READING COMPREHENSION CONSTRAINS WORD READING: A TONGUE TWISTER STUDY BY MODERATING ATTENTIONAL CONTROL

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THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Arts in the
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By

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ABSTRACT OF THESIS

READING COMPREHENSION CONSTRAINS WORD READING: A TONGUE TWISTER STUDY BY MODERATING ATTENTIONAL CONTROL

Numerous research studies show word reading performance influences reading comprehension. Few studies investigate how reading comprehension influences word reading. The current study explores whether alleviating the attention required for reading comprehension correlates with a better word reading performance. Three types of tongue twister reading tasks that involve recall (RR), semantic priming (PP), and instructional focus on the phonological information (PF) all have a high demand for attention on word reading. Differently, the attention demanded by PP tasks on reading comprehension is smaller than RR and RF tasks. Numbers of speech errors are used to manifest the variability of these three attentional control modes. It is predicted that during tongue twister readings, task types demanding less attention on reading comprehension will elicit fewer speech errors. Mixed and fixed effect Poisson regression analysis with RR tasks as the comparison foundation shows a highly significant correlation ($p<.001$) between total speech error numbers and PP tasks; no significant correlations between total speech error numbers and PF tasks. These results offer evidence that reducing the attention demanded on reading comprehension alleviates the attentional control strain and allows better performance on word reading. This study suggests understanding the interaction between reading comprehension and word reading through speech errors by including executive functions like attentional control is a hopeful direction. Improvements and future directions are discussed in the end.

KEYWORDS: reading comprehension, word reading, speech errors, attentional control, tongue twister

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To those who seek truth

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CHAPTER 1. INTRODUCTION

It is believed that word reading and reading comprehension are two separate and connected units in terms of the cognitive process of reading (Perfetti et al., 2005; Kim, 2020; Hoover & Gough, 1990; Feng et al., 2021). Their functions are moderated by domain-general skills like working memory and attentional control. In recent years, researchers have been investigating the association among them by finding statistical connections among participants' executive functions and literacy-related skill evaluation scores (Spencer & Cutting, 2021; Kim, 2020; Kibby et al., 2014; Lancaster et al., 2021; Arrington et al., 2014; Sesma et al., 2009; Rezaei & Jeddi, 2020). Although such studies have a large participant number, their research targets are often elementary school children or groups with reading-related disabilities. In addition, a skill evaluation is a general and temporal estimation of people's ability which is not adequate to reflect dynamic interactions between executive functions and literacy-related cognitive processing when the reading is happening. A longitudinal study that tracks people's reading skill development could overcome such a shortcoming (Verhoeven et al., 2011; Nakamoto et al., 2007; Hjetland et al., 2019; Byrne et al., 1992; Seigneuric & Ehrlich, 2005; Huemer & Mann, 2010) but most study targets of such research are also young children with normal or abnormal reading abilities. Young children's cognitive process of reading could be different from adults' (see review in Gao et al., 2016), therefore it is also important to create conditions to study adults' dynamic cognitive processing of reading, which is what my current research focuses. Meanwhile, there is rich research about how word reading influences reading comprehension on diversified participants (Garcia & Cain, 2014; Keenan et al., 2008; Kendeou et al., 2009; Perfetti & Hogaboam, 1975; Savage, 2006). Although the influence from reading comprehension to word reading has been mentioned here and there by scholars who attempted to propose a reading model (Perfetti et al., 2010), an empirical experiment that can zoom in the influence from reading comprehension to word reading is rare. Hence, the current research aims to study how reading comprehension influences word reading via moderating attentional control in adults with no reading disabilities.

CHAPTER 2. LITERATURE REVIEW

2.1 Word reading, reading comprehension, and attentional control

Word reading in this research refers to the process from seeing words to saying words out. This process involves both effortless (e.g., sight word recognition: Radach et al., 2008; Munger et al., 2016; Levy, 1978) and effortful (e.g., decoding: Perfetti et al., 2010; Aarnoutse et al., 2001; Ziegler et al. 2014; Dietz et al., 2005; Wentink et al., 1997) processes. Reading comprehension involves a series of cognitive processes such as integrating and inferencing the text and monitoring the coherence of the generated representations of text (Cain et al., 2004; Perfetti et al. 2005; Fletcher, 2006; Cutting & Scarborough, 2006). Attentional control, also called inhibitory or interference control (Nigg, 2000), refers to cognitive processes that execute the initiated behavior and inhibit other disturbing or less relevant behaviors (Conners, 2009). It taps on both automatic and effortful processes. Skilled readers often read effortlessly unless the reading materials (e.g., text difficulty), readers themselves (e.g., emotion), or environments (e.g., noise) change and cause them monitoring or modifying their behaviors consciously, for example, controlling their attention (Norman & Shallice, 1986).

Although how word reading and reading comprehension interact with each other remains contentious, researchers agree that literacy-related reading processes—word reading and reading comprehension—are two separate and connected events (Perfetti et al., 2005). Attentional control is a separate reading component that monitors and facilitates the functions of these two events (Gough & Tunmer, 1986; Sesma et al., 2009). Reading comprehension can be hampered by low ability in word reading as it costs too many cognitive resources that should be devoted to reading comprehension (Perfetti & Hart, 2002). People who are less skilled in reading comprehension perform worse on understanding the materials even if their word reading skills match their peers (Spencer, & Wagner, 2018); people who have Attentional Deficit Hyperactivity Disorder perform worse in reading-related tasks than their healthy peers (Banich et al., 2009; Mason et al., 2005).

In summary, less-skilled reading comprehension consumes more cognitive resources than it should. The extra cognitive resource that reading comprehension consumes should be allocated to word reading by automatic and effortful attentional control if the reading is smooth and successful (Samuels, 1981). Attention is one of the cognitive resources whose capacity is limited, and its allocation to word reading and reading comprehension falls in a ratio range for successful reading. Such a ratio range is dependent on individual's cognitive capabilities. However, if there is an issue with readers' word reading or reading comprehension abilities or functions, namely the attention allocation ratio range falls out of the successful attention allocation ratio range, the cooperation between reading comprehension and word reading could be glitchy. Some overt manifestations of such a glitch are speech errors, lowered reading speed, and mistakes in recalling the content of reading materials.

2.2 Tongue twisters, semantic priming, and instructional focus tasks

The Tongue Twister effect refers to readers' prolonged reading time after silently or orally reading text that starts with the same onset phoneme (McCutchen & Perfetti, 1982). Tongue twister reading and its by-product speech errors have been used as tools to manifest the cognitive progress of language processing. For example, some researchers utilize tongue twister reading to probe the function of verbal working memories and the relationship between decoding and comprehension (Leong et al., 2008; Keller et al., 2003). Psycholinguists summarize the type of speech errors in speech production and reading based on their features and causes such as phonemic, morphological, and syntactical characteristics of reading materials (Boomer & Laver, 1968; Eysenck & Keane, 2020). By analyzing the characteristics of speech errors and calculating their numbers, researchers could find the connection between speech errors and cognitive processing functions (Netelenbos et al., 2018; Engelhardt et al, 2013; Dodd, 2011; Mandal et al., 2020).

When reading tongue twisters, readers' comprehension and memorization of the content could be hampered; their recall of the content is less precise than for texts without tongue twister effects. (Keller et al., 2003; Zhang & Perfetti, 1993; McCutchen et al., 1991). To recall the content of the text, people rely on linguistic-related cues such as phonological, syntactical, and semantical features of sentences and other cues like personal experience. The phonological features of tongue twisters are arranged abnormally in comparison with the majority of the reading materials people browse. Such a phonological abnormality means a large portion of attention will be allocated to word reading by attentional control. If readers are expected to recall the text content after reading, they face even greater challenges on attentional control. Since the attentional control can be further challenged, it can also be alleviated. For instance, through priming techniques to reduce the attention that reading comprehension needs.

