may take place over an interval of time and sections of the input must be related to one another for the message to be properly understood (Caplan & Waters, 2005). For this reason, speech understanding is heavily dependent on working memory, which is the processing, temporary storage, and manipulation of information in the presence of a complex cognitive task (Baddeley, 2003; Buchsbaum, 2016; Grundy & Timmer, 2017).

1.6 Purpose

Previous studies have measured differences in bilinguals and monolinguals working memory through non-linguistically demanding tasks, such as picture tasks, visuospatial tasks, and digit span tasks. Moreover, many of these studies have tested bilingual participants in one language, which may not be representative of bilinguals' comprehensive working memory abilities. Therefore, the purpose of the present study was to examine the working memory performance of Spanish/English bilingual individuals using a linguistically demanding working memory task presented in both English and Spanish. The aims of this study were to determine; (1) if there is a difference in working memory performance between monolinguals and bilinguals, and (2) whether working memory performance differs between bilinguals' first language (L1) versus their second language (L2). We hypothesized that Spanish/English bilingual speakers will have better working memory performance compared to English monolinguals, and that Spanish/English bilingual speakers will have better working memory performance in their L1 compared to their L2. Because variables, such as ethnicity, SES, and language status, have been shown to influence performance on measures of executive function (Bialystok, 2011), we attempted to control for these variables in the current study. First, all of the participants in this study were recruited from El Paso, TX, which is a minority–majority city on the United States–Mexico border. Briefly, a minority–majority city is a term used to refer to an area in which a racial and/or ethnic minority (relative to the whole country's population) makes up a majority of the local population. The area is relatively homogenous in terms of ethnicity as 80% of the population in the El Paso borderland region, whether they are bilingual or monolingual, identify as being Mexican American and Hispanic (U.S. Census Bureau, 2007). Second, we assessed participants' SES using the Hollingshead a validated measure of socioeconomic status. Last, only English monolinguals and S/E bilinguals who acquired English before age 7 years were recruited to participate in the current study. We specifically chose to examine working memory performance in early simultaneous bilinguals because it is this group that the bilingual advantage has been best documented (Bialystok, 2007).

CHAPTER 2: METHODS AND PROCEDURES

2.1 IRB Approval

The University of Texas at El Paso's institutional review board for human subjects approved this study.

2.2 Participants

Participants were recruited from the University of Texas at El Paso and from the El Paso, Texas region using poster advertisement and social media to establish a sample of convenience. Bilingual participants received a $25 gift card and monolingual participants received a $15 gift card as compensation for completing the study. Each participant was provided a written informed consent prior to participating in the study.

Twenty English monolinguals aged 18-25 (SD= 1.64) and twenty S/E bilinguals aged 18-33 (SD= 3.17) participated in this study. The sample size (n= 40) employed in this study was sufficient to detect any medium-sized main effect or interaction (f = .3, $p = 0.05$) in a mixed model analysis of variance with at least 80% power. All participants completed a demographic questionnaire to obtain information regarding their country of origin, education/degree status, general health, and occupation status as well as the occupation status of their mother and father (See Table 2.1 for participant characteristics). All participants in this study had hearing thresholds <25 dBHL from 250-8000 Hz bilaterally (ANSI, 2007) consistent with normal hearing. The Hollingshead Two Factor Index of Socioeconomic Status was used to generate a measure of the participants' social status and was based on the education and occupation of the head of the participant's household (Hollingshead, 1975; Yale, 2011). Participants scores are shown in Table 2.1. There were no significant differences between Hollingshead scores between the two participant groups (p > .05).

Table 2.1 Mean, standard deviation, and participant demographics by group.

	Monolinguals (M)	Bilinguals (B)
Age	22.5 (1.64)	24.2 (3.17)
Years of Education	16.05 (1.76)	15.95 (1.32)
Years of Education in English	16.05 (1.76)	15.35 (1.90)
Non-Hispanic (%)	30%	N/A
Hispanic (%)	70%	100%
Hollingshead Score	22.5 (6.44)	25.45 (18.16)

Note. Mean (Standard Deviation). Hollingshead Score was obtained to measure social status of the participants (Hollingshead, 1957; Hollingshead, 1975).

