The Pennsylvania State University

The Graduate School

PREDICTORS OF SENTENCE REPETITION: PHONOLOGICAL SHORT-TERM MEMORY, WORKING MEMORY, AND LONG-TERM MEMORY

A Thesis in

Communication Sciences and Disorders

by

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Submitted in Partial Fulfillment
of the requirements
for the Degree of

Master of Science

May 2022

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ABSTRACT

Speech language pathology clinicians use standardized assessments to determine the need for services for children who have language disorders, and sentence repetition is frequently included in the battery of standardized assessments. Sentence repetition is a complex language task that requires comprehension and production of language. Possible cognitive processes involved in processing language for sentence repetition tasks include phonological short-term memory, working memory, and long-term memory. In this study, 16 monolingual English-speakers and 26 bilingual English-speakers completed working memory tasks, nonword repetition tasks, and sentence repetition tasks with varying complexity. Results suggested monolingual speakers relied more on working memory to recall sentences while bilingual speakers relied more on phonological short-term memory.

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Introduction

Sentence repetition tasks are frequently used to assess language ability in children who may have language disorders. Since sentence repetition involves multiple language processes, such as comprehension, phonological short-term memory, working memory, and speech production, sentence repetition tasks give clinicians some insight into a client's language abilities. However, because these language processes are interconnected, it can be hard to determine which process or mechanism is causing a deficit in language abilities. Past research has suggested that possible variables that could predict sentence repetition scores include syntactic complexity, working memory, phonological short-term memory, and long-term memory. The current study will focus on syntactic complexity, phonological short-term memory, working memory, and long-term memory in monolingual and bilingual adults who experienced typical language development.

Bilingual speakers have different experiences with language compared to monolinguals, and these experiences affect language processing and accuracy. They score differently compared to monolinguals in language processing tasks, especially when they acquire their second language at a later age. McDonald (2000) found early second language acquirers of English scored similarly to native English speakers in a grammaticality task while late second language acquirers of English scored differently compared to both the early language acquirers and English native speakers. Past research has also suggested bilinguals with more exposure to their second language and those who use the language both internally with self-talk and externally with person-to-person talk are more likely to score higher in second language proficiency (Gullife, *et al*, 2021). More experience with a language makes one more proficient at using the language.

Children with typical language development and those with atypical development also have different experiences. These differences may be due to a difference in language network locations or types of cognitive skills used for language processing (Vansteensel *et al*, 2021). Children with atypical development need intensive therapy sessions and exposure to grammar structures over longer time periods to improve their language skills (Smith-Locke, Leitao, Lambert & Nickels 2013; Law, Garret & Nye, 2004). Since children with atypical language development have different experiences and require more exposure compared to typically developing children, they are somewhat similar to bilingual speakers who have different experiences from monolingual speakers and require more exposure to a language to learn grammatical structures. In this study, adult bilingual speakers were recruited due to their variations in exposure, which may have an impact on scores for clinical evaluations (Cowan, 2021).

Syntactic Complexity

When analyzing syntactic complexity, one can use a number of factors including argument and adjunct structures, functional verb units, the number of agents or objects or length of the sentence. Arguments in sentences rely on implicit relationships between the agent, verb, and object of the sentences while adjuncts are optional modifiers in a sentence (Poll, Miller & van Hell, 2016). Argument sentences are likely to carry a transitive verb and an accompanying noun phrase while adjunct sentences tend to include intransitive verbs. Adjuncts are difficult for both people without language disorders and those with language disorders. However, they are more difficult for those with language disorders since the individuals with disorders have a reduced or impaired ability to acquire language knowledge compared to typically developing individuals. Adjunct sentence structures tend to cause a higher burden on working memory capacity, so these sentence types are expected to be more difficult for individuals with language disorders and for bilinguals.

Combinations of length and grammar complexity conditions affect sentence processing. Longer sentences that have adjuncts are more difficult to process compared to short sentences with adjunct modifiers. Poll *et al.* (2016) discovered that language disorder status, length, and argument vs adjunct sentences all affect sentence repetition accuracy. In particular, those with a language disorder are more likely to score lower on sentence repetition tasks. And all participants, regardless of disorder status, are likely to score lower on sentences that are long and also on sentences that include adjunct modifier phrases. Their conclusions of length affecting recall are also consistent with past studies that found sentences with more actions and objects in the sentence tended to be more difficult for participants to recall (Allen & Baddeley, 2008).

Working Memory

Poll *et al.* (2016) indicated that working memory capacity predicted the ability to recall sentences. They also found those in the language disorder group tended to score lower on working memory measures with verbal responses compared to those without language disorders. In particular, they found as sentences increased in length, participants with stronger working memory capacities scores tended to score higher on sentence recall tasks, and those with high working memory capacity scores also tended to score higher on sentences that included adjunct modifiers. Tasks used to measure working memory capacity include backwards digit span and dual processing tasks (Parente, Kolakowsky-Hayner, Krug & Wilk, 1999).

Poll and colleagues. (2013) explored four models of working memory for sentence repetition. Their analysis supported three of the four models. All of the supported models included integrations between cognitive processes. The integrated model is also supported by past research that suggests phonological memory, working memory, and long-term memory all work together to affect recall of sentence-like word lists (Jefferies, Lambon Ralph & Baddeley, 2004).

