Is Phonological Short-Term Memory Related to Orthographic Learning?

by

Hesam Farahani

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To the Irreplaceable Memory of my Father

and

Dr. Fariborz Raisdana

Abstract

When we learn new words we have to learn the form of these words, too. Learning the written form is referred to as orthographic learning. University students encounter discipline-specific jargon when they are reading. To date, research has focused on orthographic learning in children. Accordingly, this thesis examined orthographic learning in a sample of university students and asked: (a) To what extent do university students demonstrate orthographic learning of novel words encountered exclusively through text? (b) What are the sources of individual differences in university students' orthographic learning? Specifically, this thesis considered the potential relation between orthographic learning and phonological shot-term memory, word reading ability, spelling and receptive vocabulary. The participants for this study were university students who were native speakers of English language. Because COVID-19 disrupted data collection, this thesis is based on a reduced sample size of 5 participants. These participants had an average accuracy of 63% for the orthographic form of the new words on the day one of testing and a mean of 74% correct three days later. Logistic regression was used to evaluate the relation between orthographic learning and individual differences. This allowed for the investigation of relations at the level of the item rather than participants. There were 32 items on the orthographic choice task, as such, across the five participants, there was a total of 160 items. Logistic regression across these 160 items revealed that students who were better spellers generally had higher accuracy on the orthographic learning task. Modelling also suggested that phonological short-term memory might be related to delayed retention of orthographic forms. Taken together, these results illustrate that university students learn the orthographic form of words encountered through texts. These results also help clarify some of the skills that university students might

draw on to support their orthographic learning through text, namely existing orthographic knowledge (spelling) and skill with remembering the phonological form of newly heard words.

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1. Introduction

Before launching into the topic at hand, I would like to invite you to read the following brief text:

> Heraclitus of the city of Ephesus in Asia Minor (now Turkey) lived approximately 535-480 BC. He was one of the Presocratic philosophers of nature, who tried to establish the unity of matter despite its manifest variety. According to Heraclitus, the world is characterized by constant change: nothing is ever the same, everything is in constant flux. It is, for example, impossible to step into the same river twice, because the second time it is no longer, in a very material sense, the same river. His most famous phrase is, of course: *panta rhei,* 'everything flows'. He took it that the original form of matter is fire, the most changeable and volatile of all. The constant change consists, in principle, in a downward process of densification and then again an upward process of rarification: from fire into air into water into earth, and back into water, air and fire. From these four 'elements', fire, air, water and earth, all other varieties of matter are derived (Seuren, 1998, p.5).

What do you think about the words in the text? Do you think a first-year university student knows all the words in the text (e.g., Heraclitus, Ephesus, *panta rhei*, densification, rarification)? Are there some words that they might need to learn while they are reading? Of course, it is difficult to answer such questions without knowing specifics of the student: Is he/she a fluent reader and speller of English language? Does he/she have any reading difficulties? What courses he/she has taken to this point? And many other relevant questions. As the reader may be

familiar with the words in the above text, I provide one further illustration, where an invented word has been inserted into the text:

> Sam is in the forest, and the birds are quiet. Sam decides to renoak them.
> To renoak means to make sing again. Sam starts to renoak the birds. He likes to renoak them.

It is likely that students who are beginning to specialize in a specific academic field, encounter many new words through text, particularly discipline specific jargon (Hayes-Harb et al., 2010; Nagy & Townsend, 2012). The acquisition of these vocabularies are of great importance because the lack of this knowledge has consistently been identified as a barrier to student success (Corson, 1997; Garcia, 1991; Nagy & Townsend, 2012; Snow & Kim, 2007). As such, it is important to understand the way in which university students learn new words through reading. A part of learning new words, in addition to learning the meaning, is the orthographic form (spelling) of the words. Accordingly, this thesis investigates the way students learn the orthographic form of new words through texts.

To understand the importance of learning the orthographic form of words, it is first helpful to reflect on the importance of learning the phonological form of words. Gathercole (2006) argues that learners must learn the phonological form of to be acquired words; otherwise, there would be no form on which to attach meaning. Thus, learning the form of words is an essential part of word learning. Similarly, I contend that when readers encounter new words through text, they must learn the orthographic form of that word. As it turns out, we are really good at doing this (Share, 1995). To illustrate this learning, without referring back to the passage, look closely at the following spellings: RENOAK/RENOKE. What was the correct

spelling for the action introduced in the text? Do you know how to read this new word? Since both spellings are "pseudowords", that is, invented words which do not actually exist, there is no prior knowledge to rely on for assistance. Moreover, because both spellings sound precisely alike, you can only rely on your memory of the orthographic form to select the correct spelling of the newly encountered word. How was your performance? Did you select the RENOAK?

According to Share (1999, 2008, 2011), adult readers and young beginner readers perform unexpectedly strong in choosing the right spelling. Studies have shown that even if the spelling task had been presented after the reader had reached to the end of this chapter, their choices would be remarkably accurate. This strong performance takes place irrespective of the fact that both spellings are equally "word-like." This pattern holds if we replace word within the text with the alternative spelling RENOKE. Participants show a preference for the spelling they encountered within the text (Share, 1999). Share (2008, 2011) also shows that the readers not only perform surprisingly well in distinguishing the correct spelling from its control spelling (homophonic foil) but can implement this new knowledge in a variety of tasks such as spelling task and naming times (meaning that the target spelling is read more quickly and with less errors compared to the alternative spelling). A further point of interest is that this learning takes place extremely quickly. In the text presented above, there were only four incidence of the target word "renoak," but a single encounter might be enough for learning of the orthographic form of newly encountered words to begin (Share, 2004). Another surprising ability is the durability of this learning. Past research has shown that up to a month later, the readers still distinguish the target spelling – probably with less certainty, but at levels well above the 50% chance level – from the foils (Share 2008, 2011). Overall, a growing body of literature now illustrates that this process of choosing these visual-orthographic forms of unfamiliar words, "orthographic learning,"

is impressively fast and durable process (Share, 2008, 2011). To date, much of this body of research has looked at children who are simultaneously learning new words and learning how to read. University students, in contrast, must still be learning new words from text but already have substantial word reading abilities. Accordingly, this thesis examines orthographic learning in university students.

1.1. Reading Development and Triangle Model

In order to understand orthographic learning in university students, it is important to consider the components of word learning more generally. In alphabetic languages, readers have a system of mappings between the graphemes (letter and letter groups) of written words and the phonemes (the smallest units of speech) of spoken words (Ehri, 1992; Snowling et al., 2020). It is generally believed that phonological skills support alphabetic decoding (Brady & Shankweiler, 1991; Byrne, 1998; Goswami & Bryant, 1990). As such, the forms of words are important for reading. Thus, one can think of a triangle of components: semantics, the orthographic form, and the phonological form. Thus, the 'triangle model,' a computational model proposed by Seidenberg and McClelland (1989), to illustrate these key components is particularly relevant as a conceptual framework for this thesis. According to this model, processing is "interactive." That is, these three codes interact and connect to each other in order to establish word recognition system (see Figure 1.1).

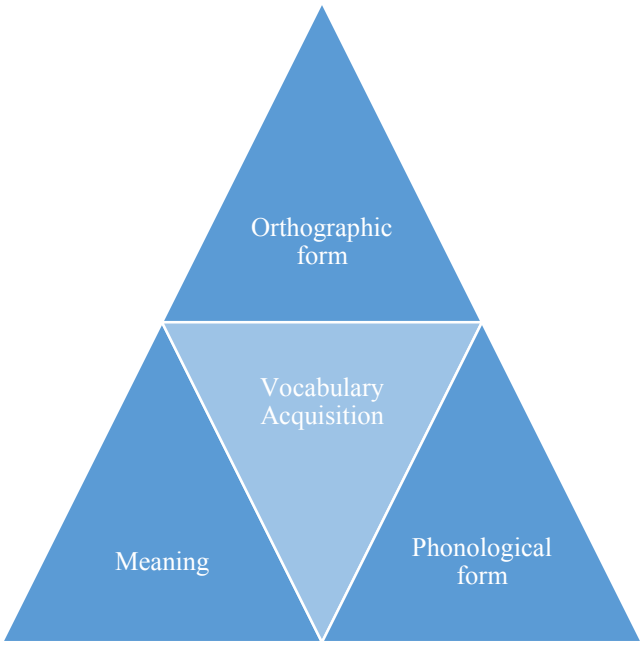

Figure 1.1 Visual representation of the three components to vocabulary acquisition

To learn a newly encountered word, one must learn the orthographic form (print), phonological form (sounds) and the semantics (meaning) of the word. In this thesis, I focus on university student's learning of the orthographic form of new words and ask to what extent having strengths in remembering the spoken form of newly heard words is related to strengths in learning the orthographic form of newly read words. When it comes to learning the phonological form, researchers suggest that phonological short-term memory abilities, which are captured by nonword repetition tasks, underpin word learning in the spoken domain, particularly the phonological form of newly heard words (e.g., Gathercole, 2006; Gathercole & Baddeley, 1989). Thus, the question arises as to whether skills related to learning the phonological form of words are related to learning the orthographic form as well. I investigate the possibility of such a

relation in university students, who are already skilled readers, but still encounter novel words, particularly discipline-specific jargons through the texts they read.

2. Literature Review

As mentioned in Chapter 1, notwithstanding being skilled readers, university students still have to deal with the new words while reading independently, and thus it is critical to realize how they learn new words through reading. According to the triangle model (see Figure 1.1), learning the newly encountered word involves learning the orthographic form (print), phonological form (sounds) and the semantics (meaning) of the word. This thesis examines the way students learn the orthographic form of new words through reading and asks if learning the phonological form of newly encountered words are related to learning the orthographic form as well. To address this question, there are two distinct areas of inquiry that need to be bridged together: (i) self-teaching hypothesis as a way to understand orthographic learning and (ii) phonological short-term memory as a mechanism for learning the phonological form of new words. To start, we first need a more clear definition of orthographic learning.