Subjective and objective measures were used to obtain a linguistic profile for each participant. The Language Experience and Proficiency Questionnaire (LEAP-Q; Marian, Blumenfeld & Kaushanskaya, 2007) was the subjective measure used. The LEAP-Q is a validated and reliable self-rating questionnaire used to measure linguistic proficiency in multilinguals (Marian et al., 2007). The LEAP-Q assesses the experience and usage of languages across various modalities (e.g., reading, writing, speaking and understanding). Participants self-rated each modality using a 10-point Likert scale with 1 being very low proficiency and 10 being perfect proficiency. The LEAP-Q also obtains a percentage of daily use for each language as well as an age of acquisition across languages. Participant responses on the LEAP-Q are shown in Table 2.2.

The Woodcock-Munoz Language Survey III (WMLS III; Woodcock, Alvarado, & Ruef, 2017) was used to objectively measure linguistic proficiency. All participants completed the oral comprehension subtest of the WMLS III in both Spanish and English. The oral comprehension subtest measures an individual's ability to listen to and comprehend an audio-recorded passage and then provide the missing word to complete the passage (Woodcock et al., 2017). See Table 2.2 for participants' linguistic profile and performance on the English and Spanish WMLS III. There was no significant difference in performance on the English WMLS III between the two participant groups ($p > .05$)]. Bilingual participants demonstrated greater language proficiency in English than in Spanish ($p < .05$).

Table 2.2 Mean, standard deviation, and percentages of participants' linguistic profile.

	Monolinguals (M)	Bilinguals (B)
LEAP-Q		
Age Spanish Acquisition	N/A	0.75 (0.97)
Age English Acquisition	0.80 (0.89)	3.95 (1.82)
L1%	100 (0)	41.5 (20.84)
L2%	N/A	58.5 (20.84)
L1 Understanding	9.65 (0.59)	8.80 (1.05)
L1 Speaking	9.55 (0.60)	7.80 (1.36)
L1 Reading	9.60 (0.60)	7.45 (1.19)
L2 Understanding	N/A	9.30 (0.73)
L2 Speaking	N/A	9.10 (0.85)
L2 Reading	N/A	8.90 (1.62)
WMLS III English		
Raw score	29.8 (2.42)	30.25 (3.34)
AE	18.77 (3.48)	18.94 (4.64)
WMLS III Spanish		
Raw score	2.65 (4.17)	27.05 (3.95)
AE	1.14 (2.03)	12.74 (4.71)

Note. Mean (Standard Deviation), Age Equivalent (AE), and Grade Equivalent (GE).

2.3 Test Measures

Listening Span Test

A modified version of the LSPAN test, which is an auditory version of the Reading Span Test, was used to assess complex verbal working-memory performance (Doherty & Desjardins, 2015). The methods used to administer the Listening Span Test in the current study have methodological similarities to those reported for the auditory reading span test in previous studies (Pichora-Fuller et al., 1995; Sarampalis et al., 2009; Ng et al., 2013, 2015; Doherty and Desjardins, 2015). The Listening Span Test used sentences from the English and Spanish versions of the Hearing in Noise Test (HINT; Nilsson, Soli, & Sullivan, 1994; Soli, Vermiglio, Wen, & Filesari, 2002), which is comprised of 25 lists of 20 sentences (400 total sentences) that are six to eight syllables in length, phonemically matched and balanced to the other lists, and are rated at a first-grade reading level (Nilsson, Soli, & Sullivan, 1994). The HINT is normed for difficulty across languages, which allows for direct comparison of performance on the English HINT to performance on the Spanish HINT.

The HINT sentences were presented to participants in a double walled sound attenuating booth, in quiet and in the speech shaped noise (SSN), in a randomized order via a Dell computer routed through a GSI audiostar audiometer to a GSI loudspeaker (Grason-Stadler, Eden Prairie, MN, USA) located 1 meter, at ear level, in front of the participant (0°azimuth). In the SSN condition, the background masker was played continuously throughout the task. Participants were required to repeat the entire HINT sentence they heard and to identify whether the sentence made sense during a 4 s interval that followed the presentation of each sentence, and to remember the final word in each sentence for later recall. The examiner recorded only the final key word in the sentence. The memory task was manipulated by varying the number of sentences in the set (i.e., 2, 4, and 6). After all the sentences in a given set were presented, the experimenter prompted the participant to recall as many of the previously reported final key words as they could, verbally, and in any order. Twenty-four sentences were presented in each of the six experimental conditions (Quiet: set size 2, 4, 6, and Noise: set size 2, 4, 6). Performance on the Listening Span test was computed based on the percent of correctly recalled final key words. Participants were not scored on identification of coherent sentence as this was a distractor component added to deter the participant from simply remembering the last word of the sentence rather than comprehending the sentence (Daneman and Carpenter, 1980). Test instructions were presented in the target language of test administration.