Phonological Short-Term Memory

Past research has suggested children with language difficulties tend to have difficulty creating phonological representations of sounds (Nittrouer, Shune & Lowenstein, 2011). Poor phonological representations may lead to poor speech perception of phonemes and words, which would negatively impact someone's ability to recall a sentence. Having difficulty with perceiving speech sounds may lead to worse sentence recall. Past research has shown that phonological short-term memory (pSTM) tasks significantly correlate with sentence repetition tasks (Archibald, 2013; Frizelle & Fletcher, 2015).

Phonological short-term and working memory may work together to allow someone to recall a sentence. Frizelle & Fletcher (2015) found that children with SLI tend to rely on their pSTM to process simple sentences and may use more of their working memory to process complex sentences. For children who had typically developing pSTM, they were able to use their pSTM to recall simple and complex sentences. Frizelle & Fletcher (2015) suggested children who are typically developing may use less of their working memory capacity, which frees up their pSTM to process sentences for repetition. They found that performance on more complex clauses correlated with working memory measures for children with SLI.

There are two tasks that are typically used to measure pSTM: forward digit recall and non-word repetition. While researchers disagree on what non-word repetition actually measures, non-word repetition requires representations of phonemes (Coady & Evans, 2008). Past research has found that children with SLI were able to recall two and three syllable non-words as well as typically developing children, but they had more difficulty recalling four or more syllable non-words. This suggests that children with SLI have a less robust pSTM compared to typically developing children, which negatively impacts their scores on sentence repetition tasks.

Long term memory

Working memory and pSTM alone do not account for sentence recall ability. Working memory and long-term memory tend to go hand-in-hand. Spanoudis and Natsopoulos (2011) found that working memory and long-term memory were impaired for children who had SLI. Past studies have indicated that long-term memory representations may also affect someone's ability to encode and recall sentences (Riches, 2020). In particular, Riches (2020) argues people use lexical context to retrieve information from long-term memory storage because of the high frequency in which the words occur in sentences. This idea suggests that those with more lexical knowledge and stronger representations of language in their long-term memory are likely to recall sentences more accurately than those with less linguistic knowledge of a language. This also suggests that second language learners or those with language impairments would recall sentences less accurately than those who are native speakers and have no impairments since the native speakers have had more opportunities to process linguistic knowledge and improve their lexical representations and context cues.

Bilingual speakers who have earlier ages of acquisition are more likely to have greater linguistic knowledge of their second language compared to later learners. Past research has shown that bilinguals who learn English as a second language tend to score lower on grammaticality tests compared to monolingual speakers (McDonald, 2000). This could suggest that those who have less linguistic knowledge represented in their long-term memory may have more difficulty processing sentences. However, past research has found an interaction between working memory and long-term memory for bilingual speakers. In particular, bilingual speakers who score higher on working memory capacity tasks are also likely to score higher on tests that measure language skills in the second language (Kormos & Safar, 2008). Furthermore, Martin & Ellis (2012) found pSTM and working memory to both contribute to learning second language vocabulary and grammar. All three cognitive skills, pSTM, working-memory and long-term memory, interact with each other to influence sentence processing.

The purpose of the current study is to explore how monolingual speakers and bilingual speakers use working memory and pSTM to recall sentences. The following hypotheses were established for this study: 1) It is expected that all individuals will score lower on sentences that have adjunct modifiers since these kinds of sentences tend to be more complex, 2) All individuals will also score lower on longer sentences compared to shorter sentences, 3) For individuals who score lower on the nonword repetition tasks, which may be evidence of reduced phonological short-term memory, it is likely that these individuals will also score lower on the sentence recall tasks, both for complex and simple sentences, 4) It is expected that bilingual and monolingual English speakers will score similarly on simple sentences, and bilingual speakers will score lower than monolingual English speakers on more complex sentences, 5) Since bilingual speakers tend to have a less robust storage of linguistic knowledge, it is expected that bilingual speakers will use more of their working memory capacity to process long sentences, and in particular to process long adjunct sentences. Monolingual speakers of English will use more of their phonological short-term memory for complex sentences.

Chapter 1: Methods

Participants

Seventy-five participants were recruited through emails to university list-servs and social media. A standardized flyer approved by Penn State University's IRB board was used to recruit participants. Thirty-three participants were dropped from the data analysis due to withdrawal, missing demographic information, or poor recording quality. Forty-two participants remained in the analysis of the study.

Ages of the participants included in the study ranged from 18-64 with an average age of 25.81±8.01. There were 29 females, 10 males, and three individuals who listed their gender as other. Sixteen of the individuals were monolingual while 26 of them were bilingual. The bilingual participants had a mean age of acquisition of 3.42±3.43 years old. Thirteen of the bilinguals learned English between the ages of 0-3 and were considered simultaneous bilinguals. The other thirteen bilingual speakers learned English after the age of three and were considered sequential bilingual speakers. The bilingual speakers spoke a range of languages, including 21 Spanish speakers, 2 French speakers, 1 Arabic speaker, and 1 Tagalog speaker. The participants self-reported a range of proficiency for the English language, from 68-100 on a scale of 0-100. Seven individuals reported learning more than two languages. All participants, except for one, had some college education. Seventeen participants reported current enrollment in a 4-year degree program, five reported having earned bachelor's degrees, five reported current enrollment in a graduate program, eight reported having earned a master's degree, two reported current enrollment in a doctoral program, and four reported having earned a doctoral degree.

