The Immediate Effects of Abdominal Breath-Control on Phonological Working Memory Performance and L2 Word Learning

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An abstract of
a thesis submitted to the Faculty of Emory College of Arts and Sciences
of Emory University in partial fulfillment
of the requirements of the degree of
Bachelor of Arts with Honors

Linguistics

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Abstract

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Working memory refers to a short-term ability to store and manipulate information that can be utilized for various cognitive tasks and has been found to be a strong predictor of second language (L2) vocabulary learning (Baddeley, 2003; Juffs & Harrington, 2011; Rice & Tokowicz, 2020). One practical method that could potentially aid L2 learners' working memory performance in learning novel vocabulary is deep breathing, which consists of slowing down one's breath and focusing on abdominal movement during respiration. For example, researchers in psychophysiology have found deep breathing exercises to induce cardiorespiratory synchronization and enhance the activity of respiratory and diaphragmatic muscles, leading to optimal increased levels of inhaled oxygen, and greater oxygen concentration in the body has been associated with improved cognitive functioning on working memory tasks (Nirmalasari, 2020; Kim et al., 2013; Laborde et al., 2021). However, to date, there have been no studies in the field of L2 acquisition connecting deep breathing with word learning. In order to bridge this research gap, the current study aimed to analyze the impact of a short-term abdominal breath-control intervention on facilitating L2 word learning in Lithuanian for Lithuanian-naive L1 English speakers. 36 undergraduate participants who are functionally monolingual L1 speakers of American English and have never acquired Lithuanian were recruited. All participants completed a backwards digit span task, and then half were randomly placed into the control group in which they watched a video from NASA about findings in space, while the other half were assigned to the experimental group that engaged in 17 minutes of slow breathing

exercises following a familiarization period (Laborde et al., 2021). Then, all participants proceeded onto the word learning task before completing a vocabulary quiz at the end (Kemp & McDonald, 2021). The findings show that those in the breathing experimental group had significantly higher scores on the working memory task compared to the control group, while the two groups had no difference in L2 word learning accuracy, potentially due to the cognitive effects of slow breathing wearing off before reaching the vocabulary quiz at the end. Future research is needed in order to further explore the effects of slow, deep breathing on enhancing cognition, as breath-control may be a promising approach to be implemented in the foreign language classroom as a cost-free method to effectively increase working memory performance, especially for disadvantaged students who have had limited opportunities to enhance their cognition.

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Acknowledgements

First, I give thanks to my advisor, Dr. Yun Kim, who spent countless hours providing her wisdom, support, and guidance for me to develop this thesis as a researcher in my own right. She inspires me to hope to become a professor one day who motivates students to maximize their potential with a heart of compassion as she did for me. I thank the other members of my committee who provided me with essential feedback and suggestions: Dr. Seth Goss who helped me run the statistical analysis, Drs. Daniel Walter and Lynne Nygaard who critiqued my methodology and guided me throughout my data interpretation, and Dr. Donald Noble who deepened my understanding of the psychophysiological correlates of slow, deep breathing. I also have sincere appreciation for the Emory Undergraduate Research Programs that enabled me to compensate all my participants with a small gift through the Independent Research Grant I received and for Leonardo Michelini, my graduate student mentor in the Speech and Language Perception Lab who helped me with the data analysis as well.

Second, I am forever grateful for my parents and grandmothers who have always been my greatest background of prayer, and I am thankful for my Aunt Danielle who took care to help me formulate ideas for my research question that drove this entire study. I especially give thanks to my grandfather, the late Elder Bong Ki Yoon, who I know is praying for me in heaven and dedicate this thesis to him. Although he physically left our side the summer before I started my honors thesis, he will always be my greatest role model for my intellectual and spiritual pursuits.

Third, I express my appreciation for my senior pastor, beloved church members, and closest friends who continuously encouraged me and kept my research in their hearts. I am especially grateful for my church elder, Dr. Chang Hyun Khang from the University of Georgia, who regularly checked in with me to nurture my spiritual and mental well-being and expanded my perspectives through insightful conversations about research in academia as I prepared this thesis. I also express my gratitude to my spiritual mentor in Korea, Reverend Kwang Su Ryu, who encouraged me to connect my research interests in language learning with my faith by investigating the power contained within the breath of life, which lies at the core of the fundamental principles of creation.

Greatest of all, I give all glory to God who is my number one Supporter and thank Him for accurately guiding my steps to Emory where I ended up meeting such incredible professors and discovering the passions He predestined for me. With this opportunity given from the throne above to walk the covenant journey of the fulfillment of His promises in my life, my sincerest desire is for this thesis and all of my future research endeavors to glorify Him—and testify of His faithfulness and the unique hope I found in Christ Jesus.

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The Immediate Effects of Abdominal Breath-Control on Phonological Working Memory Performance and L2 Word Learning

Among many psycholinguistic processes that accompany second language (L2) acquisition, one process that has been found to predict outcomes in L2 learning is individual variation in working memory abilities (Juffs & Harrington, 2011). Specifically, L2 learners who perform better on phonological working memory tasks tend to perform better on foreign language vocabulary learning tasks, especially for those who are in the earlier stages of acquisition that call for greater reliance on domain-general abilities such as working memory, as opposed to more language-based abilities that are used by advanced learners (Wen & Li, 2019; Rice & Tokowicz, 2020). In order to address individual variation in working memory performance and support L2 learners who may not be as strong in working memory functioning, a practical approach that may boost L2 learners' cognition is abdominal breath-control, which is also known as paced breathing or slow, deep breathing. Commonly explored in the psychophysiology and neuroscience literature, abdominal breath-control consists of slowing down one's breath to less than 10 breathing cycles per minute, which has been found to correlate with better cognitive functioning and especially better performance in working memory tasks (Zaccaro et al., 2018). The psychophysiological correlates of slow, deep breathing suggest that the extraction of greater oxygen through the breath as well as the production of slow cortical oscillations may explain why studies have found a significant benefit in cognition for those engaging in breath-control exercises (Nirmalasari, 2020; Noble & Hochman, 2019). However, because a gap remains between the fields of psychophysiology and L2 acquisition, I explore and analyze the immediate effects of practicing abdominal breath-control on phonological working memory performance and L2 word learning in Lithuanian for L1 speakers of American English who are Lithuanian-naive in the present study.