2.4 Procedures

Testing was performed in one 2-hour test session at the University of Texas at El Paso Campbell Building. First, participants completed the demographic questionnaire and the LEAP-Q (Marian et al., 2007). Hearing thresholds were obtained at octave frequencies bilaterally at 250 Hz through 8000 Hz (ASHA, 2003). Speech recognition was measured in quiet and in background noise at +8 dB SNR using 20 sentences from the English (Nilsson, Soli, & Sullivan, 1994) and

Spanish (Soli, Vermiglio, Wen, & Filesari, 2002) versions of the HINT. The bilingual group completed the HINT in English and Spanish and the monolingual group completed the task in English only. All participants had excellent speech recognition scores of at least 96% correct on the English HINT in quiet and in background noise. The bilingual participants' scored 96% or better on the Spanish HINT in both quiet and in background. All participants completed the oral comprehension subtest from the WMLS III in both English and Spanish (Woodcock, Alvarado, & Ruef, 2017).

The LSPAN test was then presented to all participants. The English and Spanish versions of the LSPAN were administered to all bilingual participants in a randomized order. The LSPAN was always presented first in the background noise condition in sets of 2, 4, and 6 and then in quiet in sets of 2, 4, and 6 as is consistent with standard instructions for administering this test.

2.5 Data Analysis

Statistical analysis of the data was conducted using IBM SPSS v22 (SPSS Inc., Chicago III.) software. The data was analyzed using a mixed model analysis of variance (mixed model ANOVA). A .05 significance level was used for all analyses, and Greenhouse-Geiser corrections (Greenhouse and Geisser, 1959) were implemented where an assumption of sphericity was not appropriate. In cases where we found significant effects, we conducted post-hoc t-tests. All post-hoc tests were assessed with Bonferroni-corrected $\alpha = .05$, two-tailed, unless otherwise noted.

CHAPTER 3: RESULTS

3.1 Performance on LSPAN

Figure 3.1 and 3.2 show English monolinguals' and Spanish English bilinguals' mean performance on the English-LSPAN in quiet and in noise across the 2, 4, and 6-span conditions. There were significant main effects of span and noise conditions. Participants performed significantly better on the 2-span condition compared to the 4- and 6-span conditions [F (2,76) =323.45; p = <.001; η_{p2} = 1.00] and participants' working memory performance was significantly better in quiet compared to background noise [F (1,38) =22.25; p = <.001; η_{p2} = .996]. There was a 2-way interaction between span and noise. Participants performed significantly better in quiet than background noise in only the 4- and 6-span conditions [F (2,76) =3.84; p =.026; η_{p2} = .680]. There was a 3-way interaction between span condition, noise condition, and language group. Bilingual participants performed significantly better than monolinguals in quiet and noise on the 4-span condition, and in quiet on the 6-span condition [F (2,76) =3.114; p =.05; η_{p2} = .583].