2.1. What is Orthographic Learning?

Orthographic learning is defined as the process of learning the visual-orthographic forms (the acquisition of word-specific orthographic representations) of new words (de Jong & Share, 2007; Share 1995, 2004, 2008, 2011). In young readers, orthographic learning supports the development of word recognition (Share, 2008). Word recognition is usually defined as the ability to distinguish words automatically and accurately even in the absence of semantic context and readers can recognize words in two diverse ways: automatically or by decoding (Hayes & Flanigan, 2015; Stanovich, 2000). Skilled readers have well-established word recognition skills, but as described in Chapter 1, they still encounter new words through text that they must read and learn, particularly university students who encounter discipline-specific jargon in text. To learn these new orthographic forms, Ehri (1992) explains that readers map

between the phonological and orthographic forms (sounds and spelling). This mapping between graphemes and phonemes is a required part of word reading. It is believed that phonological skills strengthen this system of alphabetic decoding (Brady & Shankweiler, 1991; Byrne, 1998; Goswami & Bryant, 1990). The ability to map between the phonological and orthographic form has been suggested as an important component of orthographic learning (Share, 2008). This link between phonological and orthographic form has historically been tested by looking at children's ability to decode novel words. This is based on the assumption that once decoded the word will be familiar, that is, already acquired through spoken language. But, what if the word has not yet been learned at all. Then both the phonological and orthographic forms need to be learned. As such, in this thesis I look to see if the ability to remember the phonological form of words is linked to the ability to remember the orthographic form of new words.

2.2. What Portrays a Successful Orthographic Learning?

One component necessary to understanding orthographic learning is understand what the outcome of successful orthographic learning might be. The extensive work of Perfetti, Share, and Ehri suggest several key features of a skilled orthographic word-recognition system, which is highly related to orthographic learning. First, according to Perfetti (1992), this system involves the development of *fully specified* (in comparison to partially specified) internal representations. By this he means that for the unique identification of the word to be read, the input code (letters) is adequate without the need for judging between multiple competing partially activated candidates. In such conditions, the existence of the context is not required for the identification of the word since the correct word can be thoroughly specified by the input code (i.e., the orthographic form). As Perfetti (1992) explains, "this means that a given letter string will be

sufficient to activate a specific word and to quickly bring about the recognition of that word rather than some other word." (p.157).

For Perfetti, the second characteristic of a skilled word-recognition system is that there is *autonomy* in the word-recognition process. He argues that, although it is undeniable that reading system is a deeply interactive mechanism, skilled "lexical" retrieval is remarkably modular and is mainly affected by input code (letters) and other factors just play a minimal role. Ehri (2005) also argues that the orthographic recognition (or sight word) process is also automatic. She believes that this process cannot be switched on and off or strategically controlled. She also proposes that word-recognition process functions largely unconsciously. She explains that the successful word recognition continues in a mandatory manner, with no necessity for conscious attention to the presented stimulus. The full concentration on the task of absorbing the meaning of the text is the benefit of this unconscious and automatic word recognition system. The autonomy of the reading system can be illustrated through the well-known Stroop effect, where we have to override our automatic word reading of the orthographic form (a color name) in order to say the physical color of the text. Thus, the autonomy of the word recognition allows the conscious attention to be applied to derive the meaning. Indeed, this is what university students are ultimately expected to do, but I want to consider what happens when they encounter new words within the text. In sum, learning the orthographic form is not just important for learning new words but for accurately and efficiently reading that word when it is encountered again in text.

As such, an important question arises as to what skills support successful orthographic learning. Share (1995) discusses this point in regards to orthographic learning in children who are developing their word reading skills. He suggests that the acquisition of word recognition

happens in an item-based pattern. He argues that a child might be reading some words with a lot of difficulty and a great deal of reliance on context and alphabetic decoding, whereas, at the same time, reading other words automatically, with ease and less contextual reliance (sight words). This suggests that we should be considering orthographic learning for each word that is encountered, until it is learned and automatic. This leads to the question of what skills do children draw on to do this item-based learning of orthographic forms. For children, some of important predictors of orthographic learning include: alphabetic and reading skills; orthographic processing skills; print exposure; and semantic knowledge (Castles & Nation, 2006). The extent to which these predictors also support orthographic learning in university students remains an understudied area of investigation. As such, much of the remaining literature review focuses on research with children.

2.2.1. Alphabetic and Reading Skills

A first step towards orthographic learning is to identify the newly encountered word. An important part of that stems from the ability to recognize the orthographic form that needs to be learned. In an alphabetic language like English this means being able to use the alphabetic code to decode the new word. Alphabetic decoding (which is usually measured by nonword reading tasks) plays a considerable role in word recognition process (Adams, 1990; Wagner & Torgesen, 1987). Firth (1972, as cited in Castles & Nation, 2006) reports a high correlation (.9) between nonword reading and word reading. This high correlation, which is derived from longitudinal studies of children at the end of kindergarten year (mean age of 5 years 11 months), at the end of grade 1 (mean age of 6 years 11 months) and at the end of grade 2 (mean age of 7 years 11 months), suggests that reading development is tied to early alphabetic skills (Jorm et al., 1984). This notion is supported by findings from studies which focus on dyslexic samples. These

studies indicate that those who have poor word reading skills also show low scores in nonword reading tasks (e.g., Rack et al., 1992). Therefore, alphabetic skills, and more specifically word decoding skills, are a critical predictor of a successful orthographic learning (Share, 1995). It is important to note that the research so far has focused on children who are developing readers. University students, in contrast, are skilled readers and decoders. Yet, being a skilled readers does not mean that they already know the orthographic form of all words they will encounter. University students still need to deal with new words as they read academic texts. Thus, it is important to investigate how they decode new words and how their decoding ability relates to their orthographic learning. Accordingly, this thesis includes a measure of the decoding (nonword reading skills) of the university student participants.

The need for further consideration of how orthographic learning might unfold in university students is emphasized by the fact that, even among children, a number of studies have shown that alphabetic and reading skills are not the only factors for the development of a skilled word recognition system. These studies indicate that after controlling for these two skills, considerable variance in terms of word reading remains unaccounted for (for reviews, see Juel et al., 1986; Nation & Snowling, 2004). Findings from these studies suggest that, although these skills are necessary, they are not merely adequate for a successful orthographic word recognition (Castles & Nation, 2006). Hence, a successful orthographic learning which is fully specified and autonomous may depend on other factors. In the case of this thesis, I consider if phonological short-term memory abilities, because of their importance for learning the phonological form of newly heard words are also related to orthographic learning.

2.2.2. Orthographic Processing Skills

Consistent with the findings which indicate the inadequacy of decoding (alphabetic) skills in developing a skilled orthographic learning, several researchers have suggested that a skill which is generally referred to as "orthographic processing" might be the second essential predictor of successful word recognition (e.g., Berninger, 1994, 1995). Tasks such as orthographic choice (e.g., which is a word? *rain* or *rine*) or sensitivity to orthographic constraints (e.g., which is most like a word? *beff* or *ffeb*) are generally used to measure orthographic processing skills (Castles & Nation, 2006). Although decoding skills play a key role in such tasks, they are not uniquely sufficient for successful performance. That is, to answer correctly to such tasks, one must activate their orthographic knowledge. Studies show that orthographic processing skills, even after controlling for alphabetic and word reading skills, predict variance in word recognition (Barker et al., 1992; Cunningham & Stanovich, 1990) and as outlined above word recognition is a key part of orthographic learning.

It is worth-noting, however, that a number of authors have raised objections to the construct of "orthographic processing" and its position as an independent predictor of successful word recognition. First, several researchers have noted that there is not a general consensus on the definition of orthographic processing skill (e.g., Castles & Nation, 2006; Vellutino et al., 1995; Wagner & Barker, 1994). Some authors concentrate on the capability to keep information about general patterns and characteristics of the orthography. For instance, according to Vellutino et al. (1994), orthographic coding is "the ability to represent the unique array of letters that defines a printed word, as well as general aspects of the writing system such as sequential dependencies, structural redundancies, letter position frequencies, and so forth" (p. 314). For

some others, orthographic processing skill means having access to specific word representations. For example, Frith (1985) defines this skill as "instant analysis of words into orthographic units without phonological conversion" (p. 306) and according to Szeszulski and Manis (1990) it "allows direct access to a mental lexicon for familiar words based on their unique orthography" (p. 182). This tension and lack of consensus are evident in the tasks used to measure orthographic processing with some measuring the capability to access unique, word-specific representations, while others assessing sensitivities to general orthographic attributes of the language (Castles & Nation, 2006). Even if a definition can be agreed on, the issue of how to interpret the results of many studies of orthographic processing which try to identify independent predictors of successful word recognition seems to remain problematic. If we opt for the definition which portrays orthographic processing skills as the awareness of orthographic regularities in the language (the task which asks, which is most like a word? *beff* or *ffeb*), here we can see a more indirect connection to skilled word recognition, and hence the task represents a more promising predictor from this perspective.

A study conducted by Cunningham et al. (2001) showed that children's orthographic processing skills in second grade, even after both alphabetic and phonological skills were controlled for, were responsible for unique variance in word reading in third grade. However, in this study researchers did not control for children's pre-existing word recognition skills before evaluating the relationship between orthographic processing skills in second grade and word reading in third grade. This makes it almost impossible to know how much of this relationship stems from the pre-existing word recognition skills that children in second grade initially brought to the task. Studies have shown that even children are aware of orthographic regularities (Cassar & Treiman, 1997; Pacton et al., 2001). According to Cassar and Treiman (1997), six-year-old

children are sensitive to the general patterns and properties of orthography and even kindergarten children have the ability to recognize which written sequences are more word-like. Given that even children develop sensitivity to the orthographic regularities even after short exposure to written language, we expect adults to be fully sensitive to orthographic regularities. Still, individual differences in orthographic skills are expected (Castles & Nation, 2006; Share, 1995, 2011). Accordingly, in the current study, although I do not give specific consideration to orthographic regularities, I test the extent to which the spelling abilities of university students generally are related to their orthographic learning.