Priming refers to a phenomenon where the exposure to a previous stimulus influences the response in a subsequent stimulus without conscious guidance or intention (Weingarten et al., 2016; Fukawa, 2016). A stimulus that is designed for priming the subsequent semantic processing can reduce the load of higher cognitive resources demanded for reading comprehension (La Heij et al., 1990; Sperber et al., 1979). In a tongue twister reading scenario, where a large portion of attention will be allocated to word reading due to the abnormal phonological features of tongue twister text, doing a priming task before reading, for instance, looking at a few pictures related to the upcoming reading content, could reduce the attention that reading comprehension demanded and, therefore, relieve the attentional control challenge. If this is true, then we might see readers perform better in word reading with reduced or even none speech errors.

If creating a priming condition (where there is no conscious guidance) might potentially relieve the attentional control challenge, could intentionally instructing readers to only focus on word reading achieving a similar result? Perfetti et al. (2005) said instructing readers to focus could not improve readers' reading performance. Lavie et al. (2004)'s load theory suggests that the distractor's interference with the target activity increases when cognitive control (e.g., attentional control) load is high. The act of following an instruction may raise attentional control needs and increase the distractor's (i.e., reading comprehension) interference with the target activity of word reading.

In summary, tongue twister, semantic priming, and instructional focus tasks require various attention allocation strategies (i.e., attentional control) in reading. Studies related to these keywords have inspired the experiment design of the current study. This study aims to explore the interactions between word reading and reading comprehension with an emphasis on how reading comprehension influences word reading when the higher cognitive function attentional control is included as a moderator. Its experiment contains three types of tongue twister reading tasks where the requirement of attentional control is various. The speech error number is used to manifest such variabilities.

This thesis aims to explore the following research question: Whether alleviating the attention required for reading comprehension could witness an improved word reading processing when the demanded attention on word reading is high. The prediction of experimental results for the research question is that alleviating the attention required for reading comprehension could witness an improved word reading processing when the attention required for word reading is high. The improved word reading processing is overtly manifested by the smaller number of speech errors.

CHAPTER 3. STUDY DESIGN

3.1 Experiment Design

The entire study has two components–reading tongue twisters aloud based on different task instructions and completing a post-experiment survey that collects participants' language background. The tongue twister reading experiment records readers' reading, calculates readers' speech error numbers, and categorizes speech errors. By comparing the speech error numbers under different attentional control modes (each task represents an attentional control mode) for the attention allocation on word reading and reading comprehension, the researcher is able to deduct the interactions between word reading and reading comprehension. The reason for collecting readers' language background information in the post-experiment survey is some research shows multilingual speakers have more advantages on executive functions over monolingual speakers (Antoniou et al., 2015; Schroeder & Marian, 2012). Although such a claim is contentious (Antón et al, 2014; Paap & Greenberg, 2013), it is possible that multilingual speakers might make fewer speech errors than monolingual speakers and skew the statistical analysis if their language background is not considered as a covariate. However, exploring whether being exposed or able to speak another language other than English could result in a different speech error eliciting status across task types is not the focus of this study. The current study is dedicated to exploring whether alleviating the attention required for reading comprehension could witness an improved word reading processing when the required attention for the word reading is high by comparing the number of speech errors made in different attentional control modes where the requirements of attention on reading comprehension are various.

There are three types of tasks in the reading experiments – Read and Recall (RR), Picture Priming (PP), and Phonological Focus (PF). All the types of tasks have the common requirement of reading the tongue twister sentence aloud right away as fast as possible when it appears on the screen. RR tasks ask readers to recall the content after completing the tongue twister reading. PP tasks show three pictures that visualize three words of the upcoming tongue twister sentence before reading. Pictures are played automatically on the screen one by one with an interval of 5 seconds. PF tasks give instructions to participants before reading to focus on pronunciation precision and ignore the content of the tongue twister sentences.

Each task contains a sentence that is composed of 11 to 15 English words. Compared to reading a tongue twister paragraph, reading a tongue twister sentence has a lower requirement on participants' domain-general and literacy-related skills. Except for the word 'Peking', all the composed words are frequently used daily based on the definition of the Oxford English Dictionary (Oxford University Press, n.d.). Contents of sentences are daily topics (See Figure 2 for complete sentences in the experiment). Each sentence contains 9 different words with the voiceless bilabial plosive [p] as the onset. For example, '*Petite Penny peeks at pretty Patty's party for panicked peeing puppies*'. The syntactical structure of each sentence is similar. A speech error can be made due to complicated literacy-skill-related or domain-general-skill-related reasons. The design considerations mentioned above tried to avoid speech errors that might be elicited by rare words, significantly different syntactic structures, different numbers of words starting with [p], and different tongue twister stimuli other than [p]. Each word with onset [p] only appears once ensuring that readers will not have chance to learn to pronounce certain repeated words effortlessly. Ideally, differences in numbers of speech errors are only being elicited because of different attentional control modes (each task corresponds with an attentional control mode).

RR tasks are control tasks. PP and PF tasks are experimental tasks. All three types of tasks require a high resource of attention on word reading because of the phonological features of sentences that can elicit tongue twister effects. The three tasks have various requirements for attention on reading comprehension. RR tasks require the highest amount of attention on reading comprehension, because expecting to recall the content means participants will consciously devote attention to it. PP tasks require the lowest amount of attention on reading comprehension. Three pictures that represent the meaning of three words from the subsequent sentence create a semantic priming effect on participants' reading and reduce the load of attention needed to be devoted to reading comprehension. The attention resource requirement on reading comprehension of PF tasks is greater than PP but whether its amount is greater or smaller than RR tasks is undetermined. Its undetermined requirement for attention on reading comprehension is not an issue for this study because the purpose of designing PF tasks is to diversify attentional control modes. Instructing participants to focus on pronunciation precision may not be helpful to readers in terms of inhibiting the reading comprehension and focusing on word reading. Such an instruction may increase the capacity of cognitive processing and increase the distractor (i.e., reading comprehension)'s interference with the target (i.e., word reading) according to Lavie et al. (2004)'s load theory (see the Figure 1 below). In summary, the high requirement of attention resources on word reading in these three tasks and various attention resource requirements on reading comprehension determine that participants' attentional control mode for word reading and reading comprehension is different across task types. It is expected that the less the reading comprehension requires the attention resource, the less interference it is with word reading, namely the less challenging the attentional control is. Therefore, fewer speech errors shall be observed. It is predicted that (1) PP tasks shall include the least number of speech errors. (2) The number of speech errors of RR and PF tasks shall be greater than PP tasks. (3) Due to the fact that the difference in the attention demanded for reading comprehension between PF and RR tasks is not theoretically deducible, and PF tasks could potentially increase the attentional control challenge based on Lavie et al. (2004)'s load theory, the number of speech errors in PF tasks may be no less than in RR tasks. This prediction of the relative level of attention required for word reading and reading comprehension in each of the three experimental task types is summarized in Figure 1 below.

RR	PP	PF
Word Reading: **H**	Word Reading: **H**	Word Reading: **H**
Reading Comprehension: **H**	Reading Comprehension: **L**	Reading Comprehension: **> PP**

Figure 1 Attention Demanded to Process Word Reading and Reading Comprehension in Different Types of Tasks

It is almost impossible to create a priming effect on word reading or reading comprehension to reduce the attention resource demanded for each of these processes separately during reading. The reasons include the idea that word reading and reading comprehension are two connected events (Kim, 2017; Hoover & Gough, 1990). In addition, a word is stored in memory in a format where all of its phonological, morphological, and semantic information is connected (Perfetti et al., 2010). Stimulating one linguistic feature of the word could evoke other linguistic information of the word. However, compared to using audio or writing formats of the words to prime the reading comprehension, which offers direct phonological information to word reading, picture hints create much fewer phonological priming effects on word reading. Meanwhile, although seeing picture hints could not avoid phonological priming effects on word reading completely, its phonological priming effects are minor and do not influence the various attention demands on reading comprehension that different tasks create. Using the speech error numbers generated in different tasks, where attention allocation needs on reading comprehension are various, to study the interactions of the word reading and reading comprehension is the core concept of the experiment design. Without prior knowledge of the syntactic structure of the tongue twister sentence, participants still need to allocate much of the attention to word reading. On the other hand, three pictures could offer only 33%[1] clues of the upcoming words containing the onset [p], which further limits phonological priming effects that picture priming might bring on word reading.

