CHAPTER SIX: Bi-directional Lexical Influences during Oral Reading

6.1. Abstract

Although reading aloud is associated with less skilled readers and children, it is an incredibly complex task that recruits multiple processes such as oculomotor, visual, orthographic, phonological, semantic, memory and speech processes. During oral reading, readers' eyes are typically two words ahead of the voice, suggesting that at any given time, the articulated word differs (N-2) from the fixated word (N). In this study, we investigated the presence of dual task costs on eye movements (i.e., gaze duration) and speech processes (i.e., articulation duration) based on lexical effects of word frequency and length during children's sentence reading. Our main questions were whether the frequency and length of the articulated word N-2 (*speech load*) impacted gaze durations of N and whether the same variables for the fixated word N (*foveal load*) impacted articulation duration of word N-2. The frequency of the word a reader was uttering (N-2) impacted the gaze duration of a concurrently fixated word (N). However, the reverse effect was not significant. That is, the frequency of the fixated word (N) did not significantly impact the time needed to utter word N-2. Findings are discussed in the context of attention allocation during dual tasks and the encapsulation of output processes.

6.2. Introduction

Reading aloud is considered a complex task (Inhoff & Radach, 2014; Moers et al., 2017), resulting in greater brain activation compared to silent reading (Galin et al., 1992). It simultaneously activates spoken and written language processes (Carreiras et al., 2007; Price et al., 2006). Although inner speech occurs during silent reading (Abramson & Goldinger, 1997; Huestegge, 2010) and underlying oral and silent reading processes are similar (Juel & Holmes, 1981), the overt articulation requirement during oral reading makes it more resource-demanding. This may be especially true for developing readers whose reading aloud focuses on fluency and text comprehension. Therefore, oral reading can be likened to a dual-task situation, i.e., simultaneous word recognition and articulation (Gordon & Hoedemaker, 2016; Kim et al., 2019). Such situations lead to the depletion of cognitive resources, and a reduction in reading speed as observed in oral reading (Huestegge et al., 2014; Krieber et al., 2017).

Another complexity during oral reading arises from the need to coordinate the eye and the voice. This coordination is necessary to ensure that the mind can grasp the meaning of text before the voice utters it (Buswell, 1920). Typically, the eyes are two or three words ahead of the voice (Inhoff et al., 2011; Laubrock & Kliegl, 2015), and this distance is called the *eye-voice span* (EVS; Buswell, 1920). It is well established that oral reading is slower than silent reading (Adedeji et al., 2021; Anderson & Swanson, 1937; Krieber et al., 2017; Vorstius et al., 2014) due to the coordination of the EVS (Inhoff et al., 2011; Laubrock & Kliegl, 2015). However, the combination of a dual-task situation and the presence of an EVS suggests that at almost any given time, the fixated and articulated words will differ. Ashby et al. (2012) proposed that interference from stored phonological representations in working memory on activated phonological presentations of the currently fixated word could be the source of reduced perceptual span during oral reading. We propose that, in addition to this, interference could arise from articulatory processes. Research has not yet determined whether lexical interference effects from articulatory processes can contribute to increased reading times. Therefore, we explored this possibility for the first time by investigating the extent to which lexical characteristics of the articulated word (usually N-2) interferes with the gaze duration of the concurrently fixated word (N). Additionally, we investigated whether lexical characteristics of fixated words (N) interfere with the articulation duration of the concurrently articulated words (usually N-2). For simplicity, we would address the former effect as *speech load* and the latter effect as *foveal load*. This is likely a fruitful research inquiry as it provides an insight into the distribution of attentional resources and the encapsulation of word recognition and speech-motor processes.