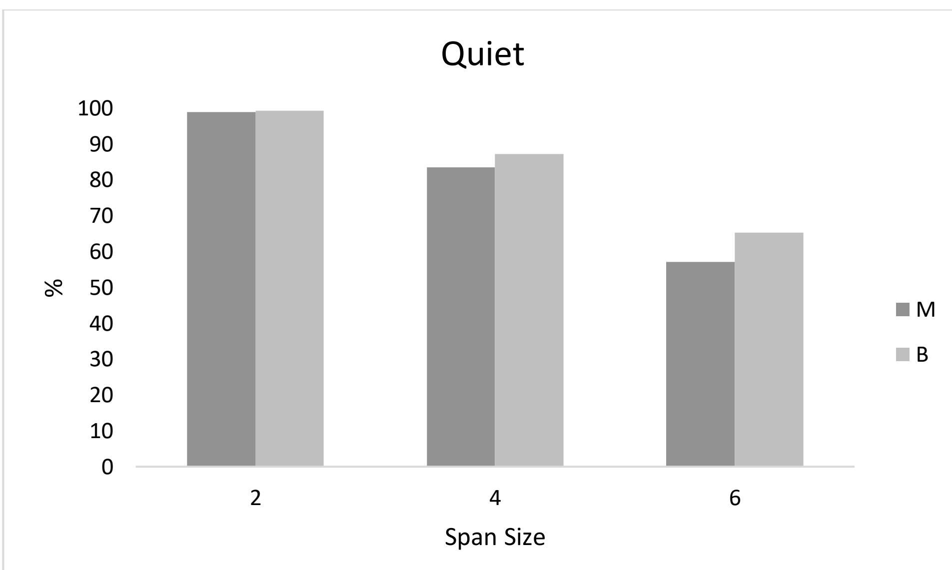

Figure 3.1 Monolinguals' (M) vs Bilinguals' (B) mean performance on English-LSPAN in quiet

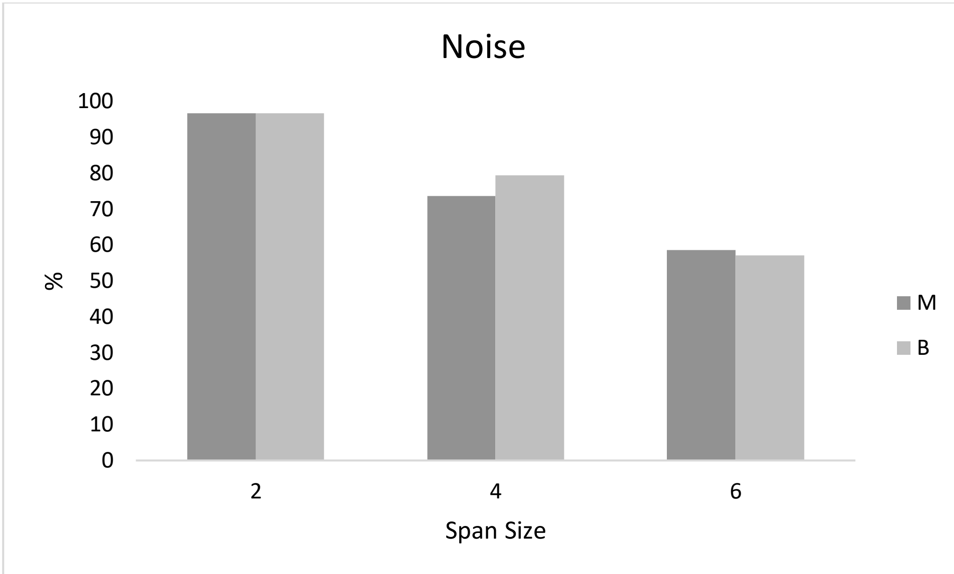

Figure 3.2 Monolinguals' (M) vs Bilinguals' (B) mean performance on English-LSPAN in noise

3.2 S/E bilinguals' performance on English vs Spanish LSPAN

Figure 3.3 and 3.4 show bilinguals' mean performance on the English-LSPAN in quiet and in noise across 2, 4, and 6-span conditions. There was a significant main effect of span, noise condition, and language. Bilingual participants performed significantly better on the 2-span condition compared to the 4- and 6-span conditions [F (2,38) =178.23; *p* =<.001; η_{p2} = 1.000], and they performed significantly better in quiet than in noise [F (1,19) =17.71; *p* =<.001; η_{p2} = .979]. Bilingual participants also performed significantly better in English than in Spanish [F (1,19) =17.89; *p* =<.001; η_{p2} = .980]. Lastly, there was a 2-way interaction between span and language. Bilingual participants performed significantly better on the 4-span condition in English than in Spanish [F (2,38) =5.66; *p* =<.001; η_{p2} = .833].