Since this experiment does not measure participants' domain-general and literacy-related skills, seeing three pictures reduces the chance that seeing too many pictures might overload participants' working memory because most adults' central memory limit is between 3 to 5 meaningful items (Cowan, 2010). The overload of participants' working memory could result in speech errors (Farquharson et al., 2018 Baddeley & Hitch, 1974), which could diminish the semantic priming effect aimed to alleviate the attention needed on reading comprehension. The design of a 5-second interval is adequate for adult participants to capture the information even if they face mental pressure during the experiment. The interval is considered to be short enough to not distract participants' attention or discourage their patience in continuing the research (Antes, 1974).

The reading part is divided into three blocks. The first block is a practice block. In the other two blocks, one block focuses on the comparison between RR and PP tasks; one block

[1] There are 9 words in each sentence that start with "p", so 3/9 = 33%

focuses on the comparison between RR and PF tasks. In the practice block, oral reading was not recorded nor studied. Participants are aware that they might be interrupted by the researcher during the practice block for further instructions but will not be interrupted during their reading after the practice block unless they raise a question. The practice block contains each type of task and is designed to guide the participant to get some familiarity with the upcoming task requirements. Each task only appears once to avoid the potentiality that participants could learn to read out tongue twisters fluently by adjusting their attentional control mode. The following Figure 2 lists the tongue twisters in their experimental groupings and indicates the type of task (RR, PP, PF) in which they were embedded.

RR	• Picky Peter in pajamas points at premium pies on Pennsylvania plaza.
PP	• Purchaser Pat is plagued by pricy pearls and prawns in the Pacific.
PF	• The plump professor prefers to pause the plan for paddling in the public pond.
RR 1	• Petite Penny peeks at pretty Patty's party for panicked peeing puppies.
PP 1	• Painters paint papa pandas pinching pepper with pink paws on paper.
PP 2	• Priest Paul's parents passe a pack of pecan and pick the pasta pan.
RR 2	• Pam purchases a pair of pants at a palace where a pale phantom pops up.
RR 3	• Peter's pen pal parks on the pebble path prepared for passengers in Paris.
PF 1	• Poor Pearson pecked by a passing peacock pays a price for probing Peking.
PF 2	• Proud pilot punched by a pacing puffy pig playing ping-pong.
RR 4	• Poet Pedro posts a piece of poetry. On posters about peeling piles of peaches.

Figure 2 Tongue Twister Sentence for Each Task

After completing the practice block, participants complete either the PP or PF block first. The order is randomized by a cross-list generated by the R program. 30 participants conducted the experiment with the PP block shown first and 30 participants conducted the experiment with the PF block shown first. Within the PP block, there are 4 tongue twister tasks, each containing a different tongue twister sentence, arranged in this order: RR->PP->PP->RR. Within the PF block, there are 4 tongue twister tasks, each containing a different tongue twister sentence, arranged in this order: RR->PF->PF->RR. See Figure 3 below for illustration of the flow of experiments.

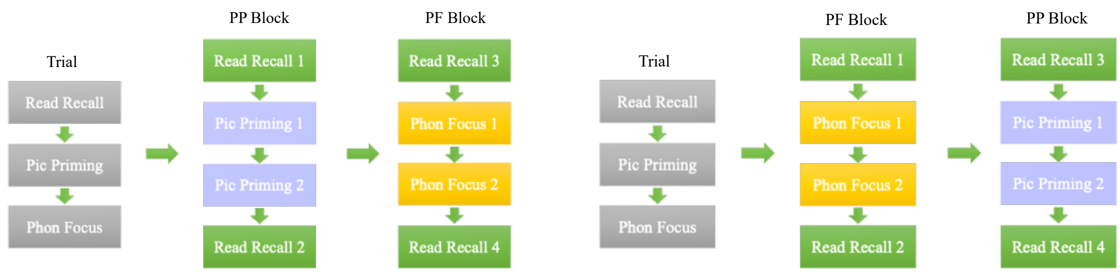

Figure 3 Experiment Flow

3.2 Participants

60 people from the University of Kentucky whose native language is English participated in the online experiment. Fifty-nine of them were affiliated with the Department of Linguistics or the Department of Psychology. One of them was an undergraduate pedestrian. Undergraduate psychology and linguistics students were compensated with extra credit for participating in this study. The pedestrian, the linguistic graduate students, and the faculty participants were not given any type of reward for their participation. 50 participants' data were considered viable in view that they followed the instructions throughout the entire study. The median and mode of their age were both 20. The average age was 22.63. The maximum and the minimum age were 56 and 18. There were 12 male participants and 38 female participants. 15 participants were multilingual speakers, and 35 participants were monolingual speakers. There was not a pre-selection of readers' reading ability.

The research protocol did not fall into the category that was allowed to ask participants to offer their medical information, for example, dyslexia. The current study assumed all the participants who were students and faculty on campus had average reading abilities. Among the 50 participants who followed the instructions throughout the experiment, one participant took about 3 times longer in completing the reading task than the other 49 participants. The data of this participant was considered viable because the extended time was spent on reading instructions and asking questions, not in performing the tongue twister tasks. The reading time for each sentence of this participant was within the average reading time of the other 49 participants.

3.3 Experiment procedure

The entire study was conducted online and took about 20 minutes to complete per participant except for one participant who took about 60 minutes to complete. Participants booked a time slot via the link on the recruitment script sent to them. Once they reserved an experiment time slot, a Zoom (Yuan, 2011) virtual online meeting room link was sent to them. The researcher obtained participants' oral agreement on participating in the experiment after the participant joined the online meeting session at the scheduled time. Then the researcher documented the participants' name and the course they registered for and sent such information to their course instructor later to award extra course credits to them (for undergraduate student participants from psychology). They were sent a link about the online interactive experiment with either the PF or PP block appearing first decided by a cross-list generated in R. The online experiment had been tested to function successfully on both Windows and MacOS systems and multiple mainstream browsers such as Safari, Google Chrome, Firefox, and Microsoft Edge. If participants encountered any technical issues on opening the online experiment, the researcher helped to diagnose the issue remotely.

To start the online experiment, they were suggested to leave the welcome page there and listen to the researcher's introduction about the experiment procedure and content. They were introduced to the type of tasks and what they would be asked to do in each task. They were suggested to take as much time as they need to read instructions for each task and ask the researcher for clarifications if they have any confusion. The researcher emphasized that once they see the tongue twister sentence appear on the screen, they need to read it right away and at their fastest speed. The researcher explained that making speech errors while tongue twister reading is normal, and it could be fun to take this experiment. The researcher used an active and energetic tone to talk with participants in order to relieve their pressure on upcoming experiments and motivate them to complete the entire experiment. Participants were aware that they might be interrupted by the researcher while they were performing the practice block if the researcher thought they did not follow the task instructions, or their reading speed could be faster. They were told that they would not be interrupted after the practice block unless they decide to quit or ask for assistance. They were frequently checked by the researcher with the question ‘Does it make sense?’ to confirm their understanding. They were expected to stay online to complete a post-experiment survey that included demographic information and language-background-related questions after completing the experiment.