2.2.3. Print Exposure

Print exposure has been shown to significantly, though modest, contribute to successful word recognition regardless of contribution made by alphabetic and phonological skills. In a study conducted by Cunningham and Stanovich (1993), children aged 6-7 were asked to carry out a group of tasks including measures of phonological and orthographic processing skill, measures of word recognition, and an index of exposure to print. In addition to the contribution of both phonological abilities and orthographic processing skills, they found out that print exposure predicts skilled orthographic word recognition. It goes without saying that in the absence of print exposure, orthographic learning cannot happen. Therefore, print exposure must account for successful word recognition to some degree. Cunningham and Stanovich (1998) underscore that unsuccessful readers have had less exposure to reading materials in their very early reading development. Moreover, according to Allington (1984), the fact that these poor readers are often exposed to the texts which tend to be way difficult for them has deteriorated their problem. These unpleasant reading experiences convince them to minimize their exposure to written language. For the university students, it is expected that they have had a great deal of

print exposure and therefore this component of developing a successful orthographic reading can be taken for granted.

2.2.4. Semantic Knowledge

When discussing orthographic learning, it is important to acknowledge that orthography is only one part of vocabulary acquisition (see Figure 1.1). Ultimately, university students need to learn the meanings of the discipline-specific jargon that they encounter in texts. As such, although this thesis focuses on orthographic learning, it is important to also consider the role of semantics. A number of authors have suggested that semantic factors (or meaning information) impact word reading in skilled adults. Lupker (2005) emphasizes that, "any successful model of word recognition will need to have a mechanism for explaining the impact of semantics, both the impact of the semantic context within which the word is processed and the impact of the semantic attributes of the word itself" (p. 40). Thus, it seems logical to evaluate the contribution of semantic factors to successful orthographic learning. A study conducted by Balota et al. (2004) investigates the impact of semantic variables on word recognition system. In their study, they used 2428 single-syllable words and assessed the predictors of word naming and visual lexical decision across them. They found that semantic factors accounted for both naming speed and the speed and accuracy of lexical decision. This demonstrates that meaning information becomes activated very quickly by the input code (letters). This, they argue, makes their findings "consistent with a view in which meaning becomes activated very early on, in a cascadic manner, during lexical processing and contributes to the processes involved in reaching a sufficient level of information to drive a lexical decision or naming response" (p. 312). Observing the contribution of meaning information to the lexical processing, leads to the view that sensitivity to semantic information could be another key predictor of skilled word

recognition, and thus, an association between semantic knowledge and orthographic learning could be expected.

Similar findings can be found in the work of Nation and Snowling (2004). They tested 72 children at two points in time, first when they were aged around 8.5 and second, about 4.5 years later, when they were around 13 years of age to investigate the connection between verbal-semantic skills and word reading. Their study indicated that even after controlling for decoding (nonword reading) and phonological awareness skills, word recognition could be predicted by all measures of verbal-semantic skills (vocabulary, listening comprehension, and semantic fluency and synonym judgement). Moreover, the relationship between verbal-semantic skills and word recognition was preserved over time. That is, the measure taken at time 1 predicted unique variance in word recognition at time 2, after approximately 4 years had elapsed.

The above studies address the relation between semantics and word recognition for words that are already known to the reader. The extent to which semantics is related to orthographic learning for newly encountered words, where the meaning also needs to be learned, is less clear. It seems in the case of orthographic learning that the relation might be more indirect (Castles & Nation, 2006). In any complicated orthography, readers have to cope with irregular and unfamiliar vocabularies. Nation & Snowling (1998a) suggest that children may make use of information from oral vocabulary and combine that with the information gathered from partial decoding strategies and the appreciation of context in order to pronounce the words appropriately. This strategy helps children to acquire better vocabulary knowledge and thus to develop a better orthographic representations of words, leading to a better word recognition system. This indirect relationship may support the perspective which doubts the contribution of oral vocabulary to reading development. For instance, in their study, Muter et al. (2004), found

it was phonological skills which predicted unique variance in word recognition, but not the oral vocabulary. Nevertheless, given that vocabulary has been suggested as a possible skill that aids orthographic learning, this thesis includes a measure of receptive vocabulary.

The inclusion of a vocabulary measure is further justified by the fact that some other studies have reported a direct impact of semantic factors on word reading (e.g. Balota et al., 2004; Strain et al., 1995). In a study, Laing and Hulme (1999) asked 4-6-year-old children to associate written abbreviations (or cues) with spoken words (e.g., *bfr* for *beaver*). Their findings showed that the word imageability plays a prominent role at the rate at which children could learn these written abbreviations of words in the very early stages of reading development. As such, these findings suggest that having direct access to the meanings can assist with orthographic learning.

The relation between vocabulary and orthographic learning, however, will not be a focus of this thesis. Direct empirical investigations of the relation between meaning and orthographic learning have not found clear evidence for this relation. McKague et al. (2001) tested the effect of having a word in oral domain prior to reading that word. Their presupposition was that if semantic factors contribute to word reading, familiarizing children with the meaning of novel words in oral domain should facilitate the learning of orthographic forms of those words by children. The results of their experiments showed that previous experience with the phonological forms of novel words influenced later orthographic learning but meaning-based information provided no more support. Similar finding was reported by Nation et al. (2007) who tested orthographic learning within 8- and 9-year-old children learning to read English. Another study conducted by Cunningham (2006) also suggested that contextual support does not moderate orthographic learning. Thus, it seems that learning the orthographic form of words might more

closely tied to skills related to the phonological form of words than to the semantics. Accordingly, this thesis focuses on orthographic and phonological forms as a means to understand orthographic learning in university students.

2.3. Mechanisms for Orthographic Learning

There are a number of mechanisms in the literature which have tried to explain as to how orthographic learning develops. These mechanisms include direct instruction (e.g., Chall, 1987), contextual guessing (e.g., Goodman, 1967; Smith, 1988), and phonological recoding (or decoding) (Share, 1995). Share (1995) argues that neither direct instruction nor contextual guessing are plausible to make substantial contribution to orthographic learning, and claims that "the ability to translate printed words *independently* into their spoken equivalents assumes a central role in reading acquisition" (p. 155). Thus it seems that phonological recoding (print-to-sound translation) appears to provide the more reliable means for understanding orthographic learning (Share, 1995). According to Share (1995), "phonological recoding functions as a self-teaching mechanism enabling the learner to acquire the detailed orthographic representations necessary for rapid, autonomous, visual word recognition" (p.152). He refers to this mechanism as the self-teaching hypothesis.

2.4. The Self-Teaching Hypothesis

One of the most cited theories which provides some specification on the development of orthographic learning is the self-teaching hypothesis, described by Share (1995). According to this theory, "each successful decoding encounter with an unfamiliar word provides an opportunity to acquire the word-specific orthographic information that is the foundation of skilled word recognition" (p.155). In this vein, some empirical studies have suggested that a

limited number of successful exposure to unfamiliar words seem to be adequate for the acquisition of orthographic representations, both for young readers (Manis, 1985; Reitsma, 1983a, 1983b) and adult skilled readers (Brooks, 1977). In this way, decoding functions as a "built-in teacher" which enables the independent development of both word-specific and general orthographic knowledge. To date, much of the theoretical development of the self-teaching hypothesis and empirical investigation of this hypothesis has focused on children's ability to learn the orthographic form of newly read words. As such, I will first focus on the self-teaching hypothesis and how it describes the development of orthographic knowledge and orthographic learning in childhood before considering what this might look like in skilled readers, such as the university students considered in this thesis.

According to Share (1995), the self-teaching mechanism comprises three key features. First, "the developmental role of phonological recoding is seen as *item-based* rather than *stage-based"* (p. 155). Stage-based means children get access to the meaning of a word by undergoing a developmental progression, usually by transiting from a "phonological to visual stage". This stage-based view has not responded successfully in the empirical findings (Barron, 1986; Jorm & Share, 1983), whereas, the item-based view argues that word recognition depends on how frequently a child is exposed to a specific word and how successfully and naturally he/she has identified that word. This means that the more a child encounters a particular word through text the more he/she will learn the orthographic properties of that word (item). Given the rapid acquisition of orthographic information (Brooks, 1977; Manis, 1985; Reitsma, 1983a, 1983b), items with high frequency are usually distinguished visually and with less reliance on phonological decoding from the beginning stages of reading development. For the unfamiliar words, a child relies mostly on phonological decoding. This is an important distinction because it

differs radically from traditional stage models of reading development, which consider a child transiting from one processing mode to another (i.e., phonological to visual). The item-based nature of orthographic learning suggests that children are learning the orthographic form one word at a time. This item-based learning eventually allows children to develop, from item-based experiences, their orthographic knowledge for their language as a whole, such as double consonants can occur at the end of words but not at the beginning in English (cf. “mess”, “dress”, “miss”, but no words begin with “ss”).

The second feature of the self-teaching hypothesis is that “the process of phonological recoding becomes increasingly "lexicalized" in the course of reading development” (Share, 1995, p.156). Unlike the many discussions around the reading process which views the phonological recoding as an unalterable routine (e.g., Barron, 1986; Coltheart, 1978, 2005), lexicalization considers phonological recoding as a developmental process. This is especially true for English language because of the opaque nature of the orthographic system. Thus, users must continue to learn lexical specific orthographies throughout their lives. According to Share (2011), “most English language readers start out with a relatively simple set of one-to-one letter-sound correspondence that are relatively insensitive to orthographic and morphemic context” (p. 52). These basic correspondences are usually invariable and thus cannot always be correct given that English does not have a one-to-one correspondence between grapheme and phoneme. As print exposure increases, these basic grapheme-phoneme relationships become “lexicalized,” that is “modified in the light of lexical constraints imposed by a growing body of orthographic knowledge” (p. 52). With more print exposure, the reader becomes sensitive to other regularities such as context, positional, and morphemic constraints which are far beyond the basic letter-sound correspondence. In sum, orthographic learning involves learning the specific spelling

patterns of a given word. For example, that the /o/ phoneme is spelled with an “oa” in the word “boat” but an “oe” in the word “toe”.