6.2.1. Attention during word recognition and speech production

Cognitive psychologists have been interested in dual task performance for at least 130 years. Examination of dual task performance can increase our understanding of the function and potential interaction between different human systems (Pashler, 1994). Dual task costs or interference cause longer performance times on dual versus single tasks. These costs are theorised to result from limited attentional capacity in performing two tasks simultaneously (Kahneman, 1973, see Pashler, 1994 for alternative accounts). Oral reading combines the lexical processing stage of silent reading and post-lexical stages of speech production (Juel & Holmes, 1981; Sulpizio & Kinoshita, 2016). Evidence shows that both stages require attention (Becker, 1976; Jongman et al., 2015; Reynolds & Besner, 2006). Becker (1976), using a dual task paradigm, found a greater difference between simple and choice auditory reaction time tasks when paired with a lexical decision task compared to when performed alone. The simple task required participants to respond to a tone by a button press, while the choice task required them to identify whether they heard a high or low tone by pressing either of two buttons. Greater difference between the simple and choice task in the dual task situation was taken as an indication of word recognition processes requiring attention that interfered more with the choice task than the simple task. In addition, Becker (1976) found that this effect was larger when the lexical decision task involved low frequency words compared to high frequency words suggesting that the processing of low frequency words requires more attention.

In eye movement research, fixations are indicators of the locus of attention. Longer fixation durations may indicate that more attention is being given to word recognition or syntactic integration processes (Rayner, 1977). External phonological stimuli may interfere with word recognition or sentence reading processes (Inhoff et al., 2002; Vasilev et al., 2019). Similarly, vocalisation during reading impacts eye movements differentially from silent reading. For example, Huestegge (2010) reported the absence of a vowel length effect on gaze durations during oral reading and an articulation suppression task (participants were asked to utter a single syllable in rhythm while they read). However, in either a silent reading task or a foot-tapping plus reading task, vowel length effects were found (Huestegge, 2010). This finding, alongside Becker (1976), suggests that word processing requires attention and that extra phonological and phonetic processing during oral reading competes for this attention. A limited capacity explanation (Kahneman, 1973) of dual task performance indicates that attentional resources are deployed to both articulatory and word recognition processes during oral reading, causing longer gaze durations. Thus, disrupting the efficient lexical processing that occurs during silent reading. Attentional allocation to word recognition processes during reading is supported by the E-Z reader model of eye movements, where attention is allocated serially to words, and attention cannot be given to the next word unless complete lexical access for the current word is achieved (Reichle et al., 2013; Reichle et al., 2003; Reichle et al., 2009).

Post-lexical stages of speech production also require attention (Fournet et al., 2021; Jongman et al., 2015). Attentional demands during speech production are supported by research on language intrusion errors in bilinguals (Declerck et al., 2016; Schotter et al., 2019). Schotter et al. (2019) found that bilinguals initiated regressions to words on which oral reading errors occurred and later corrected compared to correctly produced words. Further evidence of this comes from a recent series of dual task experiments showing that an additional cognitive task may impact speech production stages. Fournet et al. (2021) found dual task costs in a verbal task requiring limited lexical processing (i.e., repetition of the days of the week) while performing a non-verbal inhibitory task (Go/No-go). The Go/No-go task involved responding to either of two symbols (*x* or +) presented on the screen by pressing a button. Word rates during the verbal tasks were higher when performed alone compared to when performed with the inhibitory Go/No-go task. Dual task costs were also found for the inhibitory task. However, the pattern of effects for the verbal task was limited to older adults as younger adults' word rates were unaffected by dual task costs. This finding was attributed to the possibility that the executive control system may allocate more attention to the more difficult inhibition task. Hence, disrupting production stages of the verbal task in older adults whose speech rates are slower than younger adults (Fournet et al., 2021). This study suggests that oral reading places demands on the cognitive system where readers must devote attention to both articulation and ongoing word recognition processes (Zhou et al., 2021). However, what remains unknown is whether the attentional demands in one domain can influence processing efficiency of the other domain. Beyond the theory of limited attentional resources, these questions are of theoretical importance, considering the notion of modularity and encapsulation of cognitive and peripheral systems (Clarke, 2020; Coltheart, 1999; Fodor, 1983).