Then they were instructed to turn off their camera and the researcher would also turn off the camera. The online experiment compiled through the OpenSesame software (Mathôt & Theeuwes, 2012) was published on the JATOS (Lange et al., 2015) server in order to generate shareable online experiment links. Through prior tests, it was determined that the online experiment opened by JATOS links could run abnormally if the screen of the participant was shared with the researcher through Zoom screen sharing. Since the current study did not measure the time of participants’ responses, turning off the camera did not influence the study goals. Another advantage of turning off the camera was reducing the pressure that the researcher might create in supervising participants. In general, the researcher did not see the online experiment interface while the participant was performing the experiment. Participants took as much time as they need to read and comprehend the instructions. The researcher stayed online but did not make a sound after the practice block ended. After the practice block was completed, the researcher turned on the Zoom recording function to record participants’ reading till they completed the entire experiment. Then they completed the online post-experiment survey.

CHAPTER 4. DATA

4.1 Data storage

Recorded data was stored on the researcher's fingerprint encrypted personal computer and uploaded to the student identity encrypted University of Kentucky OneDrive cloud drive. Each participant's recording file has been saved in a folder named with the order (1-50) of the participation and which block they completed first (PP vs. PF). Depending on which block they have completed first, if the PP block was completed first, the folder name contains an Arabic number 1, and if the PF task was completed first, the folder name contains an Arabic number 2. Within each folder, there is a .mp4 video file saved by Zoom automatically and a .wav file later converted for further annotation convenience.

4.2 Data annotation

For each participant's recording in a tongue twister reading task, the total number of speech errors and the number of speech errors in each category was counted. They were documented on the researcher's University of Kentucky Google spreadsheet. This study aims to investigate the interactions between word reading and reading comprehension when the attention allocated on these two components is various by comparing the number of speech errors made in different attentional control modes under different task requirements. It is predicted that under the same criteria where the word reading needs a large amount of attention, the lower the attention required by the reading comprehension, the fewer speech errors are made. To precisely and scientifically calculate the number of speech errors, it is necessary to categorize them to exclude some errors that are not of interest for the current study. For example, adding an '-s' after the object noun when the subject noun contains a '-s'. This is a type of error caused by the design of the tongue twister sentence. It is a morpho-syntactic error made by the majority of the participants. Such an error can also happen in the reading of the normal reading materials, hence it is not considered as a byproduct of the failure of attentional control in inhibiting the reading comprehension and focusing on the word reading. The recall answers of participants were also documented in order to double-check whether a speech error is made in cases where a portion of the recording is acoustically indistinguishable.

A classification of 10 error types according to which the observed errors were cataloged was devised: a short pause, short pause and quickly reread, short pause and quickly reread greater than 2 words, long pause, hesitation, misread a word, misread and quickly reread, misread and pause, add phonemes to word, and omit a word. There are three types of speech errors that weigh heavier than other types. They are *short pause and quickly reread >= 2 words*, *long pause*, and *misread and pause.* The participants' eye movements are not tracked during the experiments so if they make these types of errors, it is considered that a reread of the sentence and reconstructing of the linguistic information of the sentence is happening and might influence the speech error numbers made in the remaining part of the sentence (Inhoff et al., 2011; Levy et al., 2009). However, if these types of errors are made approaching the end of the sentence, their weights are documented as 1. Detailed definitions for each speech error type are listed in Table 1 below.

Table 1 Speech Error Types and Weights

Error Type	Weight	Definition
short pause	1	A pause followed by a quick reading of the upcoming word.
short pause and quickly reread	1	A quick and almost autonomous self-correction behavior after pause triggered by reading and monitoring cognitive functions.
short pause and quickly reread >=2 words	1.5	A self-correction behavior that is considered to involve the reorganization of the linguistic information and potentially influence the upcoming reading correct rate.
long pause	1.5	A pause does not followed by a longer time before reading the upcoming word.
hesitation	1	A prolonged pronunciation of a specific word.
misread a word	1	Pronounce a word mistakenly.
misread and quickly reread	1	A quick and almost autonomous self-correction behavior after misreading a word triggered by reading and monitoring cognitive functions.
misread and pause	1.5	A self-correction behavior that is considered to involve the reorganization of the linguistic information and potentially influence the upcoming reading correct rate.
add phonemes to words	1	Insert a sound that does not belong to the original reading sentence anywhere in a word.
omit a word	1	Leave a word unread.

There were three rounds of annotation. In the first round, each subject's error speech was documented. The researcher used Praat (Boersma, 2001), an audio analysis software, to select and listen to the subject's reading of each tongue twister sentence and judge the type of pause the subject makes. There were about 400 sentence reading records given that 50 participants each read 8 sentences, although a few of them omitted the reading of some sentences[2]. In the second round, the researcher counted the total number of errors the subject made for each sentence and counted the number of each type of error for each sentence. In the third round, speech errors that were elicited because of the design of the tongue twister sentences were removed. The count of total error numbers and the count of each type of error for every tongue twister sentence were adjusted accordingly. The uncounted speech errors include morpho-syntactic speech errors: adding '-s' after 'post', adding '-s' after 'pecan', and a syntactic speech error by making a mistake prior to or during the reading of 'papa panda'; and speech errors caused by the inclusion of words in the tongue twister sentences that were unfamiliar: making a speech error prior to or during the reading of 'probing Peking' or 'Peking'; making speech errors prior to or during the reading of 'phantom'.

4.3 Statistical analysis

All the text of the annotated data was removed, and it was converted to a table that has 25 columns and 401 rows. Each subject's data takes 8 rows. The 25 columns include: subject number, session order, demographic information, post-experiment survey binomial answers, the total number of speech errors, number of each type of speech error, session number, task number, task type, recall correct rate[3], and whether contains entity error (mistakenly recall the subject and object of the sentence). All the data was sorted in the format of .csv. The R programming language was used to clean and convert the data in the programming environment of RStudio. Readxl (Wickham & Bryan, 2019), dplyr (Wickham et al., 2015, reshape2 (Wickham, 2007), and lme4 (Bates et al., 2014) libraries were used during data cleaning and statistical model construction.

Across all participants, the minimum total speech error number is 0.00 and the maximum total speech error number is 5.00. The descriptive statistics (mean, median, mode, standard

[2] Across all participants, 2 RR, 2 PF, and 3 PP tasks' data are missing because participants did not complete them. If all participants had completed all tasks, 200 RR tasks, 100 PF tasks, and 100 PP tasks' speech errors would have been recorded. These missed data (2/200 RR tasks; 2/100 PF tasks' 3/100 PP tasks) represent a small portion of the data that was targeted for collection.

[3] Words being recalled correctly divided by the total words of a sentence

deviation, and confidence interval) for the total speech errors recorded for the experiment are provided in Table 2 below.

Table 2 Descriptive Statistic for Total Speech Error Numbers

All Participants' Data					
	Mean	Median	Mode	SD	95% CI
RR	1.0	1.0	0.0	1.173	1.0 ± 0.163
PP	0.5	0.0	0.0	0.742	0.5 ± 0.145
PF	1.0	1.0	0.0	1.030	1.0 ± 0.202
Participants Taking PP Block First					
	Mean	Median	Mode	SD	95% CI
RR	1.1	1.0	0.0	1.213	1.1 ± 0.238
PP	0.5	0.0	0.0	0.726	0.5 ± 0.201
PF	1.1	1.0	1.0	1.043	1.1 ± 0.289
Participants Taking PF Block First					
	Mean	Median	Mode	SD	95% CI
RR	0.9	1.0	0.0	1.131	0.9 ± 0.222
PP	0.6	0.0	0.0	0.764	0.6 ± 0.212
PF	0.9	1.0	0.0	1.019	0.9 ± 0.283

**Note: SD=Standard Deviation, CI=Confidence Interval*

The Poisson regression was used to analyze the correlation between total speech error numbers and the types of tasks. Specifically, the model uses the speech error numbers of the RR tasks as the foundation to compare with the speech error numbers in PP and PF tasks. During this comparison, block order (PP or PF appearing first), whether participants have been exposed intensively in multilingual environments, and whether participants are multilingual speakers are included as covariates. Poisson regression is a generalized linear model that is often used for counting data. It is expected that a correlation between the total speech error numbers (outcome variable) and the type of tasks (predictor variable) exists. It is also expected that the fewer attention resources needed for reading comprehension, the fewer speech errors are made. Two Poisson regression models were run in R studio. One was a fixed-effects Poisson model, in which subject number is not included as a covariate and the other was a mixed-effects Poisson regression model including subject number.