The third key feature is that “the self-teaching mechanism involves two component processes: phonological and orthographic” (Share, 1995, p. 56). Share claims that the phonological component is primary and orthographic component is secondary even though both processes independently contribute to the acquisition of successful word recognition. Phonological decoding (the capability to apply the knowledge of spelling-sound relationships for the identification of novel words) provides the essential and fundamental basis for reading development, or as Share (1995) describes it, phonological decoding is “the *sine qua non* of reading acquisition" (p. 156) and thus orthographic learning. Overall, according to self-teaching hypothesis, letter-sound knowledge and rudimentary decoding skills equip children with a means of translating a printed word into its spoken correspondence. This successful decoding experience provides an opportunity to acquire word-specific orthographic information of the nature needed to support fast and efficient word recognition. Share also proposes that the ability to use contextual information to determine exact word pronunciations on the basis of a partial decoding attempt plays an important role in self-teaching. That is, in being able to determine the phonological form of the word, readers are aided in learning the orthographic form of the word. This argument is based on children who are learning the orthographic form of words while simultaneously learning to phonetically decode words. University students are expert phonological decoders but will continue to encounter new words within the texts they read and must continue to learn these new items, both in terms of spelling and meaning. As such, considering the extent to which skill with the phonological form of words is related to orthographic learning in this group of readers remains an open question.

Before returning to the notion of how the self-teaching hypothesis might apply to skilled readers, like university students, it is important to consider the empirical evidence for the self-teaching hypothesis in children for whom this framework was originally proposed. To test the self-teaching hypothesis, Share (1999) developed an orthographic learning paradigm in which children decoded nonwords in story contexts. Forty normal second grade readers (aged 8 years), learning to read Hebrew, were tested to evaluate the self-teaching hypothesis. None of the participants had reading difficulties. Participants were asked to read aloud short stories each containing an embedded novel word appearing either four or six times. The participants read on their own, without any feedback or guidance from the researcher, much like you read the sample text in Chapter 1. Three days after exposure, Share investigated whether orthographic learning had taken place. Three measures were administered, Orthographic choice, naming and spelling. First, he investigated children's ability to distinguish the correct spelling of the target words in an orthographic choice task. Each child was presented with four alternate spellings of the target word, the original target word alongside a homophone foil (as an English example, the target word *yait* would be presented alongside the homophone *yate*) and two nonhomophonic foils that shared letters with the target item. The result showed that participants opted for the correct target word on 70% of occasions. This was five times more than they chose the homophone foil. This suggests that even with very limited exposure the children had learned something of the orthographic form of these new words.

Further evidence for orthographic learning can be seen in the results of the second and third measures that Share utilized. In the second measure of orthographic learning, Share simply asked children to read aloud a list of words in which both the original and homophonic spellings of the targets were embedded. Consistent with the result of the orthographic choice task, children

named target words faster than homophonic control words. The final measure required children to “reproduce from memory” (write) the spelling of the original target words. The researcher made every endeavor to elicit the child’s own representation of the target words by first reminding the topic of a story (e.g., “Do you remember the story you read to me about the hottest town in the world?” (p. 105) and then, in case the participant could not remember the name, s/he was supplied with the first syllable. If this did not work, the full target word was provided. Consistent with the results of other measures, participants were more likely to reproduce the target spelling pattern rather than the spelling pattern of homophonic foil. Therefore, taken together, these three measures (orthographic choice, naming, and spelling) illustrated the clear evidence of orthographic learning. Moreover, Share found that number of exposures (either four or six) made no difference in learning, convincing him to conclude that second graders show substantial orthographic learning after as few as four exposures to unfamiliar words.

Share moved the experiment further by examining this quick orthographic learning under conditions designed to minimize phonological decoding. As mentioned above, central to the self-learning hypothesis is that orthographic learning depends on phonological decoding. To investigate this aspect of self-teaching hypothesis, Share (1999; experiments 2-4) tested the orthographic learning under conditions where chances for initial phonological decoding were minimized (e.g., by decreasing initial exposure time to 300 ms, and by requesting participants to engage in concurrent vocalization during exposure). Share explains that because participants in this experiment were relatively fluent decoders, some automatic phonological activation was expected despite various interventions to prevent decoding. Thus, the researcher expected the substantial reduction but not elimination of phonological decoding. It was found that under these conditions, the degree of orthographic learning was significantly reduced across all three posttest

measures. This suggests that initial phonological decoding is absolutely essential, as stated by the self-teaching hypothesis.

A number of studies (Ehri & Saltmarsh, 1995; Reitsma, 1983a, 1983b, 1989; Share, 1999) have suggested that four or more encounters provide viable orthographic learning among normal readers. Another study (Hogaboam & Perfetti, 1978) reported the sufficiency of three exposures for reliable orthographic learning. According to Share (2004), these data suggest a ‘‘threshold’’ model of orthographic learning, in which significant learning takes place only after some threshold level of experience. In contrast to a threshold model, contemporary connectionist learning algorithms claim that only one exposure to a novel word produces significant learning (Harm & Seidenberg, 1999; Plaut et al., 1996). As such, initial investigations were not clear as to the number of exposures needed to result in orthographic learning.

To clarify this point about the number of exposures, Share (2004) conducted follow up investigations that increase our understanding of orthographic learning through contexts of self-teaching (i.e., reading without support). In this study (Share, 2004; experiment 1) two issues were addressed: 1) how many exposures to a word do children need in order to support orthographic learning, and 2) how durable this learning is. Replicating Share (1999) and using the same paradigm, 36 third grade children learning to read Hebrew participated in this study. Children were asked to read stories in which each target word appeared either four times, twice, or once. Three measures (orthographic choice, naming, and spelling) were administered after intervals of 3, 7, and 30 days and orthographic learning was then assessed. The results showed the clear evidence of orthographic learning across three tasks. Remarkably, the retention data proved to be impressive, with orthographic learning remaining constant even after 30 days,

regardless of the number of exposures to each target word. Therefore, it seems that a single decoding opportunity is adequate to develop strong and long-lasting orthographic learning.

It is important to note that Share's work is based on Hebrew, a non-European language, which is a highly regular orthography with simple syllable structures and few consonant clusters in which children learn to decode very quickly (Share, 1999, 2004). Share's studies described above illustrated second- and third graders who decoded target words successfully and very accurately (decoding levels more than 90%). This very high level of phonological recoding provided a strong basis for self-teaching and orthographic learning. It is important to consider the extent to which this framework extends to less regular and less transparent orthography, such as English, where levels of phonological decoding might be considerably lower. To answer this issue, Cunningham et al. (2002) conducted a study in second grade children learning to read English. They implemented the same paradigm as Share's (1999). Ten short stories were adapted from Share's Hebrew stories and translated to a version more appropriate for North-American English speakers. Each target novel word appeared six times in a story. Children were asked to read the stories aloud. They read the stories on their own with no guidance or assistance from the researcher apart from reading the title of the story. If participants had difficulty reading a word, they were instructed to try and read it by themselves. The same three aforementioned measures of orthographic learning were administered. In line with the difficulty of phonological decoding in English, decoding accuracy was lower than that of Share's Hebrew experiments (74% versus upward of 90% respectively). Although decoding accuracy was lower, orthographic learning took place. Three day after the text reading, participants were quicker and more accurate at distinguishing, producing, and naming the target items compared to that of homophonic foils. The important finding from this study, as it relates to this thesis, is that

Cunningham et al. (2002) also found a relationship between orthographic learning and initial target decoding accuracy. Thus, consistent with the self-teaching hypothesis, they obtained significant correlation between phonological decoding and orthographic learning.

A number of recent studies (e.g., Nation et al., 2007; Tucker et al., 2016) have further demonstrated that children learning to read in English are able to learn about the orthographic properties of words from encounters with these words when they are reading on their own, without explicit instruction. Nation et al. (2007) examined the orthographic learning through self-teaching hypothesis in children learning to read English. A total of 42 participants, aged between 8 and 9 years old, were tested for the orthographic learning. For half of the participants, nonwords were presented within the context and the other half saw the nonwords in the absence of context. The children encountered the nonwords either once, twice or four times. Orthographic learning was then assessed through orthographic choice task after 1 and 7 days. Nation et al.'s found an increase of orthographic learning as the number of exposures increased, although single exposure also predicted orthographic learning.

Tucker et al. (2016) tested the orthographic learning in the third and fifth graders using the similar paradigm, but added a morphologically complex condition. In this study, researchers divided 141 participants into three groups. First group read the stories which had the base form of nonwords (e.g., *feap*) embedded in them, second group was presented with stories carrying the nonwords in morphologically complex forms (e.g., *feaper*), and third group read stories which had orthographically complex forms of nonwords (e.g., *feaple*). Orthographic learning was then tested through orthographic choice task. Unlike previous studies, this study investigated children's accuracy with the form of the word they had encountered as well as the forms from the other two conditions, which the children had not previously seen. As such, this study

assessed children's ability to transfer their learning across orthographic forms. Their result indicated that children were more likely than chance to select the correct spelling of all forms irrespective of what form they saw in the story reading phase. Tucker et al. (2016) also found the occurrence of orthographic learning and the transferability of this learning experience in distinguishing the spelling of new words which are morphologically or orthographically similar regardless of successful or unsuccessful decoding of the newly encountered nonwords during the exposure phase, although successful decoding caused higher orthographic learning. The researchers suggest that learning the phonological forms of novel words "facilitate the formation of new orthographic representations and transfer of those representations to newly encountered words on the basis of orthographic analogies" (p. 91). Accordingly, through an investigation of homophonic foils, my thesis investigates the role of acquiring the phonological forms of newly encountered words in learning the orthographic forms (spelling) of new words in university students.

In sum, the existing evidence suggests that children are able to learn a lot about new words while reading independently and without instruction. As has been previously noted, despite being skilled readers, university students still encounter many new words while reading, especially discipline specific jargon (Nagy & Townsend, 2012; Hayes-Harb et al., 2010). As such, one remaining question is the extent to which university students learn the orthographic form of newly encountered words while reading. Preliminary evidence suggests that there is a lack of clarity about exactly how orthographic learning occurs in university students. Chalmers and Burt (2008) investigated the early stages of acquiring the orthographic forms of the newly encountered words in university students. They asked if the presence of either semantic information or phonological forms or both during the training session had any impact on

university students' performance on spelling recognition test. Their findings suggest that the presence of either semantic information or phonological forms helps students to obtain higher scores on spelling test. The provision of both phonology and meaning did not affect students' performance on subsequent spelling test. They also found that when the meaning was provided but the phonology was not and students produced their own pronunciations, they performed better in the spelling test. This shows that phonological decoding influences the learning of the orthography of newly encountered words.