Modularity represents a controversial topic in human cognition (Barrett & Kurzban, 2006). One critical feature of modularity is the degree of informational encapsulation, i.e., immunity from interference from other domains (Fodor, 1983). Evidence against strong encapsulation of input systems (McGurk effect; McGurk & MacDonald, 1976) and output systems (Huestegge et al., 2014) have been documented. For example, Huestegge et al. (2014) show that when participants were required to give an oculomotor and verbal response simultaneously, dual response costs were found regardless of how the stimulus was presented (i.e., visual or auditory). Assuming increased fixation durations in oral reading are in part due to dual-task costs, conceding to the absence of encapsulation, our research presents a novel attempt to explore whether there are degrees to the interference from speech output on word recognition processes and vice versa dependent on lexical variables such as word frequency and length.

6.2.2. Lexical effects on word recognition and speech production

The frequency effect on word recognition is robust and evident in naming latencies, lexical decision reaction times, event-related potential, and eye movements (Dambacher et al., 2006; Hyona & Olson, 1995; Inhoff, 1984; Just & Carpenter, 1980; Kliegl et al., 2004; Monsell et al., 1989; Rayner & Duffy, 1986; Rayner, Reichle, et al., 2006; Schilling et al., 1998; Staub et al., 2010). Specifically, in eye movement records, readers spend less time fixating high frequency words compared to low frequency words (Rayner, Reichle, et al., 2006; Schilling et al., 1998; Tiffin-Richards & Schroeder, 2015b). Similarly, word length effects are well established. For instance, longer words receive longer and/or more fixations compared to shorter words (Hyona & Olson, 1995; Joseph et al., 2009; Kliegl et al., 2004; Tiffin-Richards & Schroeder, 2015b).

However, frequency effects on speech production are more controversial. When producing speech, speakers choose high frequency words quicker, more often, and with fewer errors compared to low frequency words (Navarrete et al., 2006). However, debates surround the source and reliability of the frequency effect beyond lexical access (Almeida et al., 2007; Balota & Chumbley, 1985; Gerhand & Barry, 1998; Monsell et al., 1989; Mousikou & Rastle, 2015). Some claim the frequency effect during speech production comes from the lexical processing stage (Jescheniak & Levelt, 1994), which cascades onto the production stages (Balota & Chumbley, 1985). Others argue its source is articulatory, where more frequent words are faster to produce because the articulatory motor programs have been initiated and executed more frequently (Bybee, 2006). However, Gahl (2008) showed that lemma frequency (frequency relating to word meaning and syntactic characteristics) impacted spoken duration of words with similar phonological forms (e.g., *time* and *thyme*). This finding contradicts an articulatory source of frequency effects. Consequently, Gahl (2008) proposed that frequency effects are word and context-specific, impacting all aspects of language production and comprehension.

Reading aloud and speech production are similar in the phonological, phonetic and motor execution stages (Sulpizio & Kinoshita, 2016). Therefore, one should expect similar frequency effects on articulation duration during reading aloud. However, the evidence is mixed (Davies et al., 2017; Kawamoto et al., 1999; Moers et al., 2017; Mousikou & Rastle, 2015). Kawamoto et al. (1999) reported frequency effects for initial phoneme duration but not rime duration for monosyllabic words. Similarly, Mousikou and Rastle (2015) revealed no frequency effects on word naming duration but found small effects on the initial phoneme during picture naming. In a study exploring predictability and frequency effects during reading aloud of Dutch sentences by children (8 to 12 year olds), adolescents (12 to 18 year olds) and older adults (62 to 95 year olds), effects of frequency on content word articulation durations were found only when predictability was excluded from the models. However, frequency effects were consistent for function words whether or not predictability was included (Moers et al., 2017). Overall, these studies do not preclude the possibility of a frequency effect on articulation duration during oral sentence reading. Consequently, frequency effects on articulation duration may reflect a cascaded view of lexical processing where articulation could begin before lexical access is completed or lexical activation spills over to articulatory processes (Balota & Yap, 2006).