Table 3 below shows the results of the fixed-effects Poisson regression model. These statistical results show there are significant correlations between speech error numbers and PP tasks ($p < .001$), speech error numbers and order 2 ($p < .001$), speech error numbers and being exposed intensively to multilingual environments ($p < .001$), and speech error numbers and multilingual speakers (p < .001). No significant correlation between the total number of speech errors and PF tasks was found (p = .949). The above-mentioned P-values are highlighted in yellow in the Table 3. PF tasks have 0.55% fewer chances of eliciting speech errors than RR tasks. PP tasks have 46.99% fewer chances of eliciting speech errors than RR tasks. Participants who have been exposed to multilingual environments have 30.88% fewer chances of making speech errors than participants who have not. Participants who are multilingual speakers have 43.02% fewer chances of making speech errors than monolingual speakers. The above-mentioned comparison results are highlighted in blue in Table 3.

Table 3 Fixed-Effects Poisson Regression Model Results

```
Deviance Residuals:
    Min       1Q   Median       3Q      Max
-2.4852  -1.5613  -0.6533   0.6564   3.7412

Coefficients:
                Estimate Std. Error z value Pr(>|z|)
(Intercept)     1.127573   0.068596  16.438  < 2e-16 ***
TypePhonology  -0.005486   0.086610  -0.063 0.949493
TypePicture    -0.634761   0.109541  -5.795 6.84e-09 ***
order2         -0.294859   0.076644  -3.847 0.000120 ***
lang_exposeyes -0.369364   0.107839  -3.425 0.000614 ***
multilingualys -0.562538   0.134946  -4.169 3.06e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for poisson family taken to be 1)

Null deviance: 1077.07  on 392  degrees of freedom
Residual deviance:  938.48  on 387  degrees of freedom
(7 observations deleted due to missingness)
AIC: 1571.5

Number of Fisher Scoring iterations: 6

(Intercept)  TypePhn     TypePct     order2      lang_exposeyes    bilingualyes
3.0881509    0.9945288   0.5300620   0.7446366   0.6911736         0.5697612

95% Confidence Interval:

                    2.5 %     97.5 %
(Intercept)     0.9910633  1.2599938
TypePhonology  -0.1769813  0.1627367
TypePicture    -0.8542124 -0.4243582
order2         -0.4453689 -0.1448001
lang_exposeyes -0.5857197 -0.1625529
bilingualyes   -0.8267792 -0.2970438
```

Table 4 below shows the results of the mixed-effects Poisson regression model. These statistical results show there are significant correlations between speech error numbers and PP tasks ($p < .001$), speech error numbers and order 2 ($p < 0.015$), and speech error numbers and multilingual speakers ($p < 0.018$). No significant correlation between the total number of speech errors and PF tasks are found with the P value smaller than 0.8689. The above-mentioned P-values are highlighted in yellow in Table 4. PF tasks have 1.42% fewer chances of eliciting speech errors than RR tasks. PP tasks have 47.47% fewer chances of eliciting speech errors than RR tasks. Participants who complete PF block first have 34.36% fewer chances of making speech errors than participants who complete PP tasks first. Participants who have been exposed to multilingual environments have 29.68% fewer chances of making speech errors than participants who have not. Participants who are multilingual speakers have 48.46% fewer chances of making speech errors than monolingual speakers. The above-mentioned comparison results are highlighted in blue in Table 4. In sum, the results of the mixed-effects Poisson regression model are similar to the fixed-effects Poisson regression model. The above-mentioned comparison results are highlighted in blue in Table 4.

Table 4 Mixed-Effects Poisson Regression Model Results

```
AIC      BIC     logLik    deviance   df.resid
873.9    901.8   -430.0    859.9      386

Scaled residuals:
    Min      1Q  Median      3Q     Max
-2.0730 -1.0268 -0.5728  0.8017  4.3753

Random effects:
 Groups       Name        Variance Std.Dev.
 subject_name (Intercept) 0.2863   0.535
Number of obs: 393, groups:  subject_name, 50

Fixed effects:
               Estimate   Std.Error z value  Pr(>|z|)
(Intercept)     1.07546    0.15459   6.957   3.48e-12 ***
TypePhonology  -0.01435    0.08691  -0.165   0.8689
TypePicture    -0.64375    0.10958  -5.875   4.23e-09 ***
order2         -0.42098    0.17311  -2.432   0.0150 *
lang_exposeyes -0.35213    0.24538  -1.435   0.1513
multilingualys -0.66287    0.27939  -2.373   0.0177 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
Correlation of Fixed Effects:
            (Intr) TypPhn TypPct order2 lng_xp
TypePhonlgy -0.206
TypePicture -0.145  0.259

Correlation of Fixed Effects:
               (Intr) TypPhn TypPct order2 lng_xp
TypePhonlgy    -0.206
TypePicture    -0.145  0.259
order2         -0.630  0.037 -0.001
lang_expsys    -0.381  0.001 -0.001  0.056
multilingualys -0.078  0.005  0.002  0.132 -0.676

(Intercept)   TypePhn   TypePct    order2    lang_exposeyes multilingualyes
 2.9313397    0.9857551 0.5253200  0.6564051  0.7031898       0.5153690


95% Confidence Interval:
                    2.5 %      97.5 %
.sig01          0.3959945  0.72239755
(Intercept)     0.7639401  1.38531435
TypePhonology  -0.1864256  0.15445104
TypePicture    -0.8632651 -0.43327642
order2         -0.7757511 -0.08307721
lang_exposeyes -0.8497735  0.13986257
multilingualys -1.2331645 -0.10973426
```

CHAPTER 5. DISCUSSION

5.1 Discussion of statistical analysis

The descriptive statistical results show that PP tasks have the lowest mean and mode among other tasks. Participants who take the PF block first make less speech errors in RR and PF tasks compared to those who take PP tasks first. However, there is not a reduction of speech errors in PP tasks for participants who take PF block first. The median, mean, and mode of RR tasks and PF tasks are almost identical except for the PF's mode data for participants taking the PP task first.

The inferential statistical results show that whether or not one considers the random effect into the Poisson regression model the correlation between the total number of speech errors and PP tasks is highly significant with a p value smaller than 0.001. In the fixed-effect Poisson regression model, the correlation between speech error numbers and order, speech error numbers, and speech error numbers and multilingual speakers are highly significant with p values smaller than 0.001. The mixed-effects Poisson regression model also shows that there is a highly significant correlation between speech error numbers and PP tasks with a p-value smaller than 0.0001; and there are significant correlations between speech error numbers and PF block appearing first and speech error numbers and multilingual speakers with p values smaller than 0.02.

PP tasks are designed to require the least attention on reading comprehension with the presumption that all types of tasks require a high amount of attention on word reading. When one considers the highly significant correlation between the total number of speech errors and PP tasks, its smallest mean compared to other two types of tasks including the influence of the block order or not, and about 47% fewer chances of having speech errors than RR tasks in Poisson regression models including the random effect or not, this accumulation of results offers evidence to the research question prediction that alleviating the attention required for reading comprehension could witness an improved word reading processing when the attention demand for word reading is high. Within this study, the assumption that speech errors could be used to study different attentional control modes is constructed based on previous literature discussed in Chapter 2 instead of a designed experiment to specifically validate this claim. Therefore, the correlation between the total number of speech errors and PP task offers evidence to this assumption. The result is exciting because it suggests that using speech errors to study the interactions between reading comprehension and word reading is promising. Compared to EEG and fMRI approaches which seem to have better tracking of the change of cognitive processing, calculating, and analyzing speech errors cost way less and could be effective.