Procedure and Materials

Data from this study was collected by the Child Language Development Lab at Penn State University via the remote platform Zoom from December 2020 to March 2021. Prospective participants emailed a lab account to indicate their interest, and a research assistant followed up with screening questions, which included 1) Are you 18 years old or older, 2) What is your first language? If you speak more than one language, please list language(s) spoken and your proficiency, 3) Have you ever experienced any of the following: concussion, head injury, traumatic brain injury, TIA, stroke, or seizure?, 4) Have you ever had problems with talking, listening, or reading? Do you still have problems now?, 5) Which hand do you use to write with?

After the participants answered the screening questions, they were sent a link to a survey on Qualtrics that included a consent form for the experiment. After they affirmed consent electronically, a research assistant scheduled the participant for a Zoom meeting with an experimenter and a record keeper.

There were four orders of administration. All participants received the digit span task first; then they received the nonword repetition task with either English-specific or neutral prosody. Next they completed either the Clinical Evaluation of Language Fundamentals, fourth edition (CELF-4; Semel , Wiig & Secord, 2004) sentence recall task or Poll Sentence recall task, verbal fluency form A or B, the second sentence recall task, either the Dollahan & Campbell nonword repetition task, and the other nonword repetition task not given before. The first seven tasks were administered over Zoom. A lexical decision task and a word list recall task were administered with the Gorilla platform via the participant’s browser.

Below is an example of order 1:

- Digit span
- Crosslinguistic NWR specific prosody
- CELF sentence recall
- Verb fluency task – Form A or B (had the same categories in different orders)
- Poll sentence recall
- Dollaghan & Campbell NWR
- Crosslinguistic NWR neutral prosody
- Lexical decision
- Word List recall

This study will look at the data from the digit span, crosslinguistic nonword repetition neutral prosody task (NWR – N), Dollaghan & Campbell nonword repetition task (NWR – DC), CELF sentence recall, and Poll sentence recall.

Digit Span

The digit span subtest from the Weschler Adult Intelligence Scale, 3rd edition (1997), was used in the experiment. Both the forward digit span task and backward digit span tasks used a binary scoring with 1 point for all digits in a string repeated correctly. If a participant missed two strings of the same length, the task was discontinued.

Nonword Repetition Tasks

Two nonword repetition tasks were used in the study: a crosslinguistic neutral prosody nonword repetition task (NWR – N) designed for bilingual speakers created by Chiat, Polisenska, & Szewczy (2012) and a nonword repetition task (NWR – DC) designed to minimize biases created by Dollaghan & Campbell (1998). Both tasks were recorded by female speakers. One of the speakers was from the Midwest while the other speaker was from the south Gulf area.

Interrater reliability was calculated on the word, syllable, and phoneme level with 12% of participants. Due to a higher interrater reliability for the phoneme scoring, the total percent phonemes correct (PPC) for participants were used in the data analysis. Scoring matched the pattern of Dollaghan & Campbell (1998). Substitutions and omissions were counted as errors, but additions of sounds were not counted as errors.

The interrater reliability across participants for NWR- N ranged from 89.3-98.2%, and the interrater reliability for NWR – DC ranged from 86-98%.

Sentence Recall Tasks

The CELF and Poll sentence recall tasks were scored on a 4-point scale. An exact recall of the sentence received a score of 3. If the participant substituted, omitted, or added one word, they received a score of 2. If they substituted, omitted, or added 2-3 words, they received a score of 1. If 4 or more substitutions, omissions or additions were noted, the sentence was scored as a 0. The total possible score for the CELF sentence recall task was 72 while the total possible score for the Poll sentence recall task was 108, 54 for adjunct sentences and 54 for argument sentences. Sentences for ages 9-12 were used for the CELF sentence recall task.

Poll sentences came from Poll *et al* (2016), and they had two conditions: length and complexity. In the length condition, there were two variables, short and long. Short sentences had 16 syllables while long sentences had 25 syllables. The complexity condition also had two variables, adjunct and argument. Adjunct sentences contained optional modifiers while argument sentences included implicit relationships. Since there was no syntactic relationship in the adjunct condition, it was considered more complex than the argument condition. Sentences used in the

Poll sentence recall task can be found in Appendix A. The sentences were recorded by two female speakers. Each speaker recorded one set of sentences.

Chapter 2: Results

Hypothesis 1:

A 2-tailed dependent t-test was used to compare total adjunct modifier scores to total argument scores (using 4-point scoring), with an alpha level set to 0.05. There were no significant differences between the scores for the adjunct sentences (M = 25.33, SD = 9.7) and the argument sentences (M = 26.29, SD = 9.5), $t(41) = 0.985$, $p = 0.17$. Hypothesis 1 was not supported. Mean for all scores for the Poll sentence recall sentences conditions can be found in Table 1.