2.5. How Does Phonological Short-Term Memory (Nonword Repetition) Relate to Word Learning?

Orthographic learning focuses on learning the written form (spelling) of newly acquired words and Share (1995) suggests that orthographic learning is tied to accurately decoding the phonological form of the word from the written text. As such, an interesting question arises as to the relation between learning the phonological and orthographic forms of words. It is, thus, worth considering the way in which phonological forms of words are learned more generally. In learning new words through spoken language, learning the phonological form of the word is a key component of this vocabulary acquisition (Gathercole, 2006). According to Gathercole, individual differences in phonological short-term memory, which is often measured by repeating the newly heard nonwords, are significantly related to the rate at which new words are learned. As she explains, for every word we now know, it was once unfamiliar and had to be learned; repeating the phonological form is thus part of establishing words in our mental lexicon.

Support for Gathercole (2006) can be found in examining the speech of young children who try to mimic the words that they hear from the first year of infancy and when they are 2 years old, they are willing to repeat a spoken nonword if asked. As such, it seems that the

repetition of phonological forms is a common part of word learning. Gathercole, however, mentions that "the apparent simplicity of the act of repeating a nonword is, however, deceptive" (p. 513) because a great deal underlies this seemingly simple ability. For instance, the ability to repeat nonwords provides insights into the quality of temporary storage that underlies learning new phonological representations, a critical element of word learning under this framework. Crucially, within the self-teaching hypothesis, the process of learning the written form of words (orthographic learning) is connected to the ability to map those words onto the phonological form of the word. Thus, the question arises as to what role phonological short-term memory might play in the orthographic learning of university students, in particular when they learn new words through text.

In order to examine the way in which phonological short-term memory might be related to orthographic learning in university students, it is important to detail the proposed relationship between phonological short-term memory and vocabulary acquisition. Gathercole (2006) describes this relationship as follows. Phonological storage plays a decisive role in both nonword repetition and word learning because the simple act of repeating a nonword relies on auditory, phonological, and motor processes. The importance of phonological storage for word learning is most clearly illustrated by considering children who have developmental language disorder, as they have been shown to have reduced phonological short-term memory, paired with language learning difficulties. In sum, the importance of phonological short-term memory has been explained in part because if one cannot remember the form, there is nothing to stick the meaning onto within the lexicon. Therefore, essentially, until children can learn the phonological forms, they have nothing to pin those concepts on to. Thus, children who perform well at keeping track of form, have an advantage in word learning.

The relationship between phonological short-term memory and word learning, at least within the oral domain, is more clearly detailed by Baddeley et al. (1998). They propose that the function of phonological short-term memory is not to remember the words we already know but to help new words to be learned. According to them "the ability to repeat a string of digits is simply a beneficiary of a more fundamental human capacity to generate a longer lasting representation of a brief and novel speech event—a new word" (p.158). The existence of such a skill is of crucial importance because, as is illustrated in Figure1.1, the phonological form of words is an important component to vocabulary acquisition. Further, as is argued within the self-teaching hypothesis, orthographic learning depends on the phonological forms (Share, 2004). According to Baddeley and colleagues, a key factor in ensuring new phonological forms are learned is the phonological loop, a temporary store for phonological patterns that is utilized to maintain the phonological form before the construction of permanent memory representations.

Phonological short-term memory is most often measured via a nonword repetition task, and performance on these tasks is highly related to vocabulary acquisition. An earlier longitudinal study by Gathercole and Baddeley (1989) showed a high correlation between vocabulary and nonword repetition scores within typically developing children. Many other studies have also reported relationship between nonword repetition and vocabulary knowledge (e.g., Avons et al., 1998; Gathercole & Baddeley, 1989; Gathercole et al., 1997; Michas & Henry, 1994). Gathercole (2006) claims that children who obtain low scores on nonword repetition tasks are slower to learn the novel phonological forms of new words.

In adulthood, the relation between nonword repetition performance and vocabulary acquisition is less clear. On one hand, Gupta's (2003) study of English speakers (aged between 18-26) found that this association between nonword repetition and vocabulary acquisition

extended into adulthood. On the other hand, a study carried out by Service and Craik (1993) failed to observe significant correlation between nonword repetition and vocabulary acquisition in young adults aged between 20-40 (mean age of 25.2 years). In interpreting these mixed findings, it is important to acknowledge a methodological limitation of Service and Craik's (1993) study. Their task included nonwords up to four syllables in length, which seems overly easy for adult participants and therefore might not capture individual differences in phonological short-term memory (Moore et al., 2017). They do not clearly present their accuracy results, but I speculate that ceiling effects could have led to the null results reported in their study. As such, it seems likely that Gupta's (2003) results are more likely to be replicable. Nevertheless, continued research in this area is needed.

Results from a study carried out by Papagno and Vallar (1995) illustrated the extension of the association between nonword repetition and word learning to extend beyond monolingual vocabulary acquisition. They tested the nonword repetition and novel word learning abilities of ten polyglot and ten non-polyglot Italian subjects. Researchers defined "polyglot" as being proficient in at least three languages. The polyglots ranged in age between 21 and 25 (mean age 23.1 years) and had started learning foreign languages at the age of 11; and the non-polyglots were aged between 22-25 (mean age 23.2 years) and had studied one foreign language, starting when they were 11. The result of their study revealed two important findings. First, the polyglots had superior performance on nonword repetition tasks compared to non-polyglots. Second, nonword repetition was strongly associated with the ability to learn novel words in the word learning task. As such, this study further emphasizes the potential role of phonological short-term memory in word learning among adults.

To conclude, I refer to conclusions of Gathercole (2006) who argues that "these findings indicate that the word learning mechanism tapped by nonword repetition operates across the life span, although its operation under some conditions may be masked in already proficient users of the language" (p. 516). In sum, Gathercole is focused on how individuals learn the phonological form of newly heard words. This thesis, in contrast, is considered with the extent to which orthographic forms are maintained in permanent memory (orthographic learning). More specifically, I ask whether strengths in the remembering the phonological form of words might be linked to remembering the orthographic form of words, especially given the emphasis placed on phonemic decoding in orthographic learning (Share, 2004).

2.6. The Current Study

This review has so far built on the notions of learning the form of words in the written (orthographic) and spoken (phonological) domains. Much of the previous work has focused on children who are learning to read and thus developing orthographic skills and reading skills in tandem. Thus, orthographic learning, including through self-teaching, is often discussed as a means to enhance word reading abilities more generally. However, in the current study, I investigate orthographic learning in university students who are already skilled readers, but who still encounter new words that need to be learned. Specifically, this thesis asks:

(a) To what extent do university students demonstrate orthographic learning of novel words encountered exclusively through text?

(b) What are the sources of individual differences in university student's orthographic learning? Specifically, I will consider general spelling abilities, phonemic decoding (reading), vocabulary and phonological short-term memory as potential sources of individual differences.

I am particularly interested in the potential relationship between phonological short-term memory, as it relates to learning the phonological (spoken) form of new words and orthographic learning which concentrates on the written form of words. To date, these avenues of inquiry have remained relatively isolated from each other and my thesis will bridge these ideas together to investigate potential connections between learning these two forms. Is it possible that individuals who have increased performance on a nonword repetition task also show increased performance learning the orthographic form of words through reading?

In considering the relation between phonological short-term memory and orthographic learning, it is important to consider other potential sources of individual difference. According to Share's (1995) self-teaching hypothesis, orthographic knowledge is characterized by phonological decoding skills, print exposure, and prior orthographic knowledge. Share argues that children use their pre-existing orthographic knowledge to self-teach the conventions and regularities of English spelling. This means that if someone has a good knowledge of the orthographic patterns of a language, s/he performs better at learning new words. As such, I included a spelling measure in my study. The other piece in orthographic learning is the essential role of phonological decoding skills (Share, 1995). Share (1999, 2004) provides direct evidence in support of the immense influence of phonological decoding in orthographic learning. The central role of phonological decoding in Share's model explains why it is necessary to include a measure of word and nonword reading. Finally, I have included a vocabulary measure for two reasons. First, Gathercole (2006) claims that if someone has a rich vocabulary size, s/he will fare better at remembering the new phonological form and thus it seems possible that an increased vocabulary size may also influence orthographic learning. Second, the explicit role of vocabulary

size in orthographic learning remains an open empirical question (e.g., Laing & Hulme, 1999; Muter et al., 2004).

3. Method

3.1. Participants

My initial plan was to recruit a total of 65 university students for this study. The motivation for this sample size is two-fold. First, I planned to analyze my data using hierarchical linear regression modelling with orthographic learning as the dependent variable, vocabulary, spelling ability and word reading as control variables and phonological short-term memory as the independent variable of interest. The general rule of thumb for this type of analysis, to avoid over-modelling the data, is that I include 10 participants for every independent variable (i.e., n = 40). However, a power analysis, based on a medium effect size between word learning and phonological STM (Gathercole, 2006) and accounting for 3 control variables and 1 key variable of interest to be included as predictors, suggests that I need to include at least 57 participants in our study.

Before describing my sample, I must provide relevant background information. Unfortunately, my data collection was disrupted by COVID-19 and the lockdown that began in March 2020. At the time, the University moved fully online, I had collected data from five participants (for both time 1 and time 2). Notably, I had appointments confirmed with 12 additional participants and was well on my way to recruit the remaining participants needed. In an attempt to expand my sample size, I spent substantial time converting my study from a face-to-face method to an online delivery. I had intended to present the two as separate studies, as the data from face-to-face would likely not be able to be incorporated with the online delivery. The online version of the study was posted to the Institute for Cognitive Science's SONA system at Carleton University. However, at the time of writing, no participants had participated in this

online version of the study. As such, following from conversations with my supervisor and the graduate advisor, I opted to write my thesis on the basis of the data from the five participants who participated in the face-to-face data collection. Upon completion of my degree, I will continue data collection via the online format so that I may advance my work towards future publications.

Participants were five undergraduate students at Carleton University in Ottawa, Canada. Students were on average 22.82 years old (SD = 2.79 years). The inclusion criteria for the study were as follows: Students (undergraduate or graduate) needed to be enrolled at a post-secondary institution in Ottawa, to age 18 and over; they needed be native speakers of English language; and they needed to have normal or corrected vision. The details on students' background information are summarized in Table 3.1.