The results back up Arrington et al. (2014), Kibby et al. (2014), Sesma et al. (2009), and Spencer and Cutting (2021)'s research where a significant correlation between central executive functions and reading comprehension was found. The backup is from a perspective that reducing the attention demand on reading comprehension in other words reducing the attentional control challenge could witness an obvious drop of speech errors. Different from their approaches that involve finding the statistical correlation among reading skill scores, the approach used in this study does not involve reading skill measurements but has robust results that support their conclusion from an angle which again casts light on using speech errors to research the cognitive processing of reading. Meanwhile, the result encourages the ideology that to depict the interactions between reading comprehension and word reading by including the function of attentional control's moderation is hopeful.

The mean number of errors in PF tasks are greater or equal to RR tasks, the median number of errors in PF tasks are equal to RR tasks, and the mode in PF tasks are equal to RR tasks, in each case whether the block order is considered or not. The inferential statistical results do not find a significance between the total speech error numbers and PF tasks. Descriptive results are in accordance with these results. The comparison foundation in the Poisson regression model is RR tasks. In the section above on study design, it is mentioned that the amount of attention required for reading comprehension for PF tasks could be greater than PP tasks, but the amount of attention required compared with RR tasks is difficult to determine theoretically.

A few explanations to the insignificant correlation between the total numbers of speech errors and PF tasks include the following. First, high cognitive resources capacity caused by following the experiment instruction could increase the distractor (reading comprehension)'s interferences with the target activity (word reading). Therefore, compared to RR tasks which also has a high demand of attention on reading comprehension, PF tasks have similar descriptive statistic results. Second, the Poisson regression model shows a significant correlation between the total number of speech errors and the PF block appearing first. In the descriptive statistics participants who complete the PF tasks first make fewer speech errors in RR and PF tasks shown by the mean. Such results suggest that with only two trials of PF tasks, documented speech errors may not be sufficiently representative to manifest the PF attentional control mode. Reasons for why taking PF or PP tasks first might influence the total speech error numbers for the entire experiment shall be further explored in the future. Potential solutions to avoid the influence of order are setting a break between these two blocks and designing more PP and PF reading trials. Third, the experiment is designed with RR tasks as the point of comparison and the Poisson regression is consistent with such a design; as discussed in the first point above, these two types of tasks (PF and RR) do have similarities in terms of attention load demands. In the future, an experiment could be designed to be able to not only compare PF tasks with RR tasks but also PF with PP tasks. In summary, including PF tasks in this study enrich the diversities of the attentional control modes and contribute to the observation of the interactions between reading comprehension and word reading.

The highly significant correlation between total speech error numbers and multilingual exposure offers support to some researchers' opinions that people who study extra languages other than their mother tongue might have an advantage in literacy-related skills like decoding and domain-general skills like attentional control (Soveri et al., 2011; Arredondo et al., 2017; Krizman et al., 2014). The inclusion of the multilingual status confirmation aimed to consider it as a covariate in the statistical model that was mainly designed for probing the relationship between total speech errors numbers and different attentional control modes, however, in the future, having a more detailed look at how the multilingual factor might influence the interactions between reading comprehension and word reading when the attentional control is considered as a moderator could be meaningful.

5.2 Limitations and future research directions

This study assumed that speech errors are the byproducts of tongue twister reading. In other words, it assumed that the existence of speech errors indicates the failure of typical cognitive processing of reading. Speech errors were used to probe the interactions between reading comprehension and word reading in different attentional control modes. It is necessary for the future to clarify the relationship between total speech error numbers across task types by adding a comparison between PF tasks versus PP tasks as mentioned at the end of the statistical result interpretation of the PF tasks, or by adding more attentional control modes such as a mode where no extra instruction is given to participants before reading tongue twisters.

Each individual's attention allocation on word reading and reading comprehension during reading could be different. The results of the current research could be more granular if in the future the measurements to individual's specific cognitive abilities (e.g., attentional control: Arrington et al., 2019; Borella et al., 2011; working memory: Baddeley, 2003 inference: Cain & Oakhill, 2006), linguistic abilities (e.g., phonological awareness, vocabulary, oral reading fluency, sight word efficiency), and text characteristics (e.g., phonology, semantics, syntax, context, length) (Cunningham & Anne Mesmer, 2014; Chall et al., 1996) are included. Measurements of these individuals' abilities could also be helpful to predict a threshold of when people successfully adjust their attentional control mode and establish a new attention allocation strategy for a unique reading situation that they are not used to but can do better after practice, for example, the tongue twister reading. Such learning ability could influence the precision of using the number of speech errors to reflect different attentional control modes. When measuring these skills, the factor of multilingualism needs to be taken into consideration. As shown in this research, multilingual speakers do make fewer speech errors across tasks compared with monolingual speakers.

It is clear that reading tongue twisters raises the challenge of word reading and requires a large amount of attention, however, what exact processes during word reading make such a high attention consumption? Is it the controlling of oral muscle to read tricky sounds or the mapping from orthography to long-term memory of phonological knowledge (e.g., making decisions)? Such questions are worthwhile to explore in the future.

Some research found reading aloud in upper-grade children could negatively influence their understanding of the reading materials although such impedance would not disfunction the parallel reading comprehension (Gao et al., 2016). This fact does not overshadow the results of the current study because tongue twister sentences are short, compared to reading paragraphs which have a higher requirement of comprehension abilities; however, in view of this fact, could the findings in the current study among word reading, reading comprehension, and attentional control be adopted to silent reading? Does reading aloud itself contribute to a portion of speech errors? It is possible to design EEG and fMRI studies to collect the scalp and brain activities in silent reading versus reading aloud when performing the current experiment and match them with behavioral speech error data to answer these questions.

All the experiments of this research were conducted online via Zoom due to the COVID-19 epidemic. During experiments intruding interference occasionally happened, although rare, like incoming phone calls. Experiment environments influence reading (Basanovic et al., 2018), if such experiments could be conducted in a well-designed laboratory environment, then research results might be more persuasive.

The speech error annotation could be more precise if the judgment of prior errors' influence on later sentence parts was based on eye-tracking data. In addition, considering the time characteristics of each type of speech errors, for example when it is made and how long it lasts, could be helpful in improving the statistical analysis of speech errors. To decide whether a pause is caused by breath or hesitation, measurements of readers' typical reading speech become necessary. In addition, the documented recall content and recall error rate could be better utilized, for example, to reveal participants' abilities like reading comprehension and working memory.

REFERENCES

Aarnoutse, C., Van Leeuwe, J., Voeten, M., & Oud, H. (2001). Development of decoding, reading comprehension, vocabulary and spelling during the elementary school years. *Reading and Writing*, *14*(1), 61-89.

Antes, J. R. (1974). The time course of picture viewing. *Journal of experimental psychology*, *103*(1), 62.

Antón, E., Duñabeitia, J. A., Estévez, A., Hernández, J. A., Castillo, A., Fuentes, L. J., ... & Carreiras, M. (2014). Is there a bilingual advantage in the ANT task? Evidence from children. *Frontiers in psychology*, *5*, 398.

Antoniou, M., Liang, E., Ettlinger, M., & Wong, P. C. (2015). The bilingual advantage in phonetic learning. *Bilingualism: Language and Cognition*, *18*(4), 683-695.

Arredondo, M. M., Hu, X. S., Satterfield, T., & Kovelman, I. (2017). Bilingualism alters children's frontal lobe functioning for attentional control. *Developmental science*, *20*(3), e12377.

Arrington, C. N., Kulesz, P. A., Francis, D. J., Fletcher, J. M., & Barnes, M. A. (2014). The contribution of attentional control and working memory to reading comprehension and decoding. *Scientific Studies of Reading*, *18*(5), 325-346.

Arrington, C. N., Malins, J. G., Winter, R., Mencl, W. E., Pugh, K. R., & Morris, R. (2019). Examining individual differences in reading and attentional control networks utilizing an oddball fMRI task. *Developmental cognitive neuroscience*, *38*, 100674.