Table 1

Mean score of Poll sentence recall conditions of length, complexity, and length x complexity

	Bilinguals	Monolinguals
Total Poll scores	44.9 (19.0)	64.6 (10.7)
Adjunct Sent	21.9 (9.3)	31.0 (7.4)
Argument sent.	21.8 (9.0)	33.6 (4.4)
Long Poll sent.	3.1 (4.9)	6.8 (5.6)
Short Poll sent.	40.9 (13.9)	57.8 (6.0)
Long Adjunct sent	1.5 (2.7)	3.5 (3.6)
Short Adjunct sent.	20.4 (7.7)	27.7 (5.1)
Long Argument sent.	1.6 (2.5)	3.3 (2.5)
Short Argument sent.	20.2 (7.3)	30.3 (2.8)

Hypothesis 2:

A 2-tailed dependent t-test with an alpha level of 0.05 was used to compare scores of all participants for longer and shorter sentences. All participants scored lower on sentences in the long condition compared to those in the short condition with an average score of 4.50, *SD* = 5.4 for the long sentences compared to 47.12, *SD* = 14.2 for the short sentences, $t(41) = 23.796$, $p<0.001$. Hypothesis 2 was supported.

Hypothesis 3:

A correlational analysis was used to calculate relations between the nonword repetition tasks and sentence recall tasks. The phoneme scores of the nonword repetition tasks were compared to the total 4-point scores of different sentence categories. All correlations are listed in Table 2. Both nonword repetition tasks positively correlated with the sentence recall tasks. Individuals who scored higher on the nonword repetition tasks were more likely to also score higher on the Poll sentences. Hypothesis 3 was supported.

Table 2

Correlation values between nonword repetition tasks and sentence recall conditions

	NWR - N	NWR - DC
NWR - N	1	0.639**
NWR – DC	0.639**	1
CELF total scores	0.407**	0.372*
Poll total scores	0.393**	0.481*
Short Poll Sent.	0.459**	0.578*
Long Poll Sent.	0.208	0.320*
Adjunct Poll Sent.	0.370*	0.499**
Argument Poll Sent.	0.428*	0.542**

*$p<0.05$ (2-tailed)

**$p<0.01$ (2-tailed)

Hypothesis 4:

A mixed ANOVA was used to compare the scores of bilingual and monolingual participants on the complexity conditions of the Poll sentences. The alpha level was set to 0.05. There was a significant group effect, $F(1, 40) = 18.984$, $p<0.01$, but there was no effect of sentence complexity, $F(1, 40) = 1.636$, $p = 0.208$. The interaction between the groups and the complexity condition of the Poll sentences was not statistically significant, $F(1, 40) = 1.737$, $p = 0.195$. For the Poll sentences, the monolingual participants scored higher in both the adjunct and argument conditions compared to the bilingual participants. Mean scores of the conditions are reported in Table 1. Hypothesis 4 was not supported.

Hypothesis 5

Hierarchical regressions were used to examine the contributions of predictor variables to sentence repetition performance on the adjunct sentences for the two different groups, bilingual and monolingual participants. For bilingual speakers, age of acquisition was entered first. Age of acquisition was collected through surveys on Qualtrics. For monolingual speakers, age of acquisition did not factor into the analysis since the age of acquisition was a constant at 0 years old. Next, the nonword repetition tasks were entered into the analysis, then backward digit span and finally forward digit span were entered.

Bilinguals

All models of the hierarchical regression for adjunct sentence scores of bilingual participants were significant at the $p<0.001$ level. Age of acquisition and NWR tasks accounted for most of the variance with R^2 *change* = 0.383, $p<0.001$ and 0.236, $p<0.05$, respectively. Values for the hierarchical regression for adjunct sentence scores for the bilingual group can be found in Table 3.

Table 3

Hierarchical regression analysis of predictors of Adjunct Sentences for bilingual participants

	Step 1	Step 2	Step 3	Step 4
AoA	-0.619***	-0.545***	-0.512***	-0.562***
NWR – N		0.515*	0.464*	0.377†
NWR – DC		-0.032	-0.105	-0.120
Digit Span Backward			0.188	0.109
Digit Span Forward				0.255
R^2	0.383	0.619	0.639	0.680
R^2 Change	0.383	0.236	0.020	0.041

†p<0.10

*p<0.05

***p<0.001

Since no statistical differences were found between the adjunct sentences and the argument sentences, a hierarchical regression was also used to examine the contributions of predictor variables to sentence repetition performance to the argument sentences. All steps of the hierarchical regression were significant at the p<0.001 level. AoA and NWR – N accounted for the most variance with R^2 *Change* = 0.271, p<0.01 and R^2 *Change* = 0.289, p<0.01, respectively. For the argument sentences, NWR – N accounted for more of the variance compared to AoA. NWR – DC, digit span backward and digit span forward all accounted for less than 10% of the variance. Values for the hierarchical regression for argument sentence scores for the bilingual group can be found in Table 4.

Table 4

Hierarchical regression analysis of predictors of Argument Sentences for bilingual participants

	Step 1	Step 2	Step 3	Step 4
AoA	-0.520**	-0.435**	-0.419*	-0.419*
NWR – N		0.538*	0.506**	0.506‡
NWR – DC		0.008	-0.039	-0.039
Digit Span Backward			0.119	0.119
Digit Span Forward				0.000
R^2	0.271	0.560	0.568	0.568
R^2 Change	0.271	0.289	0.008	0.000

‡ *p*=0.05

**p*<0.05

***p*<0.01

Finally, since there were significant differences in the total scores of Poll sentences between monolinguals and bilinguals, a hierarchical regression was used to examine the contributions of predictor variables to the total score on the Poll sentences. All models of the hierarchical regression were significant at the $p<0.001$ level. Similarly to the hierarchical regression for the adjunct sentences, AoA accounted for the most variance, R^2 *change* = 0.384, *p*<0.01 and NWR-N, *p*<0.01 accounted for the second most variance, R^2 *change* = 0.223. Values for the hierarchical regression for total Poll sentence scores for the bilingual group can be found in Table 5.