In summary, there is agreement that both articulation and word recognition require attention. Additionally, there are well-established word frequency effects in word recognition and some evidence that the same may apply to speech execution during oral reading. Therefore, in the current study, we re-analysed children's eye movement and voice data from Adedeji et al. (under revision) to unveil bidirectional lexical influences on gaze and articulation duration. In line with Moers et al. (2017), we explore whether frequency effects exist for articulation duration. If evidence of frequency effects on articulation duration is found, then in line with dual task effects on cognitive tasks during simultaneous verbal production (Fournet et al., 2021), we predict that there will be speech load effects (Figure 6.1A) on gaze duration. Higher frequency and shorter articulated words will predict reduced gaze duration times on concurrently fixated words compared to lower frequency or longer articulated words. With established frequency effects on fixation times, we predict that there will be foveal load effects on articulation duration of the concurrently articulated word (Figure 6.1B). High frequency and shorter fixated words will predict reduced articulation durations for the concurrently articulated words compared to low frequency and longer fixated words.

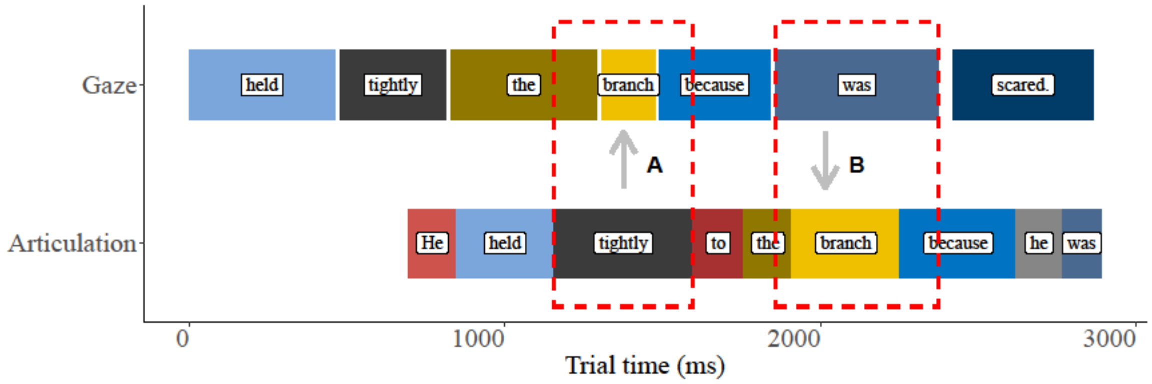

Figure 6.1. Illustration of gaze and articulation timeline showing A. Speech load effect: effect of articulated word properties on gaze duration and B. Foveal load effect: effect of fixated word properties on articulation duration. Blank spaces in gaze record represent words skipped during first pass reading and blank spaces in articulation record may represent pause/errors.

6.3. Method

6.3.1. Overview of dataset

This section summarises the methodology employed in Adedeji et al. (under revision), as the data analysed is a subset of data collected during a larger project designed to examine children's reading development during oral reading. The eye movement and voice data from 53 children aged 7 to 10 years (27 female, *Mean*=8.86, *SD*=0.93*)* from two primary schools in Bournemouth were analysed. The children read 42 experimental passages each (see Appendix A), and each passage had between 70 and 101 characters (*M*= 87.18 characters, *SD*= 8.03) consisting of two sentences spanning two lines. The eye movement data were recorded with an SR Research EyeLink 1000 Plus desktop-mounted eye-tracker with sampling frequency of 1000Hz, and voices were recorded using a Fifine USB Microphone –K056 Model device with a lag range of 3 to 24 ms. Experimental programming was done in MATLAB R2018a (MathWorks, 2014) using the Psychtoolbox v.3.0.11 (Brainard, 1997; Pelli, 1997) and Eyelink (Cornelissen, Peters, & Palmer, 2002) libraries. The experiment was run on a Windows 7 operating system. Parental consent was given, and each child participant gave written assent and was given verbal instructions before the experiment began. Participants were tested in quiet rooms within the school, where they completed two sessions of eye-tracking and offline assessments of reading-related skills.