Literature Review

Working Memory and L2 Word Learning

Working memory (WM) refers to a short-term ability to store and manipulate information that can be utilized for various cognitive tasks (Baddeley, 2003). Previous research has shown that WM can generally be divided into different components, such as the central executive, phonological loop, and visuospatial sketchpad (Baddeley, 2003; Juffs & Harrington, 2011). While the phonological loop is responsible for storing and processing phonological and verbal information, the visuospatial sketchpad takes on the role of storing and processing visual and spatial information; the central executive, on the other hand, monitors the movement of information between the phonological loop and visuospatial sketchpad (Juffs & Harrington, 2011). A variety of measures in empirical studies have been used to measure WM capacity, such as the Stroop test, digit span task, and word and sentence span tasks, and in particular, the comparison of individual variation in performance on WM tasks has been found to predict abilities and outcomes in second language (L2) acquisition (Baddeley, 2003; Juffs & Harrington, 2011). Researchers have examined the interaction between WM capacity and diverse areas of L2 learning, such as reading, writing, sentence and input processing, speaking, and syntactic acquisition and also found WM performance to significantly predict overall attained L2 proficiency (Juffs & Harrington, 2011). These findings could be because possessing a greater

WM capacity could enable an L2 learner to “parse, analyze, and effectively manipulate new linguistic items and structures” (Martin & Ellis, 2012, p. 383).

Specifically, many empirical studies have addressed WM and L2 vocabulary acquisition, also known as L2 word learning, and found WM to be a strong predictor of L2 word learning (Rice & Tokowicz, 2020). The main two areas of WM that have been investigated in regards to L2 word learning have been the phonological loop and central executive, with executive WM being a weak predictor and phonological WM being a strong one for vocabulary size (Wen & Li, 2019). Studies have also found that the role of WM, especially the capacity of the phonological loop, appears to be more relevant for L2 word learning at the earlier stages of L2 acquisition, as more advanced learners seem to be more dependent on other language-based factors, such as previous vocabulary knowledge (Wen & Li, 2019). Similar effects have been seen in laboratory-based studies using an artificial foreign language using nonword stimuli as well (Martin & Ellis, 2012).

In the psycholinguistics and second language acquisition literature, a variety of approaches have been implemented to explore L2 vocabulary learning, including but not limited to repetition training with and without retrieval practice, spaced repetition training, and semantic elaboration through generation and thematic grouping (Rice & Tokowicz, 2020). More recently, in a review of past studies on L2 word learning in the laboratory setting, Rice and Tokowicz (2020) introduced the revised hierarchical model—repetition, elaboration, and retrieval (RHM-RER) to emphasize some of the most important factors of L2 word learning based on previous findings, saying that repetition, elaboration, and retrieval can either aid or hinder learners in creating stronger lexical representations and links between L1 and L2 forms. Within the framework of this model, the researchers concluded that vocabulary learning methods limited to massed repetition of L1 to L2 form connections are typically inefficient unless practiced along with exercises that encourage L2 form-meaning connections, such as semantic elaboration.

Meditation

Given the relevance of WM capacity and L2 word learning in second language acquisition (SLA), researchers in fields such as neuroscience and psychophysiology have introduced a method that has been effective in significantly improving performance on WM tasks, displaying potential to be applied to L2 learning as well. Among other approaches, meditation has been found to significantly improve cognitive functioning in recent studies. Meditation refers to methods by which an individual tries to focus their attention in a conscious manner, perhaps by drawing attention to their breath or avoiding distracting thoughts (Chan & Woollacott, 2007). Although there are many types of meditation (e.g., transcendental, pranayama), mindfulness meditation has been commonly analyzed as a manipulated variable along with performance on memory tasks. In studies where participants in the experimental group completed mindfulness meditation, results have shown that those who were regularly practicing meditators (Moore & Malinowski, 2009) and those who completed short-term meditation of several weeks (Butola & Chauhan, 2015; Greenberg, 2018; Mrazek et al., 2013; Quach et al., 2016), days (Zeidan et al., 2010), or in a single sitting (Lueke & Lueke, 2019) had better WM performance than participants in the control group (e.g., Stroop task, digit span task).

However, there have been mixed results, with a handful of studies finding no significant differences between the experimental meditation and control groups on WM tasks (Quek et al., 2021; Yates, 2015). One potential explanation for this could be the fact that meditation is made up of multiple aspects, such as slow breathing and achieving a state of mindfulness; therefore, it can be predicted that certain aspects of meditation positively affect cognitive functioning while others do not. While certain researchers have advocated for the cognitive aspects of meditation, such as mindfulness, being crucial in improving memory and other cognitive functions (Quach et al., 2016), more recent research raises the question regarding whether this is actually the case (Zaccaro et al., 2018).

For example, Ma et al. (2021) conducted a study comparing two types of meditation: open monitoring, in which participants were asked to monitor awareness while noticing what was happening in their minds rather than having selective attention, and focused attention, in which participants had to direct their attention to their breathing. In the results, the researchers found that only participants in the focused attention meditation had improved WM performance while those in the open monitoring meditation did not experience this effect. This could be due to the fact that the focused attention meditation was more centered on the breathing aspect compared to open monitoring. Another example of a study that supports this account comes from research conducted by Laborde et al. (2021) that tested the interaction between brief slow-paced abdominal breathing on its own and WM performance. The researchers found that participants performed significantly more accurately on the Stroop test and automated operation span task for working memory after completing breath-control intervention, despite the study having no direct connections to mindfulness or meditation.