Table 3. 1 Summary of Demographic Information of Participants

	Participant 001	Participant 002	Participant 003	Participant 004	Participant 005	Mean (SD)
Age	20.58	21.08	24.92	26.67	20.83	22.816 (2.79)
Gender	Female	Female	Female	Female	Female	
Other Languages Spoken	NA	NA	French ASL	French ASL	Hausa	

All participants self-declared their gender as female in the demographic form. In terms of languages, participant 001 and 002 were monolingual English speakers. Participant 003 was a second language speaker of French and ASL (American Sign Language). Participant 004 was a bilingual French-English speaker and a second language learner of ASL. Participant 005 was also familiar with Hausa language, but not proficient. Students were also asked about the number of courses they had completed by the time they were participating in the study within the demographic form. However, there seems to have been some confusion in their responses, with

some students entering the number of credits, not courses. As it was not clear how students had chosen to respond, this information cannot be accurately reported.

3.2. Procedures: Instruments, Data Collection and Data Processing, Statistical Analyses

3.2.1. Measures

Orthographic Learning Task (Mimeau et al., under review). This is an experimental measure of orthographic learning. This task involved reading passages which contained invented words and then answering a set of multiple-choice questions about the spelling and meaning of the invented words. Participants read 16 short passages in which each invented word appeared four times. A sample passage, which you might recall from Chapter 1, is:

> Sam is in the forest, and the birds are quiet. Sam decides to renoak them. To renoak means to make sing again. Sam starts to renoak the birds. He likes to renoak them.

All invented words occupied the position of the verb in the sentences. Stories ranged in length from 29 to 37 words (mean length 34.16). The invented words on this task had the following properties: The onset (consonant(s) before the vowel) must occur in English with the same pronunciation; the rime (vowel + final consonant(s)) must occur at the end of words in English, with the same pronunciation > 50% of the time; each grapheme must be pronounced according to the typical grapheme-phoneme correspondence rules; the vowel must be pronounced the same way as the most frequent pronunciation (> 50%); the non-words must not be real words, must not look or sound similar to French words and must be bisyllabic; the non-words must have between 4 and 7 letters. The original task (Mimeau et al., under review)

included 12 invented words. I used an adapted version of this task that included 16 invented words. A full list of the invented words can be found in Appendix A.

The participants were asked to read aloud all stories one after another. The researcher (myself) audio-recorded the entire story reading. No assistance or feedback was provided by the researcher at any stage during text reading. The audio files were then used to investigate the accuracy by which the nonwords were pronounced by the participants. After reading all 16 passages, participants completed two multiple choice tasks: orthographic choice and semantic choice. These tasks were completed immediately following the completion of the stories to estimate immediate learning and a second version of the tasks was administered again three days later to estimate retention.

Orthographic choice. Each student was presented with four alternate spellings of the target nonword: (1) The correct target spelling seen earlier in the passage, (2) a homophonic foil in which the target digraph (e.g., "ea") was replaced by its alternative digraph (e.g., "ee"), (3) a letter substitution where a single letter (consonant) was replaced by another letter, and (4) two substitutions, the vowel digraph for its homophonic foil and a letter substitution. A total of 32 orthographic choice questions were undertaken by each student, meaning that apart from the original words appeared in the stories, participants were also presented with a potential root from within the invented word. For the second visit, which happed three days after session one, the same orthographic choice test was used, but the questions appeared in a different order.

Semantic choice. Each student was presented with four alternate meanings of the target nonword: (1) The correct meaning (2), the correct meaning with the addition of “again”, (3) a foil that related to the situation in the story, and (4) the foil with the addition of “again”. A total of 32 semantic choice questions were completed by each participant, meaning that the “roots”

were also included in this test, same as the orthographic choice test. For second session (three day after visit one), the same semantic choice test, in different order, was administered.

Comprehension Test of Phonological Processing: Nonword Repetition Subtest (Wagner et al., 2013). The nonword repetition subtest evaluates phonological short-term memory. This test is an individually administered, norm-referenced test. The test consists of 30 items which increase in difficulty from one syllable to nine syllable words as the task progresses. The participant listens to an audio recording of each nonword and upon hearing that word they are asked to repeat it. There are a total of 30 items on the task, with a ceiling rule of 3 successive incorrect responses. The researcher can only provide feedback on test items 1-9 and is only allowed to play the recorded nonword once. The participant's responses are scored as 1 for correct responses that contain all necessary phonemes in the correct order and 0 for responses that include any error, including deletion or substitution of any phoneme. The nonword repetition subtest provides scaled scores for individuals aged between 4-0 (years-months) to 24-11. For participants in this study who were older than 24-11, the norms for 24-11 were used to estimate their scaled score. The nonword repetition subtest has a mean scaled score of 10 with a standard deviation of 3. I audio-recorded the test to verify the accuracy of scoring.

Test of Word Reading Efficiency (Torgesen et al., 2012). This test is an individually administered test that measures word reading fluency in two areas: sight word reading and phonetic decoding skills. The Sight Word Efficiency (SWE) subtest evaluates the number of real words that one can read through a vertical list within 45 seconds. This test is developed to provide a measure of the size of an individual's sight word vocabulary, words that can be processed as individual orthographic units, and distinguished and read with less effort. The SWE form A consists of 108 items which increase in difficulty from frequent monosyllabic words to

less frequent polysyllabic words as the task progresses. The Phonemic Decoding Efficiency (PDE) subtest measures the capability of an individual to apply their grapheme-phoneme knowledge to sound out novel unknown words. The PDE subtest measures the number of nonwords that one can read (decoded) through a vertical list within 45 seconds. The TOWRE-2 has four alternate forms (Forms A, B, C, and D) for each subtest. For the current study,Version A was used for both SWE and PDE. Items in the PDE subtest are designed to represent a wide range of letter-sound correspondence. The PDE Form A consists of 66 items which increase in difficulty in terms of number and complexity of phonemes and number of syllables as the task progresses. There are eight practice items for each subtest to give the participants a chance to familiarize themselves with the task. The researcher can only provide feedback on practice items. The participant's responses are recorded as 1 for correct answers and 0 for incorrect answers. Scoring of the PDE words was based on the provided pronunciations in the TOWRE manual. Notably, some of the nonwords on PDE subtest have more than one possible pronunciation. Participants were given a correct score so long as they provided one of the listed alternatives in the manual. The participant's score for each subtest is the total number of words or nonwords read correctly within 45 seconds. Items which are skipped, or where the participant hesitates more than 3 seconds are recorded as incorrect. The SWE and PDE subtests provide scaled scores for individuals aged between 6-0 (years-months) to 24-11. For participants in this study who were older than 24-11, the norms for 24-11 were used to estimate their scaled score. The SWE and PDE subtests have a mean scaled score of 100 with a standard deviation of 15. I audio-recorded the tests to verify the accuracy of scoring.

Peabody Picture Vocabulary Test (PPVT-5; Dunn, 2019). This test is an individually administered, untimed, norm-referenced test that measures the receptive vocabulary size. The

test consists of 240 items which increase in difficulty as the task progresses items. The participant is shown a series of sheets with 4 color pictures in each. The researcher says a word aloud and the participant selects the picture that best matches that word, either by pointing to the picture or speaking the number label of that picture. The basal for this test is 3 consecutive correct responses and the ceiling is 6 successive incorrect responses. There are two training item groups which are implemented by the researcher based on the participant's age group. This training provides the participant with an opportunity to become familiar with the task. The researcher can only provide feedback on the training items. The participant's responses are recorded as 1 for correct answers and 0 for incorrect answers. The PPVT vocabulary test provides standard scores for individuals aged between 2-6 (years-months) to 90-11+. This test has a mean standard score of 100 with a standard deviation of 15. In administering this task, I made one deviation from the manual. Typically words are spoken by the researcher. However, I asked a native speaker (my supervisor) to record all words. When administering the test, instead of saying the word aloud, I played the audio recording through my laptop to ensure that my accent did not influence the participants' responses.

Wide Range Achievement Test: Spelling subtest (WRAT-5; Wilkinson & Robertson, 2017). This test is an individually administered, norm-referenced test that measures spelling. The WRAT5 has alternate forms (blue and green). For the current study, I used the green spelling subtest. The spelling subtest has two parts: letter writing (which is administered to children aged 7 years or younger) and spelling. Given that my participants are university students, I only administered the second part. They all met the basal criterion (5 items correct). The spelling test consists of 42 words which increase in difficulty from frequent one syllable to less frequent multisyllabic words as the task progresses. There are no practice items for this test, but the

researcher gives thorough instruction to the participant. The participant is provided with an answer sheet, a pencil and an eraser. The researcher first says the item number and the target word, then reads a sentence with the word in it to indicate its correct use and then says the target word again. Participant is given approximately 15 seconds to spell each word. If the participant does not respond in the allotted time, the researcher goes to the next word. The researcher is allowed to repeat the words if necessary, but no other feedback can be provided. The ceiling for this test is 5 consecutive misspells. The participant's raw score is the number of items spelled correctly before hitting the ceiling plus the 15 points from part one (letter writing). The spelling subtest provides standard scores for individuals aged between 5-0 (years-months) to 85+.This test has a mean standard score of 100 with a standard deviation of 15.

3.2.2. Procedure

At the initial meeting, I explained the study to the participant and asked for their consent. Testing was carried out on an individual basis in a quiet office room on the 22nd floor of Dunton Tower, Carleton University. In the first visit, participants completed orthographic learning task, orthographic choice, semantic choice, CTOPP, TOWRE (SWE), TOWRE (PDE), PPVT, and WRAT.The tasks were presented in this order to all participants. After an interval of 3 days, a second version of the orthographic choice and semantic choice tasks were administered again. A native speaker of English (my supervisor) checked the accuracy of scores and analysis.

3.3. Analytic Plan

Due to the limited number of participants, the regression analysis was conducted at the level of the item. In this case, participants' responses for each item was binary (right/wrong) and therefore logistic regression was used to evaluate the relation between orthographic learning and

individual differences. There were 32 items on the orthographic choice task, as such, across the five participants, there was a total of 160 items. As such, the sample size for this analysis was 160 (items) instead of 5 participants (Blom et al., 2012). This analytic technique was chosen because logistic regression has been suggested as a reliable means for analyzing data from small samples (e.g., Blom et al., 2012; Baayen, 2008). Blom et al. (2012) explain that logistic regression has several advantages including "robustness, which is important in the case of unequal observations, missing data, and small samples" (p. 14). Notably, there is a risk that within this analysis plan the data have been over-modelled given the limited sample size. An analysis based on more participants is preferred and is planned as part of the continuation of this research as an online, instead of face-to-face study. However, the current approach at least allowed for a preliminary analysis of the data and the completion of this thesis under the current circumstances.