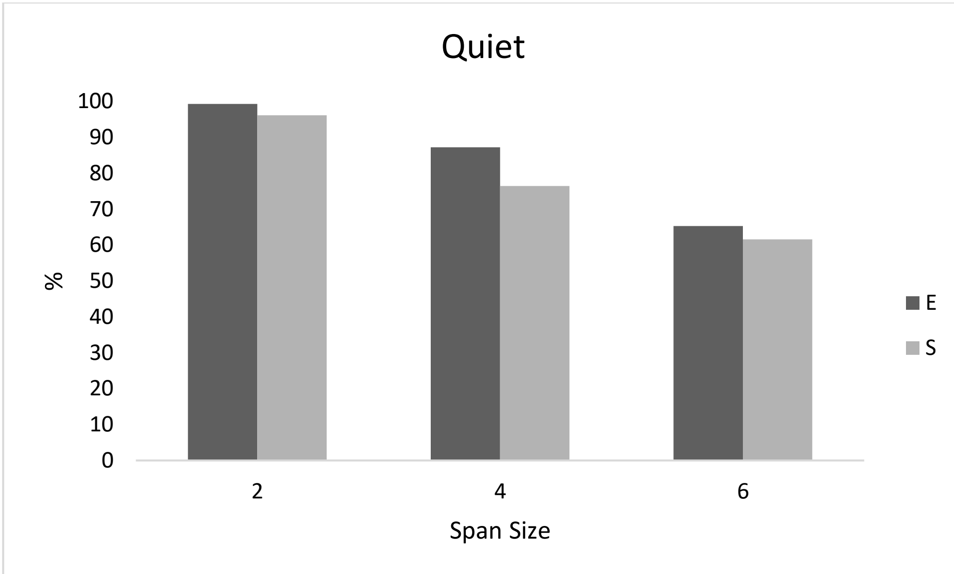

Figure 3.3 Bilinguals' mean performance on English-LSPAN vs Spanish-LSPAN in quiet

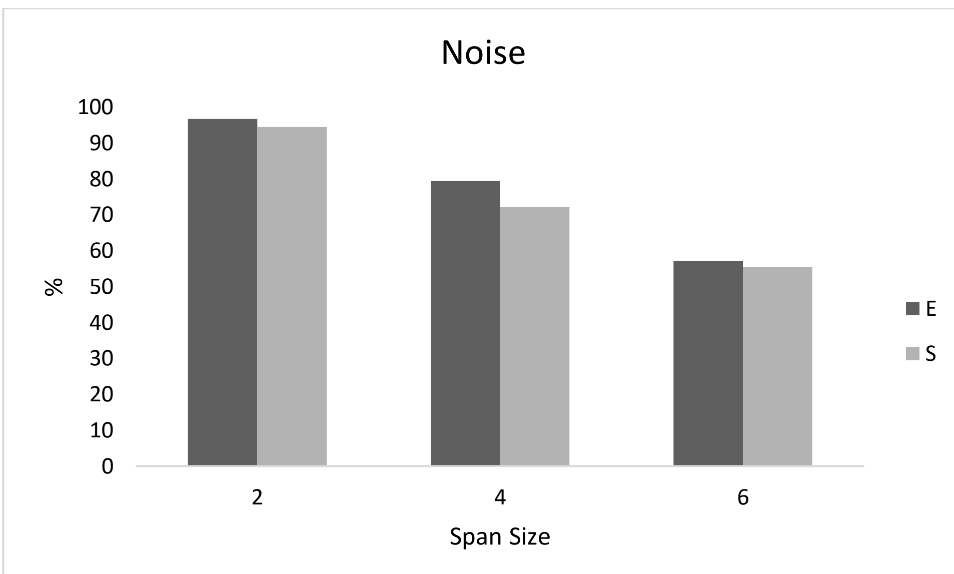

Figure 3.4 Bilinguals' mean performance on English-LSPAN vs Spanish-LSPAN in noise

CHAPTER 4: DISCUSSION

In the current study, we examined working memory performance between English monolinguals and Spanish-English bilinguals, and differences in working memory performance for bilinguals' L1 and L2. All participants in the current study performed significantly better in quiet than in noise, and performed significantly better on the 2-span condition compared to the 4-span and 6-span conditions. These findings support the capacity theory of comprehension, which states that increased task demands (noisy conditions and extrinsic load) can significantly impact individuals' working memory capacity and overall language comprehension (Just & Carpenter, 1992).

Interestingly, the Spanish-English bilinguals performed significantly better in quiet and in noise on the 4-span condition, and in quiet on the 6-span condition than the English monolinguals. This finding is consistent with previous studies that have found bilingual advantages in working memory (Grundy & Timmer, 2017). This observed advantage in working memory is attributed to the lifelong management of two language systems. Both languages are said to be activated even when only one language is in use, and the continual management of these two languages competing for selection is said to require working memory resources, which may ultimately lead to enhanced working memory performance (Grundy & Timmer, 2017).