Table 5

Hierarchical regression analysis of predictors of total scores on Poll sentences for bilingual participants

	Step 1	Step 2	Step 3	Step 4
AoA	-0.619**	-0.555**	-0.536**	-0.580***
NWR – N		0.561*	0.521*	0.429
NWR – DC		-0.119	-0.177	-0.192
Digit Span Backward			0.147	0.064
Digit Span Forward				0.269
R^2	0.384	0.553	0.546	0.580
R^2 Change	0.384	0.223	0.012	0.046

*$p<0.05$

**$p<0.01$

***$p<0.001$

Monolinguals

For the adjunct sentences, the first model of the hierarchical regression with both nonword repetition tasks was not statistically significant. The second model for the hierarchical regression approached significance, (p = 0.061). The third model that included both nonword repetition tasks and the digit spans task was significant at the $p<0.05$ level. Digit span backwards contributed the most variance to the model, R^2 *change* = 0.331, $p<0.05$. Values for the hierarchical regression for adjunct sentence scores for the monolingual group can be found in Table 6.

For the argument sentences, none of the hierarchical regression models were significant. None of the variables measured contributed significantly to the recall of sentences in the argument condition.

Table 6

Hierarchical regression analysis of predictors of Adjunct Sentences for monolingual participants

	Step 1	Step 2	Step 3
NWR – N	-0.168	-0.242	-0.204
NWR – DC	0.372	0.177	0.163
Digit Span Backward		0.622*	0.651*
Digit Span Forward			$0.375^{\dagger}$
R^2	0.115	0.446	0.585
R^2 Change	0.115	0.331	0.139

$^{\dagger}p<0.10$

$*p<0.05$

For the total score of the Poll sentences, the second model and third model of the hierarchical regression approached significance, $p = 0.080$ and $p = 0.70$, respectively. Similarly to the adjunct sentences, digit span backward contributed the most variance to the model, R^2 *change* = 0.303, $p<0.05$. Values for the hierarchical regression for total score of Poll sentences for the monolingual group can be found in Table 7. Hypothesis 5 was not supported.

Table 7

Hierarchical regression analysis of predictors of total score for Poll sentences for monolingual participants

	Step 1	Step 2	Step 3
NWR – N	-0.087	-0.158	-0.126
NWR – DC	0.367	0.181	0.169
Digit Span Backward		0.595*	0.619*
Digit Span Forward			0.316
R^2	0.116	0.419	0.517
R^2 Change	0.116	0.303	0.098

*$p<0.05$

Chapter 3: Discussion

The results for hypothesis 1 differed from the expected results. Participants did not score higher on argument sentences compared to adjunct sentences. Poll *et al* (2016) found both adults without language disorders and adults with developmental language disorder scored higher on short argument sentences compared to short adjunct sentences. With children, past studies have also found typically developing children and children with DLD made more errors on sentences with more complex syntactic structures (Riches, 2012; Kidd, Brandt, Lieven & Tomasello, 2007). Scoring may have impacted the results of this study. Studies in the past have used error rates or 4-point scales that allowed for small substitutions or derivation of words that did not change the meaning of the sentence (Poll *et al*, 2016; Riches, 2012; Kidd *et al*, 2007). This study used a 4-point scoring scale, similar to the CELF, often used for clinical evaluations, and it did not allow minor substitutions. Poll *et al* (2016) scored sentences based on the percent of words correct. They chose not to use CELF scoring protocol to avoid ceiling affects. There were a few participants in this study that scored 100% on short sentences, but there were no participants who scored 100% on long sentences. Further analysis between scoring types will be needed to determine how the scoring may mask subtle differences between complexity conditions.

The results for hypothesis 2 were similar to results of past studies. Participants scored higher on short sentences compared to long sentences. Poll *et al* (2016) suggested adults with DLD have limited storage capacity for sentences compared to typically developed adults because of their processing limitations. Similar results have also been found for children who have DLD and those who were typically developing (Zebib, Tuller, Hamann, Ibrahim & Prévost, 2020).

Working memory is typically used to explain score differences for the length of sentences since limitations in working memory typical limit storage capacity and processing. Some researchers have suggested people chunk sentences into sets of words to remember them (McCauley & Christiansen, 2019). On the other hand, past studies have also suggested the semantic content and syntactic content of the sentences can affect sentence recall. Past studies found young toddlers repeated sets of words that occurred more frequently in their lives more accurately compared to sets of words that occurred less frequently (Bannard & Matthews, 2008). In a different study, adults read frequently used sets of words faster compared to less frequently used sets of words, and they also recalled more words of a frequently used set of words compared to infrequently used sets of words (Tremblay, Derwing, Libben & Westbury, 2011). However, the stimuli used in these past studies were less grammatically complex, such as "We've got to go" and "I sat in front of the bullet train."