Given the limited sample size, the analysis for this thesis was conducted with an exploratory lens meant to guide future research on this topic. Accordingly, I took a two-step approach to the analysis. First, I conducted a hierarchical regression analysis as this was my original analytic plan. This technique allows us to investigate the relation between orthographic learning and nonword repetition after considering the variation already explained by other potentially related abilities. As such, this approach offers a more conservative estimate of the relation between orthographic learning and nonword repetition abilities. In the first step of the model, I added spelling, receptive vocabulary, and phonemic decoding (as a measure of word reading) as the independent variables. Orthographic learning was the dependent variable. In the second step of the model, I added nonword repetition. Second, given the limited sample size, I also took a less conservative approach and created a regression model that only include

orthographic learning as the dependent variable and nonword repetition as the independent variable. The first and second analytic plans were conducted for the data from the first visit and repeated with the scores from the orthographic choice task from the second visit.

4. Result

4.1. To what extent do university students demonstrate orthographic learning of novel words encountered through text?

This section provides details of the participants' performance on the orthographic learning task, as well as their performance on the other tasks administered as part of this study. Accordingly, Table 4.1 summarizes ranges, means and standard deviations for all experimental and standardized measures as well as each participant's performance on each task. As the orthographic learning tasks is an experimental measure, no standard scores are available for this task. Raw scores for the orthographic learning tasks are presented as the percentage correct. For the remaining scores, the standard or scaled score is presented. For all standardized measures, except the CTOPP, the standard mean is 100 with a standard deviation of 15. For the CTOPP, the scaled scores are based on a mean of 10 and a standard deviation of 3.

4.1.1. Orthographic Learning Task: Error Analysis

Table 4.2 provides the total number of errors each participant made on the orthographic choice task at both Time 1 and Time 2. Most participants (4/5) made less errors at Time 2 (three days after encountering the new words) compared to Time 1. For example, participant 003 made 14 errors at Time 1 and only 3 errors in Time 2. Of the errors made at Time 1, an average of 46.67% were the homophonic foil and 53.34% were one of the two letter substitution foils. Of the errors made at Time 2, 52.38% were the homophonic foil and 47.62 % were one of the two letter substitution foils.

Table 4. 1 Means, Standard Deviations, Ranges, and Each Participant's performance for All Measures at Time 1 and 2

Task	Participant						
	001	002	003	004	005	Range	Mean (SD)
Novel Word Reading – Orthographic Learning Task (% correct)	100	100	100	100	100	100–100	100 (0)
Orthographic Learning – Spelling Time 1 (% correct)	75	63	56	47	72	47 – 75	63 (11)
Orthographic Learning – Spelling Time 2 (% correct)	88	53	91	63	75	53 – 91	74 (16)
Orthographic Learning – Semantics Time 1 (% correct)	41	47	53	50	50	41 – 53	48 (5)
Orthographic Learning – Semantics Time 2 (% correct)	47	56	44	53	38	38 – 56	48 (8)
TOWRE – SWE Scaled Score	130	130	110	124	100	100–130	118.8 (13.31)
TOWRE – PDE Scaled Score	104	123	104	106	118	104–123	111 (8.89)
PPVT Standard Score	119	123	98	111	117	98–123	113.6 (9.74)
CTOPP Nonword Repetition Scaled Score	9	3	6	6	10	3–10	6.8 (2.78)
WRAT Spelling Standard Score	128	121	108	106	128	106–128	118.2 (10.64)

NOTES: TOWRE – SWE (Test of Word Reading Efficiency _ Sight Word Efficiency); TOWRE – PDE (Test of Word Reading Efficiency _ Phonemic Decoding Efficiency); PPVT (Peabody Picture Vocabulary Test); CTOPP (Comprehension Test of Phonological Processing); WRAT (Wide Range Achievement Test)

Table 4. 2 Error Analysis – Orthographic Learning Task

	Time 1			Time 2		
Participant	Total Errors	Homophone Choice	Letter Substitution Choice	Total Errors	Homophone Choice	Letter Substitution Choice
001	8	3	5	4	3	1
002	12	5	7	15	5	10
003	14	9	5	3	3	0
004	17	5	12	12	5	7
005	9	6	3	8	6	2
Total	60	28	32	42	22	20
Mean Percentage of Errors		46.67%	53.34%		52.38%	47.62%

4.2. What are the sources of individual differences in university student's orthographic learning?

Logistic regression was used to evaluate potential sources of individual differences. Specifically, the potential relation between orthographic learning and phonological short-term memory, word reading ability, spelling and receptive vocabulary was investigated. If I had conducted this analysis with the intended sample size, I would have checked for issues of collinearity by presenting a table of bivariate correlations. The limited sample size in this study, however, makes it unreasonable to conduct this many comparisons, even if a non-parametric test (e.g., Spearman) was selected. Accordingly, I opted to evaluate the relations strictly through logistic regression. To do this, I created several logistic regression models. As mentioned, the logistic regression allows for the investigation of relations at the level of the item rather than participants. Hierarchical logistic regression was used to evaluate the contribution of students' phonological short-term memory to their orthographic learning. The number of correct responses on the orthographic choice task was the dependent variable. The independent variables were nonword repetition (CTOPP), phonemic decoding (TOWRE), receptive vocabulary (PPVT) and spelling (WRAT). As detailed in the analysis plan in Chapter 3, at step 1, the TOWRE, PPVT and WRAT scores were entered into the model. At step 2, CTOPP scores were added to the model. These results are presented in Table 4.3 below.

Table 4. 3 Logistic Regression Between Orthographic Choice Task at Time 1 and WRAT, TOWRE (PDE), PPVT Raw Scores

Step 1				
	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-2.31775	7.32384	-0.316	0.752
WRAT Spelling Raw	0.19526	0.07861	2.484	0.013 *
TOWRE PDE Raw	-0.01612	0.05281	-0.305	0.760
PPVT Raw	-0.02692	0.04107	-0.656	0.512
Step 2				
(Intercept)	-1.73484	7.68442	-0.226	0.8214
WRAT Spelling Raw	0.21468	0.10946	1.961	0.0499 *
TOWRE PDE Raw	-0.02511	0.06342	-0.396	0.6921
PPVT Raw	-0.03015	0.04297	-0.702	0.4829
NWR Raw	-0.01975	0.07715	-0.256	0.7979

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

This indicates that the participants who were good spellers, were more accurate at selecting the correct orthographic choice on the orthographic learning task. The other control variables did not significantly contribute to the orthographic learning. Step 2 illustrates that after controlling for spelling ability, reading ability and vocabulary size, nonword repetition ability was not related to the participants' performance on the orthographic choice task at Time 1.

Given the limited sample size, an additional inspection of the results was conducted. In this case, a regression model was created with only nonword repetition as the independent variable. As Table 4.4 shows, nonword repetition was not related to orthographic learning at Time 1.

Table 4. 4 Logistic Regression Between Orthographic Choice Task at Time 1 and NWR Raw Scores

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-0.58555	0.83854	-0.698	0.485
NWR Raw	0.06802	0.05126	1.327	0.185

The same method for logistic regression was carried out to investigate the sources of individual differences in university students' retention of the orthographic forms, three days following reading the texts. Table 4.5 presents the relationship between orthographic choice task

at Time 2 and the scores on the WRAT, TOWRE (PDE) and PPVT. At this time point, spelling ability was significantly and positively related with orthographic learning at Time 2, $p = 0.02$. This means that the participants who scored higher on spelling the real words (WRAT), scored higher on orthographic choice task at Time 2. Vocabulary size was found to be significantly but negatively related to performance on the orthographic learning task ($p = 0.02$), suggesting that those participants with lower performance on the receptive vocabulary measure had greater accuracy on the orthographic choice task. There was a trend towards participants' phonological decoding abilities being related, but negatively, with their performance on the orthographic choice task, but this relation failed to reach significance ($p = 0.07$). Table 4.5 shows that after controlling for other variables, nonword repetition was not a significant predictor of orthographic learning.

Table 4. 5 Logistic Regression Between Orthographic Choice Task at Time 2 and WRAT, TOWRE (PDE), PPVT Raw Scores

Step 1				
	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	26.01002	10.57275	2.460	0.0139 *
WRAT Spelling Raw	0.21611	0.09031	2.393	0.0167 *
TOWRE PDE Raw	-0.11296	0.06182	-1.827	0.0677 .
PPVT Raw	-0.13049	0.05367	-2.432	0.0150 *
Step 2				
(Intercept)	28.61288	12.09466	2.366	0.0180 *
WRAT Spelling Raw	0.26289	0.12667	2.075	0.0379 *
TOWRE PDE Raw	-0.13612	0.07620	-1.786	0.0740 .
PPVT Raw	-0.14334	0.06035	-2.375	0.0176 *
NWR Raw	-0.04502	0.08422	-0.535	0.5930

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Interestingly, in the absence of controls, nonword repetition was found to be significantly related to performance on the orthographic choice task at Time 2. Table 4.6 illustrates this significant relation.

Table 4. 6 Logistic Regression Between Orthographic Choice Task at Time 2 and NWR Raw Scores

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-1.08664	0.90244	-1.204	0.2285
NWR Raw	0.13341	0.05668	2.354	0.0186 *

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

5. Discussion

In this thesis, I examined orthographic learning via the self-teaching hypothesis (Share, 1995) in university students who were native speakers of English. I was specifically interested in evaluating the influence of learning individual differences in phonological short-term memory on learning the orthographic forms of newly encountered words. In a method adapted from previous research (e.g., Cunningham et al., 2002; Share, 1999, 2004), undergraduate university students read sixteen short stories containing invented words. They then completed an orthographic choice task and semantic choice task immediately after the learning and 3 days later. I found clear evidence of orthographic learning at both time points. At Time 1, the mean raw score for the orthographic choice task was 63% (*sd* = 11%, *range* = 47% – 75%). At Time 2, the occurrence of orthographic learning was even more evident. The mean raw score for the orthographic choice task at Time 2 was 74% (*sd* = 16%, *range* = 53% – 91%). This shows that university students do learn the orthography of newly encountered words through independent reading. I then examined the influence of individual differences in phonological short-term memory, spelling, vocabulary and phonological decoding on the extent of orthographic learning for these newly encountered invented words. Using hierarchical logistic regression, I found that at Time 1, participants' spelling scores were significantly related to their orthographic choice scores, but that there was no significant relation between phonological short-term memory and orthographic learning scores. At Time 2, I found that participants' spelling ability was positively associated with their orthographic learning but surprisingly that their vocabulary scores were negatively related to their orthographic learning. Participants' phonological short-term memory was found to be positively and significantly related to their performance on the orthographic

choice task at Time 2. However, this significance was only observed in the absence of other control variables.