Slow, Deep Breathing

Isolating breathing from meditation, researchers, especially those in psychophysiology, have discussed the changes that occur in the body upon practicing slow, deep breathing that could potentially explain these findings. First, deep breathing exercises have been found to enhance the activity of respiratory and diaphragmatic muscles, leading to optimal increased levels of inhaled oxygen (Nirmalasari, 2020), and increased oxygen concentration in the body has been associated with improving cognitive functions on memory tasks (Kim et al., 2013). Secondly, focusing on breathing during meditation might be slowing down the breath, helping the lungs to expand and take in more oxygen, and this phenomenon is also able to explain the findings from Laborde et al. (2021) regarding the enhanced performance in WM tasks for participants who completed slow-paced abdominal breathing.

In addition to oxygen, another line of research from the field of neuroscience that may serve to explain the cognitive benefits of slow, deep breathing is called cardiorespiratory synchronization. Cardiorespiratory synchronization can be defined as the occurrence of synchronized rhythms in respiration and heart rate (Noble & Hochman, 2019). Previous literature has emphasized that the psychophysiological mechanisms that underlie these slow breathing techniques may lead to better cognitive functioning, relaxation, and emotion regulation, as they seem to increase heart rate variability while boosting activity in the parasympathetic nervous system (Zaccaro et al., 2018).

More specifically, Noble and Hochman (2019) have proposed a model regarding the effects of cardiorespiratory synchronization through slow, deep breathing that may explain the cognitive benefits that occur during breath-control. In this model, the researchers further laid out the basic psychophysiological correlates of slow, deep breathing and cardiorespiratory synchronization, hypothesizing that voluntary breath modulation in a slow and deep manner resonates with Mayer waves, which are oscillations in arterial blood pressure that occur at the specific frequency of 0.1 Hz in humans (Noble & Hochman, 2019). Then, these oscillatory rhythms are predicted to be sent into a brainstem nucleus called the Nucleus Tractus Solitarius, which is a major parasympathetic station (Noble & Hochman, 2019). From the Nucleus Tractus Solitarius, the oscillations are said to travel into the other parts of the brain through neural activity (Noble & Hochman, 2019). Noble and Hochman (2019) argued that this could be leading to improvement in higher-order brain activity, namely the locus coeruleus, central nucleus of the amygdala, and hippocampus, which are areas associated with regulating attention, relaxation, and memory functions, respectively. As the hippocampus is argued to be a core part of the brain that facilitates memory, especially working memory (Yonelinas, 2013), this model suggests that the slow cortical oscillations and cardiorespiratory synchronization that slow, deep breathing gives rise to could facilitate better second language acquisition: specifically, performance in phonological working memory and L2 word learning, for the purpose of this present study.

Expanding on the idea of cardiorespiratory synchronization, a recent study conducted by Karalis and Sirota (2022) with rodent populations found that the slow cortical oscillations known for being responsible for memory consolidation were mediated by breathing—not just during wakefulness but also during sleep. Karalis and Sirota (2022) examined various cortical and subcortical areas of the brain, and they found that the correlates of respiration underlied the rhythms produced in the hippocampus that are known to mediate memory consolidation during sleep. This led to the hypothesis that “breathing acts as an oscillatory pacemaker” that may be a crucial part of memory functions in the brain (Karalis & Sirota, 2022, p. 1). Relating this to language acquisition, this evidence may be in support of the prediction that the slow rhythms produced during breathing would aid L2 memory consolidation, similar to the memory function that are said to occur during sleep.

A notable finding from previous empirical studies is that the cardiorespiratory synchronization that accompanies slow, deep breathing may not necessarily require an extensive amount of experience to achieve. A study conducted by Peng et al. (2004) found that experienced meditators engaging in different breathing techniques showed heart rate dynamics characteristic of cardiorespiratory synchronization. However, similar results were found in a study done by Cysarz and Bussing (2005) which showed that the same effect was seen in inexperienced meditators. This suggests that the cardiorespiratory effects of slow, deep breathing do not necessarily require many years of learning but may appear even in those engaging with breath-control for the first time, and this could be suggestive of the slow cortical oscillations that are important for memory functions.

Connections with L2 Acquisition

As research isolating slow, deep breathing from meditation is relatively limited, to date, there has been little research done in the field of SLA making the distinction between the two. Most studies applying meditation to L2 learning have focused on examining its effects on lowering levels of language use anxiety in the foreign language classroom (Li et al., 2019; Rahman & Syafei, 2019), with one study conducted by Önem (2015) which explored the significant impact of brief meditation on both anxiety and L2 vocabulary learning.

Therefore, in order to address these gaps in the literature, the current study was based on the following research question: what is the impact of a short-term intervention of slow, deep breathing exercises on working memory performance and L2 word learning in Lithuanian for

Lithuanian-naive L1 English speakers? It was hypothesized that there would be a statistically significant advantage for the slow, deep breathing experimental group compared to the control group for both phonological working memory and L2 word learning.

Methodology

Before collecting data, this study received full approval from the Emory University Institutional Review Board.

Participants

The sample consisted of 36 participants. The data from six participants was excluded from the analysis due to issues in technical difficulty with their electronic devices or loud auditory distractions in the background during the breathing intervention, leaving 30 participants with successful data collection who ranged from 18 to 22 years old (M = 20.4, SD = 1.45). Participants were recruited by sending out an advertisement flyer using the Emory University listserv and through word of mouth. All subjects identified as being functional monolinguals who grew up with American English as their first language, with no minority or heritage language spoken at home. None of the participants reported experiences learning Lithuanian prior to the study, and participants had their foreign language learning experiences limited to taking several foreign languages at school. No participants regularly practiced in slow, deep breathing exercises on a regular basis.

Procedure and Measures

Each participant who expressed their desire to take part in the study met with the researcher for an hour through online video chat on the Zoom Video Communications platform, taking into consideration the conditions of the COVID-19 pandemic. Prior to starting the study, the researcher made sure that the experimental environment was controlled by confirming that all participants were in a quiet space without interruptions where they could take their mask off. In addition, all participants reported that they were wearing comfortable clothes that were loose around the waist and were sitting on a chair.