While chunking of frequently used words may sometimes occur in less complex sentences, it may not account for all cognitive processes that are happening while processing sentences, especially for bilingual speakers. Kidd *et al* (2007) found differences in English-speaking children and German-speaking children's scores for sentence repetition of subject relative clauses and object relative clauses. They found the scores depended on the syntactic structure of the language the child was tested in. Sentence repetition may include implicitly processing the syntactic structure of the sentence and the grammatical cues in order to recall the whole phrase. This is further supported by the hierarchical regression analysis of this study. Bilingual individuals relied more on their pSTM to recall sentences. Since bilingual participants were relying more on pSTM to process the sounds and less on their working memory, perhaps this suggests bilingual speakers relied less on syntactic cues compared to monolingual English-speakers. Monolingual speakers may have relied more on chunking since they have more experience with the English language and are more likely to have more frequently used phrases in their long-term memory.

The results of hypothesis 3 were expected. Both the NWR – N and NWR – DC task positively correlated with the sentence repetition tasks. Most correlations were in the 0.30 – 0.50 range, which suggests there is a moderate association between nonword repetition and sentence repetition (Cohen, 1988). Nonword repetition correlated weakly with the long sentence condition of the Poll sentence repetition task. The long sentence condition was the most difficult for the participants. Perhaps nonword repetition has a stronger impact on easier sentence repetition tasks compared to more difficult sentence repetition tasks. These results suggest pSTM has some impact on sentence repetition, but it does not account for all of the variance in the scores.

Hypothesis 4 was not supported. Monolinguals scored higher than bilinguals on all sentence types. It was expected monolinguals would score higher on more complex sentences since they have more experience and exposure to the English language, resulting in more familiarity with the grammar and phonemes of the language. However, it was unexpected that the bilingual speakers scored lower than monolinguals when recalling less complex sentences. Half of the bilingual participants were simultaneous learners while the other half were sequential leaners. However, all participants learned English before or near puberty. Typically, the earlier an individual learns a language, the higher they score on language proficiency tests, especially before the age of 15 (Johnson & Newport, 1989). Johnson & Newport (1989) found children who arrived in the US between the ages of 3-7 (sequential bilinguals) scored similarly to native speakers on grammaticality judgement tasks.

Since this group of bilinguals contained many simultaneous bilinguals, it was expected the bilinguals would perform higher on the sentence recall tasks. The results for hypothesis 4 suggest there are knowledge differences between monolingual participants and bilingual participants who used English from an early age. This knowledge difference may be the result of different experiences with the English language. For example, monolinguals have more experience with English since they use it all the time, but bilinguals who use multiple languages throughout their day aren't exposed to English in an analogous way to monolinguals. The linguistic representations of English in monolinguals and in bilinguals may differ to their different experiences with the English language. This suggests world knowledge and linguistic knowledge stored in long-term memory affects sentence repetition.

Results for hypothesis 5 were unexpected. Bilinguals relied more on their pSTM while monolinguals relied more on their working memory. These results differed from studies with children. Frizelle & Fletcher (2015) reported children with typically developing language skills with stronger language networks relied more on the pSTM while children with weaker language networks relied more on working memory. In this case, adults with more English language experience relied more on their working memory, and adults with less English language experience relied more on their pSTM. Typical developing children are still learning, so perhaps this suggests why they relied more on their pSTM. In this way, bilingual speakers may be more similar to typically developing children with their second language skills and are, therefore, relying more on their pSTM. Further studies will be needed to test this hypothesis.

Monolingual speakers may rely more on their working memory rather than their pSTM since they process more syntactic and pragmatic relationship cues to recall sentences. Just and Carpenter (1992) found that individuals with higher working memory spans read sentences faster and answered true or false comprehension questions more accurately compared to individuals with lower working memory spans. Individuals with high working memory spans more accurately answered comprehension questions about unambiguous questions compared to individuals with lower working memory spans. However, they scored similarly to individuals with lower spans on complex ambiguous sentences. Just & Carpenter (1992) hypothesized this to be the case since individuals with higher working memory spans were able to process more cues, such as pragmatic cues, since they had left over resources to allocate. Past research has suggested individuals use pragmatic cues, such as associations between animate nouns and verbs to reduce taxing working memory capacity (King & Just, 1991). This suggests monolinguals may use their working memory skills to process sentences and repeat them since they are processing more cues compared to bilingual individuals. Monolingual individuals may be relying on syntactic or semantic cues while bilingual individuals may be relying on phonological cues to recall sentences.

Limitations

The delivery of the study via a remote platform placed limitations on the quality of the data. For example, the researchers could not control for which computer software or headphones a participant received the sound through. Some participants had poor internet connections, which may have impacted the quality of the stimuli that the participant received.

Another limitation includes the lack of a reliable proficiency measure. Past research has suggested proficiency is related to scores on language measures, so using a proficiency measure may provide insight into alternate explanations for the results of this study. This study did use a self-reported proficiency measure on the Qualtrics survey, but it was not used in analysis since self-reported measures tend to be unreliable.

Finally another limitation includes the relatively high education of the participants. Since almost all of the participants had some college education, the participants may have been able to draw on educational knowledge to recall sentences. Education impact on sentence recall of specific types of sentences, such as adjunct or argument sentences, will need to be explored in the future.