6.3.2. Data treatment and analysis

In oral sentence reading, fixated and articulated words are usually overlapping. For example, viewing a word could span beyond the articulation of a word. Similarly, a word's articulation could span beyond a word's viewing. This would lead to situations where three words could be articulated successively during viewing one word or vice versa. For example, in Figure 6.1, while *because* was being fixated, the voice uttered *to* and *the*. Therefore, to ensure that the observed lexical effects are due to single words and not multiple words[7], we included only data points where the gaze duration occurred within the articulation of words for the gaze duration analysis. Similarly, we included data points where articulation duration of words occurred within gaze duration of words for the articulation duration analysis. These datasets are called non-overlapping datasets in the results section. See Figure 6.1 for illustration.

Linear mixed models (LMM) were used to analyse the data (lme4 package v1.1-21: Bates, Mächler, et al., 2015) in R software v 4.0.3 (R Core Team, 2020). For all models, participants and items were treated as crossed random effects. Initially, we adopted a full random structure (Barr et al., 2013), with random intercepts for participants and items. A random slope for each main effect for participant and item was also included. If this model did not converge, we removed random slopes from the model. The results were statistically significant if the $|t|$ values were ≥ 1.96. Lexical properties such as length and frequency of fixated words and previous words known to influence fixation durations were included in the gaze duration models (Kliegl et al., 2006; Marx et al., 2017; Rayner & Duffy, 1986). The number of phonemes and frequency of the articulated word were used as controls for the models on articulation duration as frequency effects may be confounded with the number of phonemes (Landauer & Streeter, 1973). All dependent measures were log-transformed. All continuous predictors and covariates were centred to a mean of zero in all models. The results were considered as statistically significant if the $|t|$ and $|z|$ values were ≥ 1.96. Significant and marginally significant p-values are formatted in bold and italics, respectively.

[7] There were cases where multiple words were gazed at during the articulation of one word and vice versa e.g., Figure 6.1(B). These were included in the analysis.

6.4. Results

Fixations less than 80ms that occurred within one character of a temporally adjacent fixation were combined with that fixation, any remaining fixations less than 80ms were excluded from the fixation data (11.69%). Two datasets were analysed from the final merged eye movement and audio data. The first data set was generated for the gaze duration analysis while the second dataset was generated for the articulation duration analysis. The same dataset was used for the first and second analysis. For the first analysis on foveal load effects on articulation duration, 7.5% of the data were removed due to punctuation on articulated words. For the second analysis on speech load effects on gaze duration, 18.97% of data were excluded due to punctuation on fixated or articulated words, 0.2% of data were removed due to gaze durations greater than 2400ms, and 0.3 % were excluded due to the fixated word being the articulated word as this could lead to a confound where frequency and length characteristics would be the same for the fixated and articulated word. In total, a 19.20% of data were excluded. For the third and final analysis on fixation effects on articulation duration, 16.02% of data were excluded due to punctuation on fixated and articulated words and 5 % were excluded due to the fixated word being the articulated word. Therefore, 20.25% of the merged data were excluded. Words with punctuation were excluded to forestall wrap-up effects that could occur at clause or sentence endings in the eye movement and speech records (Godde et al., 2021; Raban, 1982; Tiffin-Richards & Schroeder, 2018).

6.4.1. Descriptive Statistics

For the data examining speech load effects, the mean gaze duration was 249.2 (*SD* = 116.7, *range* = 80-1136) and for the data examining foveal load effects the articulation duration was 271.7 (*SD* = 163.6, *range* = 26.9- 2082.7).

6.4.2. Frequency effect on articulation duration

The LMM results for the influence of word frequency and length in phonemes on articulation duration are shown in Table 6.1. The result shows that both word frequency and length predicted articulation duration. Words with higher frequency were articulated faster than words with lower frequency. Similarly, words with fewer phonemes were articulated faster than words with more phonemes. These main effects were qualified by an interaction revealing that the effect of frequency was smaller for longer words.