Upon meeting the researcher on Zoom, participants were directed to an external site called Qualtrics where they were asked to fill out the consent form and a language background questionnaire. The language background questionnaire included questions to confirm language learning experiences and language use, as well as an item to indicate that they do not regularly practice slow, deep breathing exercises (Appendix A). Afterwards, participants were asked to open a website link to the experiment designed using an online behavioral experiment building platform called Gorilla Experiment Builder. Participants shared their browser screen while the researcher walked them through the tasks.

All participants began the experiment with a backwards digit span task. Then, half of the participants were randomly placed in the control group in which they watched a 28-minute video from the National Aeronautics and Space Administration (NASA) about findings in space, while the other half were put into the experimental group that learned and engaged in breath-control exercises. Following the intervention, all participants completed the L2 Lithuanian word learning task, and then they proceeded to complete the same backwards digit span task again before finishing with the vocabulary quiz. Following participation, all subjects received a $5.00 Amazon gift card as compensation. The flowchart of the order of the tasks from the Gorilla

Experiment Builder website can be found in Appendix B.

Backwards Digit Span Task

For the working memory task, the backwards digit span task was chosen due to its associations with the usage of the phonological loop of working memory, as opposed to the forwards digit span task which is associated with measuring short-term memory (Wells et al., 2018; Chere & Kirkham, 2021). The task was cloned from Massonnie's (2020) study, which Massonnie also designed using Gorilla Experiment Builder. In the task, participants were shown a series of digits and were instructed to click on the numbers using the keypad shown on the screen but in reverse order of how the numbers were presented. The digit stimuli began with a span of two with two numbers shown in total, and the span increased by one every time the participant got at least three out of the five trials correct for the given span. There were two practice trials at the beginning with feedback to ensure that the participants understood how to work the task. All digits were randomized during each trial, with every trial showing a novel set of digits. The output data had two components: the final score of how many trials they responded with perfect accuracy and the final span that they reached.

Breathing Intervention

While the control group spent 28 minutes watching a NASA video about findings in space (https://www.youtube.com/watch?v=TSiGW70kusI), the experimental group took part in a series of slow, deep breathing exercises as a partial replication of the paced breathing experimental procedure conducted in Laborde et al.'s (2021) study. First, participants received instruction for three minutes from the researcher regarding how to practice the slow, deep breathing technique (the script can be found in Appendix C). The directions were taken from Laborde et al. (2021), and they included guidelines about breathing in through the nose and out through the mouth with pursed lips. Participants were also asked to place their hands on their lower belly and chest and to try their best to keep the abdomen moving while keeping the chest relatively still during deep breathing (Laborde et al., 2021). Following the instruction, the researcher verbally confirmed with each participant to see if they were following the technique correctly.

Afterwards, participants watched guided breathing videos that were created using the EZ-Air Plus Software from the Biofeedback Federation of Europe, which can be found in the Appendix C (Laborde et al., 2021). The videos showed a yellow ball moving up and down, and participants were asked to inhale during upward movement and exhale during downward movement. The first video, which lasted eight minutes, served as a familiarization period for participants to ease into the target breathing rate of six cycles per minute. This familiarization exercise was divided into three units with one-minute breaks in between: two minutes of 10 breaths per minute (BPM), two minutes of eight BPM, and two minutes of six BPM (Laborde et al., 2021). After finishing the familiarization, the researcher confirmed with the participant again to check if the technique was being done accurately. Then, participants were directed to the second video which had the main paced breathing exercise. This video lasted for 17 minutes, and it had three units of five-minute continuous breathing at six BPM, with one-minute breaks in between each unit (Laborde et al., 2021). Inhalation lasted for 4.5 seconds and exhalation for 5.5 seconds (Laborde et al., 2021).

L2 Word Learning

Following the deep breathing session and NASA video, all participants in both groups engaged in an L2 Lithuanian word learning activity based on Kemp and McDonald's (2021) study. The vocabulary stimuli were the 10 target words that Kemp and McDonald (2021) used from a list of Lithuanian words normed for laboratory experiments with undergraduate participants, and they were balanced in terms of the number of semantic categories (Appendix D) (Kemp & McDonald, 2021). There were two words that fell into each of the following categories: vegetables, clothing, kitchen-related words, furniture, and building parts. The Lithuanian words were orthographically adjusted to keep the orthography similar to that of English, and they did not include diacritical marks (Kemp & McDonald, 2021).

Upon starting the task, participants were shown L1-L2 pairs. The pairs were shown next to each other, with the L1 English word on the left side and the L2 word on the right. The design of this task was also partially replicated from Kemp and McDonald (2021). The 10 pairs were divided into chunks of three, where participants were shown three, four, and then three pairs consecutively with each pair displayed on the screen for five seconds. In between each chunk, participants engaged in a retrieval practice that asked participants to type in the L2 equivalent word after being presented with the L1 word (Rice & Tokowicz, 2020). The correct L1-L2 pair was shown immediately after each response, regardless of the participant's accuracy. The word learning part that showed the chunks of L1-L2 pairs had a fixed order of presentation, while the retrieval practice in between each chunk randomized the items. The 10-word list was studied in this manner twice, and the entire task lasted around five minutes.

After completing the word learning task, all participants proceeded onto the second backwards digit span task before completing the vocabulary quiz at the end. The vocabulary quiz randomized all items and presented the L1 form, and participants typed in the L2 equivalent word. Scoring was based on perfect accuracy.

Results

For the first part of the data analysis, a one-way analysis of covariance (ANCOVA) was conducted on R Studio to measure the effect of the breathing exercises on the pre- and post-intervention digit span task scores for the experimental group versus the control group, while controlling for the variance in pre-intervention working memory abilities (Figure 1 and Table 1). Prior to running the analysis, the data met the assumptions for ANCOVA, as it was normally distributed, the variances of both groups were homogenous, and both groups had linearity in the data. Results of the ANCOVA show that there were significant differences in the mean post digit span score [$F(1, 27) = 6.83$, $p < 0.05$, partial $eta^2 = 0.20$] between the breathing and control groups. The covariate pre-intervention digit span score was also significant [$F(1, 27) = 32.44$, $p < 0.001$, partial $eta^2 = 0.54$], indicating that it was a strong predictor of mean post digit span score.