Baddeley, A. (2003). Working memory: looking back and looking forward. *Nature reviews neuroscience*, *4*(10), 829-839.

Baddeley, A. D., & Hitch, G. (1974). Working memory. In *Psychology of learning and motivation* (Vol. 8, pp. 47-89). Academic press.

Banich, M. T., Burgess, G. C., Depue, B. E., Ruzic, L., Bidwell, L. C., Hitt-Laustsen, S., Du, Y. P., & Willcutt, E. G. (2009). The neural basis of sustained and transient attentional control in young adults with ADHD. *Neuropsychologia*, *47*(14), 3095–3104. https://doi.org/10.1016/j.neuropsychologia.2009.07.005

Basanovic, J., Notebaert, L., Clarke, P. J., MacLeod, C., Jawinski, P., & Chen, N. T. (2018). Inhibitory attentional control in anxiety: Manipulating cognitive load in an antisaccade task. *PLoS One*, *13*(10), e0205720.

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2014). Fitting linear mixed-effects models using lme4. *arXiv preprint arXiv:1406.5823*.

Boersma, Paul (2001). Praat, a system for doing phonetics by computer. *Glot International* **5:9/10**, 341-345.

Boomer, D. S., & Laver, J. D. (1968). Slips of the tongue. *British Journal of Disorders of Communication*, *3*(1), 2-12.

Borella, E., Ludwig, C., Fagot, D., & De Ribaupierre, A. (2011). The effect of age and individual differences in attentional control: A sample case using the Hayling test. *Archives of Gerontology and Geriatrics*, *53*(1), e75-e80.

Byrne, B., Freebody, P., & Gates, A. (1992). Longitudinal data on the relations of word-reading strategies to comprehension, reading time, and phonemic awareness. *Reading Research Quarterly*, 141-151.

Cain, K., & Oakhill, J. (2006). Assessment matters: Issues in the measurement of reading comprehension. *British Journal of Educational Psychology*, *76*(4), 697-708.

Cain, K., Oakhill, J., & Bryant, P. (2004). Children's Reading Comprehension Ability: Concurrent Prediction by Working Memory, Verbal Ability, and Component Skills. *Journal of Educational Psychology, 96*(1), 31–42. https://doi.org/10.1037/0022-0663.96.1.31

Chall, J. S., Bissex, G. L., Conard, S. S., & Harris-Sharples, S. H. (1996). *Qualitative assessment of text difficulty: A practical guide for teachers and writers*. Brookline Books.
Conners, F. A. (2009). Attentional control and the simple view of reading. *Reading and Writing*, *22*(5), 591-613.

Cowan, N. (2010). The magical mystery four: How is working memory capacity limited, and why?. *Current directions in psychological science*, *19*(1), 51-57.

Cunningham, J. W., & Anne Mesmer, H. (2014). Quantitative measurement of text difficulty: What's the use?. *The Elementary School Journal*, *115*(2), 255-269.

Cutting, L. E., & Scarborough, H. S. (2006). Prediction of reading comprehension: Relative contributions of word recognition, language proficiency, and other cognitive skills can depend on how comprehension is measured. *Scientific studies of reading*, *10*(3), 277-299.

Dietz, N. A., Jones, K. M., Gareau, L., Zeffiro, T. A., & Eden, G. F. (2005). Phonological decoding involves left posterior fusiform gyrus. *Human brain mapping*, *26*(2), 81-93.

Dodd, B. (2011). Differentiating speech delay from disorder: Does it matter?. *Topics in Language Disorders*, *31*(2), 96-111.

Engelhardt, P. E., Nigg, J. T., & Ferreira, F. (2013). Is the fluency of language outputs related to individual differences in intelligence and executive function?. *Acta psychologica*, *144*(2), 424-432.

Eysenck, M. W., & Keane, M. T. (2020). *Cognitive psychology: A student's handbook*. Psychology press.

Farquharson, K., Hogan, T. P., & Bernthal, J. E. (2018). Working memory in school-age children with and without a persistent speech sound disorder. *International Journal of Speech-Language Pathology*, *20*(4), 422-433.

Feng, C., Damian, M. F., & Qu, Q. (2021). Parallel Processing of Semantics and Phonology in Spoken Production: Evidence from Blocked Cyclic Picture Naming and EEG. *Journal of Cognitive Neuroscience*, *33*(4), 725-738.

Fletcher, J. M. (2006). Measuring reading comprehension. *Scientific studies of reading*, *10*(3), 323-330.

Fukawa, N. (2016). Priming effects on affective preference for healthy products over unhealthy products upon brand exposure. *Social Marketing Quarterly*, *22*(1), 34-53.

Gao, M., Xu, E., Ren, G., & Sui, X. (2016). The differences between silent and oral reading. *Advances in Psychological Science*, *24*(1), 21.

García, J. R., & Cain, K. (2014). Decoding and reading comprehension: A meta-analysis to identify which reader and assessment characteristics influence the strength of the relationship in English. *Review of Educational Research*, *84*(1), 74-111.

Gough, P. B., & Tunmer, W. E. (1986). Decoding, reading, and reading disability. *Remedial and special education*, *7*(1), 6-10.

Hjetland, H. N., Lervåg, A., Lyster, S. A. H., Hagtvet, B. E., Hulme, C., & Melby-Lervåg, M. (2019). Pathways to reading comprehension: A longitudinal study from 4 to 9 years of age. *Journal of Educational Psychology*, *111*(5), 751.

Hoover, W. A., & Gough, P. B. (1990). The simple view of reading. *Reading and writing*, *2*(2), 127-160.

Huemer, S. V., & Mann, V. (2010). A comprehensive profile of decoding and comprehension in autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *40*(4), 485-493.

Inhoff, A. W., Solomon, M., Radach, R., & Seymour, B. A. (2011). Temporal dynamics of the eye–voice span and eye movement control during oral reading. *Journal of Cognitive Psychology*, *23*(5), 543-558.

Keenan, J. M., Betjemann, R. S., & Olson, R. K. (2008). Reading comprehension tests vary in the skills they assess: Differential dependence on decoding and oral comprehension. *Scientific Studies of Reading*, *12*(3), 281-300.

Keller, T. A., Carpenter, P. A., & Just, M. A. (2003). Brain imaging of tongue-twister sentence comprehension: Twisting the tongue and the brain. *Brain and language*, *84*(2), 189-203.

Kendeou, P., Van den Broek, P., White, M. J., & Lynch, J. S. (2009). Predicting reading comprehension in early elementary school: The independent contributions of oral language and decoding skills. *Journal of educational psychology*, *101*(4), 765.

Kibby, M. Y., Lee, S. E., & Dyer, S. M. (2014). Reading performance is predicted by more than phonological processing. *Frontiers in Psychology*, *5*, 960.

Kim, Y. S. G. (2017). Why the simple view of reading is not simplistic: Unpacking component skills of reading using a direct and indirect effect model of reading (DIER). *Scientific Studies of Reading*, *21*(4), 310-333.

Kim, Y. S. G. (2020). Hierarchical and dynamic relations of language and cognitive skills to reading comprehension: Testing the direct and indirect effects model of reading (DIER). *Journal of Educational Psychology*, *112*(4), 667.

Krizman, J., Skoe, E., Marian, V., & Kraus, N. (2014). Bilingualism increases neural response consistency and attentional control: Evidence for sensory and cognitive coupling. *Brain and language*, *128*(1), 34-40.

La Heij, W., Dirkx, J., & Kramer, P. (1990). Categorical interference and associative priming in picture naming. *British Journal of Psychology*, *81*(4), 511-525.

Lancaster, H. S., Li, J., & Gray, S. (2021). Selective visual attention skills differentially predict decoding and reading comprehension performance across reading ability profiles. *Journal of Research in Reading*.