Table 6.1. LMM Showing the Effect of Word Frequency and Word Length in Phonemes on Articulation Duration

Fixed effects	Dataset (N=13047)			
	b	*SE*	*t*	*p*
(Intercept)	2.5933	0.0111	233.8243	<0.01
Articulated word frequency	-0.1105	0.0036	-30.4165	**<0.01**
Articulated word length in phonemes	0.0674	0.002	33.8594	**<0.01**
Freq * Length	0.0082	0.0016	4.9453	**<0.01**
Random effects	Var.	SD	Corr.	
Item intercept	0.001	0.027		
Frequency slope	0.001	0.027	-0.57	
Participant intercept	0.006	0.077		
Residual	0.022	0.149		

6.4.3. Speech load effects on gaze durations

The LMM results showing speech load effect, i.e., word length in phonemes and frequency of articulated word on gaze duration of the simultaneously fixated word are shown is Table 6.2. We included previous word frequency and length to control for the possibility of spill-over effects; where the residual processing of lower frequency words spills over to the processing of the next word (Kliegl et al., 2004; Marx et al., 2017).

In the non-overlapping dataset, which is the main focus of this analysis, there were reliable speech load effects. The frequency and length in phonemes of the articulated word influenced gaze duration. Articulated words of lower frequency and longer lengths induced a cost to gaze duration of the concurrently fixated word. There were also reliable main effects of word frequency of the fixated word and frequency spill-over effects in the expected directions. There was a marginally significant interaction between frequency and length of fixated word on gaze durations. This interaction showed that the effect of frequency on gaze duration was smaller for longer words. Results from the full dataset has been included in Table E1 in the Appendix for reference purposes.

Table 6.2. LMM Analyses Showing Log-transformed Gaze Duration as a Function of Frequency and Length of Concurrently Articulated Words

Fixed effects	(N= 2295)			
	b	*SE*	*t*	*p*
(Intercept)	2.370	.008	294.836	<.01
ArtWordFreq	-.026	.004	-6.319	**<.01**
ArtWordLen	.014	.004	3.440	**<.01**
FixWordFreq	-.026	.005	-4.766	**<.01**
FixWordLen	.005	.005	.880	.38
PrevWordFreq	-.030	.010	-5.042	**<.01**
PrevWordLen	-.009	.006	-1.530	.012
FixLen*FixFreq	*.007*	*.004*	*1.686*	*.092*
Random effects	Var.	SD		
Item intercept	<.001	.013		
Part. intercept	.002	.045		
Residual	.026	.160		

Note. Statistically and marginally significant *p* values are formatted in bold and italics respectively. ArtWordLen is measured in number of phonemes

6.4.4. Foveal load effects on articulation durations

The LMM results showing foveal load effects, i.e., the influence of word length and frequency of fixated words on articulation duration of the simultaneously articulated word are shown in Table 6.3. For the non-overlapping dataset, there were no effects of fixated word frequency on articulation durations. The effect of frequency and length in phonemes on articulated word duration were in the expected directions. More frequent and shorter words took less time to pronounce compared to less frequent and longer words. Results from the full dataset has been included in Table E2 in the Appendix for reference purposes.

Table 6.3. LMM Analyses Showing Log-transformed Articulation Duration as a Function of Frequency and Length of Concurrently Fixated Words

Fixed effects	(N= 2285)			
	b	*SE*	*t*	*p*
(Intercept)	2.37	.014	173.525	**<.01**
FixWordFreq	-.01	.005	-1.017	.309
FixWordLen	.01	.006	1.41	.16
ArtWordFreq	-.124	.005	-24.263	**<.01**
ArtWordLen	.055	.005	10.683	**<.01**
Freq * Len	.007	.003	2.107	.035
Random effects	Var.	SD	Corr.	
Item intercept	<.001	.010		
Length slope	.001	.021	.33	
Participant intercept	.004	.060		
Residual	.020	.142		

Note. Statistically and marginally significant *p* values are formatted in bold and italics respectively