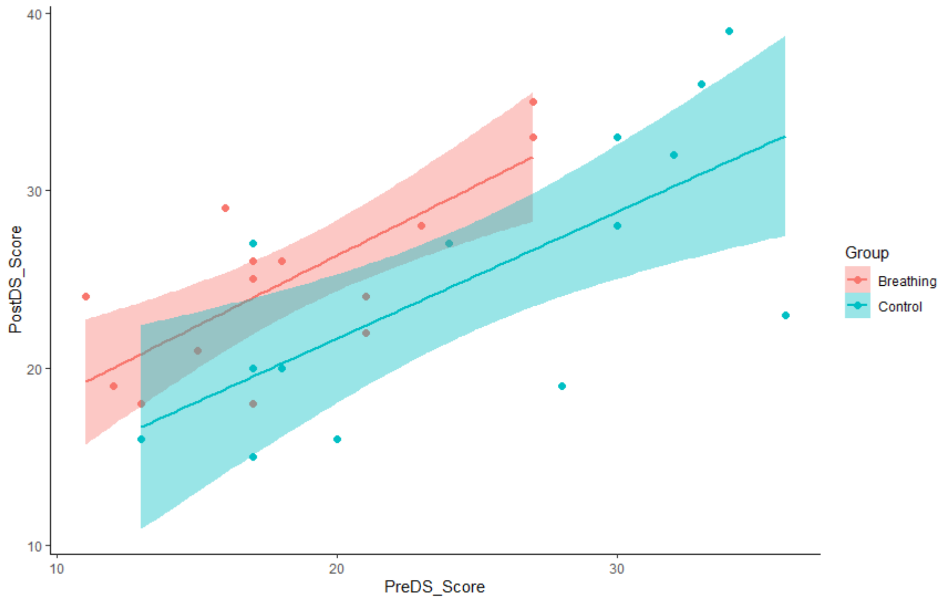


Figure 1. Scatterplot with regression lines showing the pre- and post-intervention working memory scores for the breathing and control groups.

	Pre-Intervention Digit Span Task (Avg.)		**Post-Intervention Digit Span Task (Avg.)**	
	Trial Score	**Span Values**	**Trial Score**	**Span Values**
Control	24.67	6.4	25	6.4
Experimental	18.8	5	25.4	6.6

Table 1. Average scores for pre- and post-intervention digit span task data for the control and experimental groups.

In the second part of the analysis, an independent samples *t*-test was used to compare the vocabulary quiz scores of the two groups. There was no significant difference between the control ($M = 66$, $SD = 22.61$) and breathing ($M = 53.33$, $SD = 26.64$)groups, $t(27) = 1.4$, $p > 0.05$, 95% CI [-5.76, 31.16] (Figure 2).

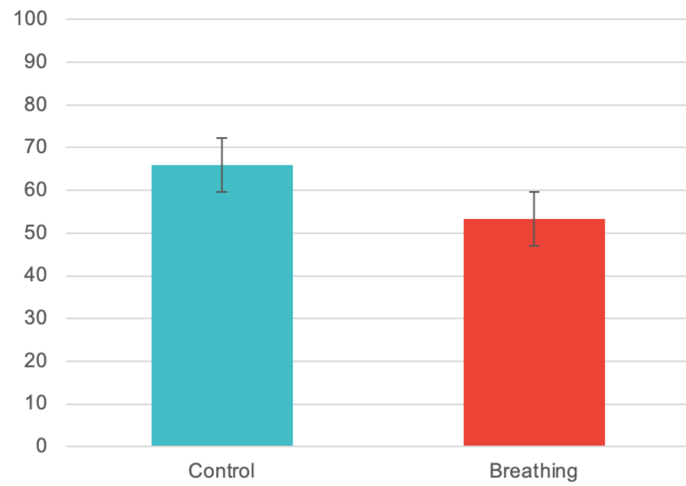


Figure 2. Percentage accuracy on the vocabulary quiz task for the control and breathing groups.

The third analysis tested to see whether there was a correlation between the pre-intervention working memory score and the vocabulary quiz outcome for all participants, regardless of the group placement. A Pearson correlation was conducted with a *p*-value of 0.05, and the output showed that there was no significant correlation between pre-intervention working memory abilities and the vocabulary quiz score, $r(28) = 0.68$, $p > 0.05$, $R^2 = 0.02$ (Figure 3).

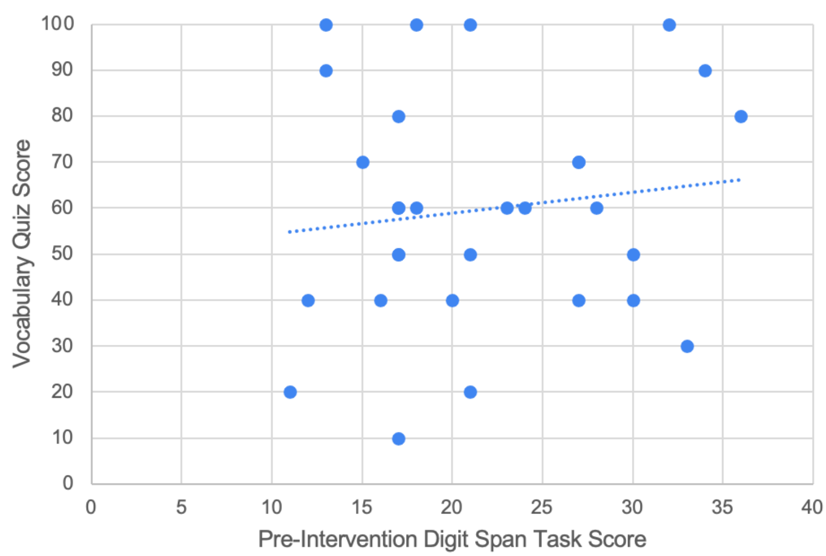


Figure 3. Scatter plot demonstrating a weak correlation between the pre-intervention digit span task score and percentage accuracy on the vocabulary quiz.