Conclusions

Long-term memory, working memory, and pSTM interact with each other, and with language skills and networks, including pragmatic cues, semantic relationships, and syntactic complexity to affect an individual's ability to recall sentences. Given the way these cognitive skills interact with each other, it is difficult to parse these apart. They all play an important role in processing language. Since sentence recall taps into multiple language and cognitive processes to give a general overview of the client's skills, it is a good tool to use when assessing an individual's language abilities. It can also be useful for identifying individuals with SLI since research demonstrated individuals with SLI tend to have difficulty with linguistic representations, working memory, and pSTM, all cognitive abilities used in sentence repetition. Since bilinguals scored differently compared to monolinguals, caution should be used when using sentence repetition tasks with bilingual speakers. Their language processes and skills are activated differently, depending on the language they are using, so testing in their second language may not reflect a bilingual's strongest language abilities.

References

Allen, R. J., & Baddeley, A. D. (2008). Working memory and sentence recall. In A. S. C. Thorn, & M. P. A. Page (Eds.), *Interactions between short-term and long-term memory in the verbal domain; interactions between short-term and long-term memory in the verbal domain* (pp. 63-85) New York: Psychology Press.

Archibald, L. M. D. (2013). The language, working memory, and other cognitive demands of verbal tasks. *Topics in Language Disorders, 33*(3), 190-207.

Bannard, C. & Matthews, D. (2008). Stored word sequences in language learning: The effect of familiarity on children's repetition of four-word combinations. *Psychological Science, 19*(3), 241-248.

Coady, J. A. & Evans, J. L. (2008). Use and interpretations of non-word repetition tasks in children with and without specific language impairments (SLI). *International Journal of Language Communication Disorders, 43*(1), 1-40.

Cohen, J. (1988). Statistical power analysis for the behavioral sciences (2nd edition). Mahwah, NJ: Erlbaum.

Cowan, T. A. (2021). *Error patterns in bilingual repetition: An analysis of cognitive linguistic and lexical-semantic factors.* [Unpublished doctoral dissertation]. Penn State University.

Dollaghan, C. & Campbell, T. F. (1998). Nonword repetition and child language impairment. *Journal of Speech, Language, and Hearing Research, 41*, 1136-1146.

Flege, J.E., Yeni-Konshian, G.H., & Liu, S. (1999). Age constraints on second-language acquisition. *Journal of Memory and Language, 41*, 78-104.

Frizelle, P. & Fletcher, P. (2015). The role of memory in processing relative clauses in children with specific language impairment. *American Journal of Speech-Language Pathology, 24*, 47-59.

Gullifer, J. W., Kousaie, S., Gilbert, A. C., Grant, A., Giroud, N., Coulter, K., Klein, D., Baum, S., Phillips, N., & Titone, D. (2021). Bilingual language experience as a multidimensional spectrum: Associations with objective and subjective language proficiency. *Applied Psycholinguistics, 42*(2), 245-278. DOI: https://doi.org/10.1017/S0142716420000521

Jefferies, E., Lambon Ralph, M. A., & Baddeley, A. D. (2004). Automatic and controlled processing in sentence recall: The role of long-term and working memory. *Journal of Memory and Language, 51*(4), 623-643.

Johnson, J. S. & Newport, E. L. (1989). Critical period effects in second language learning: The influence of maturational state on the acquisition of English as a second language. *Cognitive Psychology, 21*(1), 60-99.

Just, M. A., & Carpenter, P. A. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review, 99*(1), 122-149.

Kidd, E., Brandt, S., Lieven, E., & Tomasello, M. (2007). Object relatives made easy: A cross-linguistic comparison of the constraints influencing young children's processing of relative clauses. *Language and Cognitive Processes, 22*(6), 860-897.

King, J., & Just, M. A. (1991). Individual differences in syntactic processing: The role of working memory. *Journal of Memory and Language, 30*(5), 580-602.

Kormos, J. & Safar, A. (2008). Phonological short-term memory, working memory and foreign language performance in intensive language learning. *Bilingualism: Language and Cognition, 11,* 261-271.

Law, J., Garret, Z., Nye, C. (2004). The efficacy of treatment for children with developmental speech and language delay/disorder: A meta-analysis. *Journal of Speech, Language, and Hearing Research, 47*(4), 924-943.

Martin, K. I., & Ellis, N. C. (2012). The roles of phonological short-term memory and working memory in L2 grammar and vocabulary learning. *Studies in Second Language Acquisition, 34,* 379-413.

McCauley, S. M. & Christiansen, M. H. (2019). Language learning as language use: A cross-linguistic model of child language development. *Psychological Review, 126*(1), 1-51. DOI:10.1037/rev0000126

McDonald, J. (2000). Grammaticality judgments in a second language: influences of age of acquisition and native language. *Applied Psycholinguistics, 21*, 395-423.

Moran, S. & McCloy, D. (n.d.). Segments. *Phobile 2.0.* Retrieved 29 December 2021 from https://phoible.org/parameters.

Nittrouer, S., Shune, S., & Lowenstein, J. H. (2011). What is the deficit in phonological processing deficits: Auditory sensitivity, masking, or category formation? *Journal of Experimental Child Psychology, 108*(4), 762-785.