Lange, K., Kühn, S., & Filevich, E. (2015). " Just Another Tool for Online Studies"(JATOS): An easy solution for setup and management of web servers supporting online studies. *PloS one*, *10*(6), e0130834.

Lavie, N., Hirst, A., De Fockert, J. W., & Viding, E. (2004). Load theory of selective attention and cognitive control. *Journal of experimental psychology: General*, *133*(3), 339.

Leong, C. K., Tse, S. K., Loh, K. Y., & Hau, K. T. (2008). Text comprehension in Chinese children: Relative contribution of verbal working memory, pseudoword reading, rapid automatized naming, and onset-rime phonological segmentation. *Journal of Educational Psychology*, *100*(1), 135.

Levy, B. A. (1978). Speech processing during reading. In *Cognitive psychology and instruction* (pp. 123-151). Springer, Boston, MA.

Levy, R., Bicknell, K., Slattery, T., & Rayner, K. (2009). Eye movement evidence that readers maintain and act on uncertainty about past linguistic input. *Proceedings of the National Academy of Sciences*, *106*(50), 21086-21090.

Mandal, A. S., Fama, M. E., Skipper-Kallal, L. M., DeMarco, A. T., Lacey, E. H., & Turkeltaub, P. E. (2020). Brain structures and cognitive abilities important for the self-monitoring of speech errors. *Neurobiology of Language*, *1*(3).

Mason, D. J., Humphreys, G. W., & Kent, L. (2005). Insights into the control of attentional set in ADHD using the attentional blink paradigm. *Journal of Child Psychology and Psychiatry, 46*(12), 1345–1353. https://doi.org/10.1111/j.1469-7610.2005.01428.x

Mathôt, S., Schreij, D., & Theeuwes, J. (2012). OpenSesame: An open-source, graphical experiment builder for the social sciences. *Behavior Research Methods*, *44*(2), 314-324. doi:10.3758/s13428-011-0168-7

McCutchen, D., & Perfetti, C. A. (1982). The visual tongue-twister effect: Phonological activation in silent reading. *Journal of Verbal Learning and Verbal Behavior*, *21*(6), 672-687.

McCutchen, D., Bell, L. C., France, I. M., & Perfetti, C. A. (1991). Phoneme-specific interference in reading: The tongue-twister effect revisited. *Reading Research Quarterly*, 87-103.

Munger, K., Crandall, B. R., Cullen, K. A., Duffy, M. A., Dussling, T. M., Lewis, E., ... & Stevens, E. Y. (2016). *Steps to success: Crossing the bridge between literacy research and practice*. Open SUNY Textbooks at the State University of New York College at Geneseo.

Nakamoto, J., Lindsey, K. A., & Manis, F. R. (2007). A longitudinal analysis of English language learners' word decoding and reading comprehension. *Reading and Writing*, *20*(7), 691-719.

Netelenbos, N., Gibb, R. L., Li, F., & Gonzalez, C. L. (2018). Articulation speaks to executive function: An investigation in 4-to 6-year-olds. *Frontiers in psychology*, *9*, 172.

Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological bulletin*, *126*(2), 220.

Norman, D. A., & Shallice, T. (1986). Attention to action. In *Consciousness and self-regulation* (pp. 1-18). Springer, Boston, MA.

Oxford University Press. (n.d.). *Oxford English dictionary*. Retrieved November 22, 2021, from https://www.oed.com/

Paap, K. R., & Greenberg, Z. I. (2013). There is no coherent evidence for a bilingual advantage in executive processing. *Cognitive psychology*, *66*(2), 232-258.

Perfetti, C. A., & Hart, L. (2002). The lexical quality hypothesis. *Precursors of functional literacy*, *11*, 67-86.

Perfetti, C. A., & Hogaboam, T. (1975). Relationship between single word decoding and reading comprehension skill. *Journal of educational psychology*, *67*(4), 461.

Perfetti, C. A., Landi, N., & Oakhill, J. (2005). The Acquisition of Reading Comprehension Skill. In M. J. Snowling & C. Hulme (Eds.), *The science of reading: A handbook* (pp. 227–247). Blackwell

Perfetti, C., McKeown, M. G., & Kucan, L. (2010). Decoding, vocabulary, and comprehension. *Bringing reading research to life*, 291-303.

Radach, R., Huestegge, L., & Reilly, R. (2008). The role of global top-down factors in local eye-movement control in reading. *Psychological research*, *72*(6), 675-688.

Rezaei, A., & Jeddi, E. M. (2020). The contributions of attentional control components, phonological awareness, and working memory to reading ability. *Journal of psycholinguistic research*, *49*(1), 31-40.

Samuels, S. J. (1981). Some essentials of decoding. *Exceptional Education Quarterly*, *2*(1), 11-25.

Savage, R. (2006). Reading comprehension is not always the product of nonsense word decoding and linguistic comprehension: Evidence from teenagers who are extremely poor readers. *Scientific Studies of Reading*, *10*(2), 143-164.

Schroeder, S. R., & Marian, V. (2012). A bilingual advantage for episodic memory in older adults. *Journal of Cognitive Psychology*, *24*(5), 591-601.

Seigneuric, A., & Ehrlich, M. F. (2005). Contribution of working memory capacity to children’s reading comprehension: A longitudinal investigation. *Reading and writing*, *18*(7), 617-656.

Sesma, H. W., Mahone, E. M., Levine, T., Eason, S. H., & Cutting, L. E. (2009). The contribution of executive skills to reading comprehension. *Child Neuropsychology*, *15*(3), 232-246.

Soveri, A., Laine, M., Hämäläinen, H., & Hugdahl, K. (2011). Bilingual advantage in attentional control: Evidence from the forced-attention dichotic listening paradigm. *Bilingualism: Language and Cognition*, *14*(3), 371-378.

Spencer, M., & Cutting, L. E. (2021). Relations among executive function, decoding, and reading comprehension: An investigation of sex differences. *Discourse Processes*, *58*(1), 42-59.

Spencer, M., & Wagner, R. K. (2018). The comprehension problems of children with poor reading comprehension despite adequate decoding: A meta-analysis. *Review of educational research*, *88*(3), 366-400.

Sperber, R. D., McCauley, C., Ragain, R. D., & Weil, C. M. (1979). Semantic priming effects on picture and word processing. *Memory & Cognition*, *7*(5), 339-345.

Verhoeven, L., van Leeuwe, J., & Vermeer, A. (2011). Vocabulary growth and reading development across the elementary school years. *Scientific Studies of Reading*, *15*(1), 8-25.

Weingarten, E., Chen, Q., McAdams, M., Yi, J., Hepler, J., & Albarracín, D. (2016). From primed concepts to action: A meta-analysis of the behavioral effects of incidentally presented words. *Psychological bulletin*, *142*(5), 472.

Wentink, H. W., Van Bon, W. H., & Schreuder, R. (1997). Training of poor readers' phonological decoding skills: Evidence for syllable-bound processing. *Reading and Writing*, *9*(3), 163-192.

Wickham, H. (2007). Reshaping data with the reshape package. *Journal of statistical software*, *21*(12), 1-20.

Wickham, H., & Bryan, J. (2019). readxl: Read Excel Files. R package version 1.3. 1.

Wickham, H., Francois, R., Henry, L., & Müller, K. (2015). dplyr: A Grammar of Data Manipulation. R package version 0.4. 3. *R Found. Stat. Comput., Vienna. https://CRAN. R-project. org/package= dplyr*.

Yuan, Eric (2011). Zoom (Version 5.9.1). Retrieved from https://zoom.us/download

Zhang, S., & Perfetti, C. A. (1993). The tongue-twister effect in reading Chinese. *Journal of experimental psychology: Learning, Memory, and Cognition*, *19*(5), 1082.

Ziegler, J. C., Perry, C., & Zorzi, M. (2014). Modelling reading development through phonological decoding and self-teaching: Implications for dyslexia. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *369*(1634), 20120397.

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