Discussion

The first analysis comparing the two groups' scores on the pre- and post-intervention digit span task was aligned with the hypothesis, as there was a significant advantage that appeared for participants who completed the breathing exercises compared to the control group. The effect of being in the breathing group was significant, and this finding confirmed what Laborde et al.'s (2021) found—a cognitive advantage clearly evident in working memory performance after the implementation of a slow, deep breathing intervention. This suggests that practicing abdominal breath-control may be a practical method to enhance cognitive activity in learners immediately after completing a breathing exercise intervention.

However, contrary to the original hypothesis, the vocabulary quiz data had no significant difference between the control and breathing groups, meaning that the extent to which the participants were able to recall the Lithuanian words after the second digit span task was not impacted by the group they were placed in. This was an unexpected finding, as the original prediction was for the participants in the breathing group to have a significant advantage on both the working memory and word learning tasks. One potential explanation for this finding connects to the fact that all participants came in as individuals who do not regularly practice slow, deep breathing exercises, and as inexperienced slow breathers, they may not have been able to maximize the beneficial effects of voluntary breath-control. Another possibility is that the cognitive enhancement brought about through the breathing exercises may have aided participants in the experimental group throughout the digit span task but had been interfered with when they reached the vocabulary recall task at the end.

For the third set of results, the findings revealed no significance in the correlation between pre-intervention digit span task scores and vocabulary quiz outcome. This suggests that working memory, specifically phonological working memory capacity that is utilized during the backwards digit span task, may not be primarily responsible for the psycholinguistic mechanisms involved in L2 word learning for L2-naive learners. Although many studies have found empirical evidence in support of phonological working memory significantly predicting how well L2 learners learn foreign language vocabulary, there are others that did not find this effect (Juffs & Harrington, 2011). This ties into the greater picture of the role and influence of domain-general abilities as opposed to language-specific abilities in the brain, as phonological working memory as a domain-general ability may influence other aspects of L2 acquisition (e.g., L2 reading comprehension, L2 grammar development), but may not be a factor that systematically predicts outcomes in word learning (Erçetin, 2015; Martin & Ellis, 2012; Kaushanskaya & Yoo, 2013). Thus, this may be the reason why the breathing exercise that participants engaged with in the present study may not have had a direct impact on L2 word learning, while showing a significant influence on digit span task scores.

Limitations

Several limitations are worth considering in the interpretation of these findings. One limitation was inevitable—the COVID-19 pandemic and the difficulties in meeting participants in-person may have affected the effectiveness of the breathing exercises. Participants may have struggled to stay focused on the entirety of the breathing intervention that lasted a total of 28 minutes including the instruction, familiarization, and main exercise, and their minds may have wandered, preventing full engagement in controlling their breath. As the researcher could only see participants virtually through Zoom, keeping track of whether participants stayed engaged the whole time was challenging.

Another limitation was the lack of quantitative physiological data to measure how much oxygen participants were taking in or the frequencies that arise when cardiorespiratory synchronization is activated during slow, deep breathing. Although the literature review highlighted findings from previous studies, there is still a lack of a coherent model that consolidates all of the psychophysiological correlates of slow, deep breathing, so the benefits that the experimental breathing group experienced in improved working memory performance may possibly be due to other mechanisms (Zaccaro et al., 2018; Noble & Hochman, 2019).

Implications

Despite these limitations, the findings of the present study hold pedagogical interventions for the foreign language classroom. L2 learners come with diverse backgrounds and experiences, including individual variation in psycholinguistic abilities such as working memory. Although the precise aspects of domain-general abilities such as working memory that most directly contribute to aspects of L2 acquisition are not yet entirely understood, the findings of the present study suggest that cognitive enhancement did arise immediately after the breathing intervention. L2 learners' cognitive performance may be improved through slow, deep breathing, and the specifics regarding how exactly this should be implemented pedagogically will be better understood through future research.

More generally speaking, this study, which was contextualized in L2 acquisition, has implications that extend to general learning and classrooms of other subjects and disciplines. As working memory is an ability that has been associated with learning in other contexts, such as mathematics, L1 reading abilities, and general scholastic attainment and learning, incorporating breath-control may enhance cognitive and academic performance in settings outside of the foreign language classroom as well (Alloway, 2006).

Future directions

This study will continue with further data collection until the target number of participants is reached ($N = 66$; Laborde et al., 2021). If the current trend in the data continues to appear with further exploration, there may be a second experiment that changes the order of tasks in the methodology in order to analyze whether the cognitive benefits of slow, deep breathing may have worn off during the digit span task before reaching the vocabulary quiz. The second experiment will guide participants to complete the vocabulary quiz immediately after word learning and then go onto the digit span task to conclude the session. If the experimental breathing group's scores show an advantage in practicing breath-control for the vocabulary quiz, it would be worth considering the implementation of short-term breathing exercises at the beginning of class or before important learning activities.

Future research should address the duration of breathing exercises required and explore the variable techniques and methods involved in slow, deep breathing, to further examine how they relate to cognitive enhancement. For instance, the degree to which participants expand their abdomen and take in more oxygen during inhalation may be affected by sitting on a chair, as opposed to standing or laying down. Additionally, in the present study, participants sat relatively still throughout the breathing intervention, but doing breath-control with body movement may allow greater flow of air into the respiratory system and relax bodily tension from trying to sit still. Moreover, another interesting variable is the timing of the breathing exercise. The breathing intervention was before the cognitive and language learning tasks in this study, but engaging in breath-control during the tasks may produce different effects. This design would require the participants to already be comfortable with the breathing exercises so that they would not have an additional cognitive load that may take away from focusing on the learning and breathing simultaneously.