Parente, R., Kolakowsky-Hayner, S., Krug, K., & Wilk, C. (1999). Retraining working memory after traumatic brain injury. *NeuroRehabilitation, 13,* 157-163.

Poll, G. H., Miller, C. A., Mainela-Arnold, E., Donnelly Adams, K., Misra, M., & Park, J. S. (2013). Effects of children's working memory capacity and processing speed on their sentence imitation performance. *International Journal of Language & Communication Disorders, 48*(3), 329-342.

Poll, G. H., Miller, C. A., & van Hell, J. G. (2016). Sentence repetition accuracy in adults with developmental language impairment: Interactions of participant capacities and sentence structures. *Journal of Speech, Language, and Hearing Research, 59*(2), 302-316.

Riches, N. (2012). Sentence repetition in children with specific language impairment: An investigation of underlying mechanisms. (2012). *Internal Journal of Language & Communication Disorders, 47*(5), 499-510.

Riches, N. (2020). Commentary on special issue: Syntax and verbal short term memory. *First Language, 40*(4), 500-506.

Seeff-Gabriel, B., Chiat, S., & Dodd, B. (2010). Sentence imitation as a toll in identifying expressive and morphosyntactic difficulties in children with severe speech difficulties. *International Journal of Language Communication Disorders, 45*(6), 691-702.

Semel, E. , Wiig, E. H. , & Secord, W. A. (2004). *Clinical evaluation of language fundamentals, fourth edition* (CELF-4). Toronto, Canada: The Psychological Corporation.

Smith-Lock, K. M., Leitao, S., Lambert, L., Nickels, L. (2013). Effective intervention for expressive grammar in children with specific language impairment. *International Journal of Language & Communication Disorders, 48*(3), 265-282.

Spanoudis, G. C., & Natsopoulos, D. (2011). Memory functioning and mental verbs acquisition in children with specific language impairment. *Research in Developmental Disabilities, 32*(6), 2916-26.

Tremblay, A., Derwing, B., Libben, G., & Westbury, C. (2011). Processing advantages of lexical bundles: Evidence from self-paced reading and sentence recall tasks. *Language Learning, 61*(2), 569-613.

Vansteensel, M. J., Selten, I. S., Charbonnier, L., Berezutskaya, J., Raemaekers, M. A. H., Ramsey, N. F., Wijen, F. (2021). Reduced brain activation during spoken language processing in children with developmental language disorder and children with 22q11.2 deletion syndrome. *Neuropsychologia, 158.* DOI: https://doi.org/10.1016/j.neuropsychologia.2021.107907

Wechsler, D. (1997). WAIS-IV: Wechsler Adult Intelligence Scale—Third Edition: Manual. San Antonio, TX: Psychological Corporation.

Zebib, R., Tuller, L., Hamann, C., Ibrahim, L. A., & Prévost, P. (2020). Syntactic complexity and verbal working memory in bilingual children with and without developmental language disorder. *First Language, 40*(4), 461-484.

Appendix

Poll Sentences

Short Argument

1. The worker carved the wood with his knife but denied the evidence.
2. The widow painted the shed and frightened the mice with her hammer.
3. The president urged the army to act and blocked their glory.
4. The observer located the park and taught the kids the method.
5. The soprano played the passage and read the joke to the public.
6. The insider assigned the woman the verse to check her vision.

Short Adjunct

7. The genius realized the date at dawn and wrote in the cold.
8. My patient protested in the bath and dripped down the long hall.
9. The soul visited before the judgment but prayed at great length.
10. People hurried at the accident but crumbled at the main square.
11. The author cheated the agency at first and bragged in public.
12. The dog struggled in the pet motel and jumped at the signal.

Short Argument

13. Our grandmother injured her ego yet knit our mother new linen.
14. My brother studied the item then filled the bowl with liquid.
15. This generation tempted hope and grasped success with both hands.
16. The scholar ate an orange and inserted the seeds in sand.

17. The principal saddened the child but coaxed him into class.

18. The hotshot baked her assistant a cake and added a cherry.

Short Adjunct

19. The staff tired before the farewell and complained in the cellar.

20. The driver rushed for the jokester but crashed on the dreaded curve.

21. Our guide worried at the emergency but decided later.

22. The specialist froze at the call then replied in confusion.

23. The competition melted at our strength but rose after the snub.

24. The corporal flew at noon over the sound and drove in terror.

Long Argument

25. Management chose a plan and excited loyalty but entertained the executives with folly.

26. The graduates delighted in the trip but annoyed my aunt while the minister adjusted the tent.

27. The enterprise required a loan and asked their banker but the executive wanted assurance.

28. My grandfather added the stables and paid for the ferry but accepted assistance from the men.

29. Our candidate invited the nation to a fight but lost the primary and conceded defeat.

30. Management praised the vision and permitted an exception but the company shut the gallery.

Long Adjunct

31. The physician proposed a cure in his research but his patient swore at the complication.

32. My uncle disclosed the scheme during the call but the company cheated as usual at the port.

33. The secretary disclosed the bet in the afternoon and still raced the next morning at the brick track.

34. The beauty dreamed of glamour during vacation but her family moved after the church holiday.

35. The cohort rotated to a new danger in the summer and walked for the season without luck.

36. Council declared its purpose despite the emotion and concluded construction after the election.