Moreover, this finding sheds light on the idea that the bilingual advantage may present itself only when the task requires the same complex cognitive control processes involved in the management of two language systems. However, it is important to note that the bilingual group did not outperform the monolingual group in all conditions. When the task became too simple such as the 2-span then the bilingual advantage disappears. Similarly, we assume that when the task becomes too cognitively complex then the advantage also disappears. Specifically, differences between the two groups were only evidenced in the 4-span (quiet and noise) and 6-span (quiet only) conditions. This may indicate that the presence of a bilingual advantage is task specific. Thus, in terms of cognitive demand, the advantage may not present itself when a task is too simple or too complex. Currently, there is no objective measure distinguishing the level of simplicity or complexity required to observe the bilingual advantage, and this may explain why there are contradictory findings on its existence.

All bilinguals in the current study performed significantly better on the English LSPAN than on the Spanish version of the task in background noise. This is despite the fact that all the participants learned Spanish at birth and did not begin to acquire English until age 4. This finding may be attributed to the idea that expertise in a language will be reflected through better working memory performance in a more dominant language (usually the native language), and poorer working memory performance in a less familiar language (the foreign language) (Service, Simola, Metsänheimo, & Maury, 2002). Although English is not the bilinguals' native language, the group subjectively and objectively demonstrated greater proficiency in English than in Spanish. Additionally, the bilingual group obtained the majority or all of their schooling in English, and may be more accustomed to decoding and encoding of this non-native language in a cognitively demanding context. For this reason, it is reasonable to assume that the bilinguals in this study have developed some form of working memory mastery from the lifelong practice devoted to processing and managing a second language.

The current study confirms previous findings of a bilingual advantage in working memory performance. However, it is important to note that the bilingual advantage may only be observed on specific tasks and in conditions. If the selected working memory task is not specific to language or linguistically demanding, there is a possibility that the results may reveal no difference between monolinguals' and bilinguals' working memory capacity. Moreover, if the working memory task selected is too simple or too complex, there may also be an absence of a bilingual advantage.

Bialystok and colleagues (2012) published a review on bilingualism and its effects on the mind and brain. The authors stated that bilingualism plays a larger role in older adults in that it protects against the age-related cognitive changes that naturally occur. However, it is not clear whether the bilingual advantage found in working memory persists in older age. Future studies in this topic area should focus on investigating whether the bilingual advantage persists in older individuals and if so, does continued bilingual experience enhance working memory performance over time.

CHAPTER 5: CONCLUSION

Spanish-English bilinguals have better auditory verbal working memory performance than English monolinguals. This suggests that the constant management of two language systems may enhance working memory performance in bilingual individuals resulting in a bilingual advantage. Spanish-English bilinguals in this study demonstrated better working memory performance in English than Spanish despite learning both languages by age 4. This finding lends support to the idea that a bilinguals' performance in a specific language may be dependent on language proficiency and practices. Lastly, the bilingual advantage may only be present in tasks that reflect the linguistic nature of the advantage.

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VITA

Jordan Allyssabeth Orozco was born in Fayetteville, North Carolina. The second born of Gabriela Orozco and Juan Orozco. She graduated from Franklin High School and began courses at Texas A&M College Station, and later enrolled at the University of Texas at El Paso to complete her bachelor's degree. While pursuing a bachelor's degree she worked as a waitress at GeoGeske's and a research assistant for the Auditory and Cognitive Aging Lab. Jordan was President of the Golden Key International Honour Society, and served as Community Service Chair for the University of Texas at El Paso's National Student Speech-Language-Hearing Association (NSSLHA). She graduated Summa Cum Laude with her Bachelors of Multidisciplinary Studies in Spring 2018. In Fall 2018, she entered Graduate School at the University of Texas at El Paso Master of Science in Speech-Language Pathology. During Graduate School, Jordan worked as a waitress at Ripe Eatery, a student Notetaker, and conducted research for the Auditory and Cognitive Aging Lab under the supervision of Jamie L. Desjardins, Ph.D., CCC-A. Jordan served as Social Chair for NSSLHA from 2018-2019 and Internal Vice President from 2019-2020. She received the Dodson Travel Grant, UTEP College of Health Sciences Travel Grant, and was selected for the American Speech-Language Hearing Association's Student Research Travel Award. Jordan has presented research at the local, state, and national level.

Contact Information: jaorozco7@miners.utep.edu

This thesis/dissertation was typed by Jordan Allyssabeth Orozco.