6.5. Discussion

The main objective of this study was to examine bidirectional lexical effects during natural oral sentence reading of children. Specifically, we investigated whether word frequency and length in phonemes of the articulated word modulated the gaze duration of the concurrently fixated word. We also examined whether the frequency and length of the fixated word impacted the articulation duration of the concurrently articulated word. To begin, we examined the contentious existence of frequency effects on articulation duration during reading aloud (Moers et al., 2017; Mousikou & Rastle, 2015). The results from the current study showed: *(i)* lexical effects for articulation duration: less frequent and longer words took longer to articulate compared to shorter and more frequent words; *(ii)* speech load effects for gaze duration: articulated words of higher frequency and fewer phonemes were associated with shorter gaze durations on the concurrently fixated word compared to low frequency and long articulated words; and *(iii)* no reliable foveal load effects on articulation duration.

Effects of the articulated word's frequency on its articulation duration during reading aloud have been equivocal. Some studies show a frequency effect that is limited to the initial phonemes of words during word naming (Kawamoto et al., 1999). Others show an effect when predictability is not accounted for during sentence reading (Moers et al., 2017). Such frequency effects are based on the premise that articulation can begin after the initial phoneme has been encoded (Kawamoto et al., 1999; Mousikou & Rastle, 2015). This explanation is tenable under single-word naming conditions where articulation follows immediately after word viewing (see Romani et al., 2022 for a recent investigation). However, during sentence reading, there is at least a 500ms delay between word N viewing and word N articulation (i.e., temporal onset EVS; Inhoff et al., 2011), where readers would have recognised (or at least fixated and encoded) another word, N+1, before beginning the articulation of word N leading to an EVS. In this thesis, this value was approximately 1000ms for developing readers. That phonological encoding of other segments of N still occurs during the articulation of N is unlikely except when there is no span between the eye and the voice. Therefore, an alternative explanation may be that lexical frequency effects spill over to articulatory planning processes consistent with Gahl (2008), where articulatory plans are retrieved faster for high compared to low frequency words. Our finding regarding the word length effect on articulation durations is consistent with grade two and four readers showing longer durations for words with more letters and phonemes compared to fewer letters and phonemes (Gagl et al., 2015). This effect has also been confirmed in adults (Romani et al., 2022).

Oral reading resembles a dual task situation that requires more time than silent reading due to constraints imposed by the relatively slow speech system. Eye movements reflect this pace through increased fixation durations (Adedeji et al., 2021; Anderson & Swanson, 1937; Krieber et al., 2017; Vorstius et al., 2014). It is well established that the coordination between the eye and the voice through modulation of the EVS influences fixation durations; a larger EVS results in longer fixations to allow the voice to catch up with the eyes (Inhoff et al., 2011; Laubrock & Kliegl, 2015). This finding was also confirmed in Chapter 4. However, another critical factor that may impact eye movements during oral reading is the property of articulated words. Ashby et al. (2012) alluded to the possibility that phonological representations in working memory can interfere with phonological representations during lexical access as an explanation for reduced perceptual span during oral compared to silent reading. We took a similar stance in this study by proposing that lexical properties of the articulated word may interfere with the encoding and/or recognition of the fixated word.

Articulatory processes during oral reading recruit attention (Fournet et al., 2021), which has a knock-on effect for the lexical processing of the fixated word. This effect is especially plausible for children or less skilled readers whose word recognition processes are assumed to be less encapsulated and dependent on context (Ashby et al., 2005; Stanovich, 1990). Articulatory frequency and length effects on gaze durations of the fixated word confirm the hypothesis that increased lexical load during articulation draws attentional resources, leading to increased gaze durations on fixated words. When articulated word frequency was high, and length was short, gaze durations were shorter than when the articulated word was of low frequency and long. This effect was found when confounds such as the length and frequency of fixated words and previous word length and frequency (i.e., spill-over effects) were controlled. Therefore, simultaneous word production may cause interference with word recognition processes and delay shifting attention to the right of the current fixation. Although this interference could arise because articulatory and word recognition processes rely on similar phonological processes (Pashler, 1994), the presence of such effects on a cognitive process which requires more attention is similar to what has been found with older and younger adults during a non-verbal inhibitory task (Fournet et al., 2021). In Fournet et al. (2021), participants spent more time during a non-verbal Go/No-go task when simultaneously saying the days of the week. This result confirmed that an additional articulatory task impacted on processing time during the secondary cognitive activity.