Aside from the specifics of the breath-control methods, other aspects of working memory functions (e.g., central executive, visuospatial sketchpad) and L2 acquisition may undergo improvement through slow, deep breathing. As the present study had significant effects for phonological working memory performance, breath-control may boost abilities that relate to other processes such as auditory processing and non-native prosody perception or aid in enhancing focus and attention (Noble & Hochman, 2019). Future studies should investigate other areas of working memory, psycholinguistic functions, and L2 learning that learners could potentially enhance through voluntary breath-control.

Conclusion

In conclusion, this experiment aimed to analyze the immediate effects of short-term abdominal breath-control on phonological working memory performance and L2 Lithuanian vocabulary learning in a sample of undergraduate students who were L1 speakers of American English. The findings showed that the participants who completed the slow, deep breathing exercises had a significant advantage over the control group in the backwards digit span task for working memory, although the vocabulary quiz scores revealed no statistically significant difference between the two groups. In addition, the data analysis revealed a weak correlation between pre-intervention phonological working memory abilities and overall outcome of L2 word learning. Although the breathing intervention did not directly impact the vocabulary quiz scores, the significant advantage on the working memory task suggests that cognitive enhancement did occur following slow, deep breathing. Future research should test the different aspects of varying the timing, duration, and methods of breath-control as well as the various components of L2 acquisition that could potentially be benefited, ultimately to determine whether breath-control can be used to support L2 learners and students in classrooms of diverse subject areas all across the world.

Appendix A: Language Background Questionnaire

Name

[ ]

Gender

- Male
- Female
- Non-binary / third gender
- Other / prefer not to say

Age

[ ]

Are you an undergraduate student?

- Yes
- No

Do you speak (American) English as your dominant language?

- Yes
- No

What was the primary language of instruction at the school(s) you have attended?

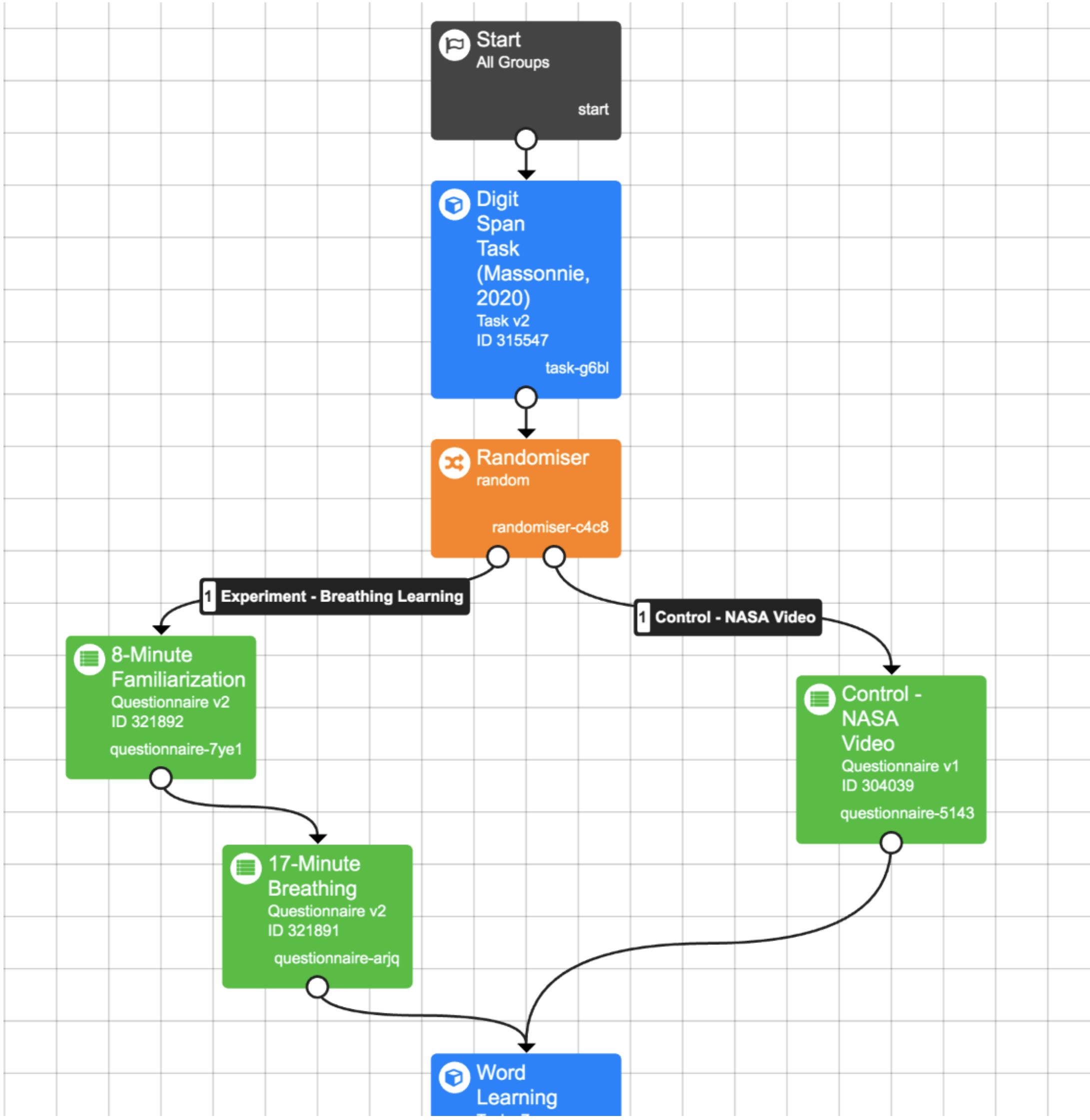
Which language(s) do you speak? Please include the dialect(s) of this/these language(s).

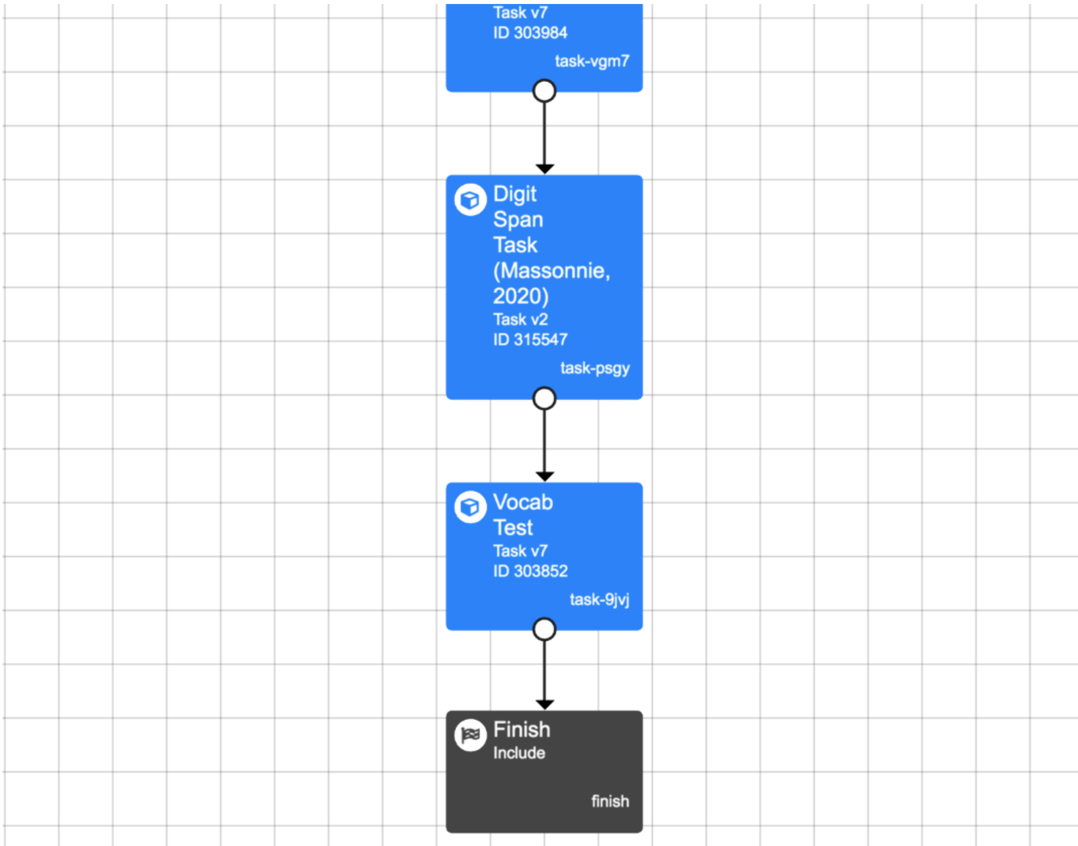
Which language(s) have you studied or learned, aside from your first language(s)? Please include the dialect(s).

Have you ever learned or studied the Lithuanian language before? Please explain the setting in which you learned Lithuanian (e.g., classroom, living in Lithuania) and the duration of your learning experience.

Do you regularly practice slow/deep breathing?

Appendix B: Gorilla Experiment Flowchart




Task v7
ID 303984
task-vgm7
Digit Span Task (Massonnie, 2020)
Task v2
ID 315547
task-psgy
Vocab Test
Task v7
ID 303852
task-9jvj
Finish
Include
finish

Appendix C: Breathing Intervention

1. **Instruction: Script**
   (Partial replication of instructions from Laborde et al., 2021)

   I'm first going to walk you through the slow, deep breathing technique, and then we'll spend eight minutes familiarizing ourselves with the exercise and then spend 17 minutes doing the actual main exercise. You can sit to the edge of your chair and lengthen your spine by sitting up straight. You can put both feet on the floor but put one foot a little bit closer to your body. Try wiggling out your shoulders to make yourself comfortable, and try to keep your eyes and face relaxed.

   When you breathe in, you can inhale through your nose, and then exhale with your mouth with pursed but relaxed lips. Try to make your breath slow, warm, and deep—slow enough so that you don't hear yourself breathing.

   Now you can put one hand on the center of your chest and the other hand on your lower stomach where your abdomen is. "The hand on the chest should not move, only the hand on the belly should move: The belly should get bigger during the inhalation phase, and smaller during the exhalation phase" (Laborde et al., 2021, p. 4). You can imagine yourself inflating a balloon in your lower abdomen, with air not entering through your nose but coming in through your belly button.

2. **Link to 8-Minute Familiarization Video:** https://youtu.be/Os6DfePRhZ0
   Participants were asked to keep their hands on their chest and abdomen during this video.

3. **Link to 17-Minute Main Exercise Video:** https://youtu.be/QyWkBfHBvX8
   Participants were asked to place their hands on their lap comfortably for this exercise.

Appendix D: L2 Word Learning Task Materials

Stimuli (Kemp & McDonald, 2021)

L1 English	L2 Lithiuanian
bean	pupa
potato	bulve
pants	kelnes
shoe	batas
fork	sakute
sink	kriakle
chair	kede
bed	lova
roof	stogas
window	langas

Appendix E: Data Set

Participant	Pre WM Score	Pre WM Span	Post WM Score	Post WM Span	Vocab Quiz
C1	21	6	24	6	100
C2	17	5	20	5	60
C3	36	8	23	6	80
C4	17	5	15	4	50
C5	13	4	16	4	90
C6	20	6	16	4	40
C7	34	9	39	9	90
C8	24	6	27	7	60
C9	30	7	28	7	40
C10	18	5	20	5	60
C11	33	8	36	10	30
C12	32	8	32	8	100
C13	28	7	19	6	60
C14	30	7	33	8	50
C15	17	5	27	7	80
B1	17	5	26	7	60
B2	16	4	29	7	40
B3	21	5	22	6	20
B4	15	4	21	5	70
B5	27	7	35	9	70
B6	13	4	18	5	100
B7	27	7	33	9	70
B8	17	4	25	7	50
B9	27	7	33	9	40
B10	18	5	26	6	100
B11	17	5	18	5	10
B12	23	6	28	7	60
B13	11	3	24	6	20
B14	12	3	19	5	40
B15	21	6	24	6	50

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