During word recognition, low frequency words attract more attention (Malmberg & Nelson, 2003) and induce more dual task costs than high frequency words (Becker, 1976). Word frequency effects are also well established on eye movement measures (Joseph et al., 2013; Raney & Rayner, 1995; Rayner & Duffy, 1986; Tiffin-Richards & Schroeder, 2015b). Therefore, it is reasonable to expect that word recognition processes for less familiar words will draw more attention which will slow articulatory processes. The study by Fournet et al. (2021) gives us an indication of this possibility. They found dual task effects for the verbal task (i.e., reciting days of the week) for the older adults (>60 years), indicating that cognitive processing impacted verbal production for these participants. However, an effect was not found for younger adults (20-46 years) with rapid and perhaps more automatic speech rates than older adults (Hazan, 2017; Jacewicz et al., 2010). The current findings are similar to what was found for the younger adults in Fournet et al. (2021), as neither fixated word frequency nor length of the fixated word impacted the articulation duration of concurrently articulated words for developing readers. However, children are less fluent than young adults aged 20-34 years during reading aloud but similar to other older adults aged 35-91 years (see Jacewicz et al., 2010). Therefore, the age overlap in the studies by Fournet et al. (2021) and Jacewicz et al. (2010) could indicate that children may indeed be similar to the adults in the former study. The frequency of children reading aloud compared to older adults may also be a suitable explanation for the observed results. Therefore, although articulation requires attention, speech motor fluency due to increased reading aloud practice limits the influence of other demanding cognitive processes like word recognition. These findings indicate that though post-lexical articulatory processes require attention enough to impact ongoing lexical processing, there is a possibility that post-lexical articulatory processes may be relatively immune from the influence of simultaneous word processing in developing readers.

Another plausible explanation could be that more attention is allocated to articulatory processes. When this happens, processing in the non-prioritized task, i.e., word recognition, may be impacted by the prioritized task, i.e., articulation. In this case, the non-prioritized task may not have an influence on the prioritize task. This explanation is likely in children who may prioritize reading speech output and reading with expressiveness compared to adults who may read aloud primarily for comprehension (Jones & Lockhart, 1919; Kragler, 1995). However, these explanations are only speculative and would require experimental designs to be fully explored.

Corpus analyses have the advantage of high ecological validity in capturing real-time reading processes. However, there is a potential that several confounds may have accounted for the observed effects. For instance, predictability which impacts eye movements (Kliegl et al., 2004; Rayner et al., 2011) and speech production (Moers et al., 2017) during reading, were neither accounted for nor controlled. Future experimental work should also consider using a RAN-type stimuli presentation where word properties such as phonological neighbours, bigram frequency, age of acquisition, etc., can be directly controlled before assessing lexical interference effects. Additionally, this design would allow the investigation of phonological interference effects (see Easson et al., 2020; Jones et al., 2016). Replications and extensions with other age groups are needed further to illuminate developmental differences in interference effects during oral reading.

In conclusion, this study presents a novel approach to studying dual-task lexical interference effects during oral sentence reading and contributes to our understanding of attention allocation during demanding cognitive processes.

6.5. Chapter Overview

Using data from children’s oral reading while their eye movements and voices were recorded, we obtained precise temporal and spatial information on speech output and lexical processing. This information permitted the assessment of speech load effects on eye movements during lexical processing and foveal load effects on speech output during articulation. Using a dual task framework, we found a cost in gaze duration when speech load was high i.e., uttering a low frequency word or a word with more phonemes. The reverse effect, i.e., foveal load on articulation durations were absent. These findings indicate the concurrent articulatory demands pull attentional resources that impact eye movements during lexical process. We discuss these and other findings in the final Chapter of this thesis.