In answer to my first research question about the extent of orthographic learning demonstrated by university students during independent reading, I found that participants' mean raw score at the orthographic choice task at Time 1 and Time 2 was 63% and 74% respectively. Chance for this task was 25%. These results indicate the occurrence of orthographic learning at both times. This high accuracy in the the orthographic choice tasks across two times shows that university students not only learn the orthography of new words they encounter solely through reading, but they also retain the information they learned over time. This finding converges with those from previous research investigating the orthographic learning both in children (e.g., Cunningham et al., 2002; Manis, 1985; Share, 1999) and adult, skilled readers (e.g., Brooks, 1977).

Another factor worth considering is the type of errors the participants made on the orthographic choice tasks. In general, participants made less errors at Time 2 (three day after story reading phase) than Time 1. It is interesting to mention that many of the errors involved choosing the homophonic foil of the target spelling (e.g., renoke instead of renoak). That is, 46.67% of the errors at Time 1 and 52.38% of the errors at Time 2 were the homophonic foil. Notably, the homophonic foils have the exact pronunciation (phonological form) as the target spellings. The other two foils on the task included letter substitution; that is, spellings have different phonological forms. In interpreting the percentage of errors that were the homophonic foil, it is important to note that there were two letter substitution foils versus one homophonic foil on the orthographic choice task. Statistically, if the participants were selecting the spellings by chance, they were more likely to make the letter substitution errors because they comprised

half the choices whereas homophone choice was one fourth of the choices. As such, I interpret their selection of the homophonic spellings as evidence that participants remembered the phonemes (sound) of the novel words, even if they did not correctly recall the orthographic form in these instances. This is consistent with the earlier findings which claim word learning is accompanied by learning the sound of the new words (Brady & Shankweiler, 1991; Byrne, 1998; Goswami & Bryant, 1990; Share, 1995). According to previous research, word learning process involves the mapping between phoneme and grapheme correspondence (e.g., Ehri, 1992; Share 1995, 1999). When someone reads a word aloud, part of learning the written form is mapping it through their phonology. If it penetrates into their phonology and they remember how the word sounds, it is possible that in some instances they could remap it to the homophonic orthographic form when they encounter it again. This error analysis thus provides an indication that learning the phonological forms of novel words play a role in the orthographic learning of university students when they read texts on their own.

The role of the phonological form in orthographic learning that was found in this study aligns with previous research with children. Share (1999) collected empirical evidence for the direct influence of phonological decoding on children's orthographic learning through four experiments. Chalmers and Burt (2008) reported the influence of phonological information on the spelling recognition test in early stages of the acquisition of novel words in adults. It is noteworthy that in Share's (1999) study the impact of phonological decoding on orthographic learning was well captured by the fortuitous mispronunciation made by the participants. In his study, when children mispronounced a nonword in the story reading phase, they selected the spellings which matched their own mispronunciation in the orthographic choice task, consistent with the self-teaching hypothesis expectation. In my study, when participants were reading the

stories aloud, there was no instance in which they mispronounced the target strings, and as such, I cannot test the relation to phonology in the same way. I speculate that the homophonic foils provide an alternative window into this phenomenon.

To address my second research question, about the sources of individual differences in phonological short-term memory, word reading ability, spelling and receptive vocabulary and their relation to individual differences in orthographic learning, I first consider the relation between orthographic learning and phonological short-term memory. A potential relation was hypothesized between these skills because orthographic learning refers to learning the orthographic form of newly learned words and according to self-teaching hypothesis, phonology (via the process of grapheme-to-phoneme translation) plays a decisive role in orthographic learning. In the case of these invented words, the phonological form is not yet known, but it is plausible that skills used to learn the phonological form of newly encountered words would then be relevant for understanding orthographic learning. One such skill is phonological short-term memory (Gathercole, 2006).

Results from the immediate orthographic choice task (at Time 1) suggest that university student's phonological short-term memory does not influence the extent to which they learn the orthographic form of newly encountered words. Undoubtedly, there is a sample size issue in the current study and therefore, the robustness of these findings is questionable. Certainly, additional studies with a larger sample are required. The evaluation of the nonword repetition abilities and their impact on learning of the orthographic forms of novel words at Time 2 (3 days after story reading phase) brought the same result as Time 1. That is, there was no evidence of the influence of phonological short-term memory on university students' orthographic learning, after controlling for spelling, vocabulary and phonological decoding. However, additional inspection

of the results was carried out at Time 2. Without these controls, nonword repetition scores were found to be significantly related to students' performance on the orthographic choice task. Unlike the Time 1 results, this result is consistent with the hypothesized relation based on the complex process, described above, of learning the new form of words involves both phonemes and graphemes (e.g., Chalmers & Burt, 2008; Gathercole, 2006; Gupta, 2003; Share, 1999). This suggests that with a larger sample size it might be found that students who have better phonological short-term memory are better at retaining the spelling of the novel words they encounter through reading.

Despite my speculation that a larger sample size might lead to the hypothesized results, at this point, particularly in the presence of other controls, I did not find that better phonological STM performance was related to improved orthographic learning among these 5 students. If, in contrast to my above speculation, these null results replicate across a larger sample, it would instead suggest that learning the orthographic form of newly encountered words through text and the ability to remember the phonological form of newly heard words (phonological STM) are disconnected from each other in adult proficient readers. Existing evidence on this point is mixed, with some studies reporting a relation between nonword repetition and word learning and other failing to find such a relation (Gupta, 2003; Service & Clarke 2003). As such, it is plausible that the null results found in this study between nonword repetition performance and orthographic learning may replicate in a larger study. That is, if nonword repetition is not related to word learning generally (Service & Clarke, 2003), maybe it is not surprising that nonword repetition and orthographic learning were not related in my study as well. Nevertheless, given that Gupta (2003) found a relation between nonword repetition scores and word learning and given that a relation was found between phonological STM and orthographic learning at Time 2

(without controls), it is possible that a study with a larger sample size would find a relation between these skills. In the end, more research is needed to detail the potentially supportive role of phonological STM in university students' orthographic learning.

In addition to considering the relation between phonological short-term memory and orthographic learning, I also considered the extent to which other skills that have been implicated in the orthographic learning of children might also be related to orthographic learning in university students. Specifically, I also considered the role of spelling ability, vocabulary and phonological decoding. Of these variables, only spelling was consistently related to orthographic learning at both Time 1 and Time 2. That is, participants who obtained higher scores on the standardized measure of spelling were more accurate on the orthographic choice task. One of the central premises of Share (1995) is that if someone is a skilled speller of a language (which indicates the depth of knowledge of the orthographic patterns of that language), s/he fares well in learning the orthographic form of new words. My finding support Share's (1995) finding with children and extend these finding to a beyond childhood to university students. In sum, it seems that university students draw on their prior orthographic knowledge (spelling abilities) in their acquisition of novel orthographic forms.

To further understand orthographic learning in university students, I also examined the impact of students' receptive vocabulary on their performance in orthographic choice task. Contrary to the relation reported in studies with children (Nation & Snowling, 1998a), a negative association between vocabulary scores and students' orthographic learning was observed at both Time 1 and Time 2, with this negative relation reaching significance at Time 2. This means that students who had lower scores on the standardized measure of vocabulary, performed better on the orthographic choice task of the spelling of novel words. The negative relation was

unexpected. Given that research that has suggested a positive or null relation, I interpret this as fortuitous consequence of the small sample size. Further research is necessary to examine the relation between vocabulary size and orthographic learning in proficient readers.

The final source of individual difference which was researched for its potential effect on students' orthographic learning was the phonological decoding abilities. The results indicated a negative relationship between phonological decoding skills and the participants' scores on orthographic choice tasks at both times. Although this relation failed to reach significance, given the *p*-value was .07, it is worth commenting on the negative relationship. The rich body of literature which suggest a positive association (e.g., Cunningham et al., 2002; Share, 1995, 1999, 2004), make this finding unanticipated as well. My finding diverges from what we expect given Share (1995) explanation of orthographic learning through self-teaching hypothesis. However, one plausible point worth mentioning is that past studies have investigated the link between phonological decoding skills and orthographic learning in relation to children who are developing reading skills. In the case of children, those who are better readers are also better orthographic learners. In current study, I measured phonemic decoding in proficient readers. The particular standardized measure (TOWER_PDE) that I used is a timed task. Thus, the students who obtained higher scores on this measure, read more quickly. I speculate that reading quickly may not allow the reader to pause and evaluate the items carefully compared to someone who reads at a slightly reduced pace. Perhaps, there is a point where one reads too quickly to fully facilitate orthographic learning. This might explain the negative association. Such an explanation, however, only needs to be evaluated if this relationship holds with a larger sample size. As was the case with vocabulary, I suspect the more likely explanation is instead that is also

fortuitous consequence of the small sample size. I hypothesize that the negative relationship would vanish with more research and more reliable sample size.

The findings of my thesis advance our theoretical understanding of university students' orthographic learning process in two key ways. First, these data provide further support for Share's (1995) self-teaching hypothesis which ascribes a central role for phonological decoding ability and prior orthographic knowledge in children's orthographic learning. Further, through the error analysis, these data suggest that even among proficient readers, the word's phonology facilitates orthographic learning even for words that are first encountered through text. As mentioned, homophonic foils in the orthographic choice tasks had the exact same phonological form (pronunciation) as the target words (e.g., renoke and renoak). What does choosing a homophonic spelling meant? I argue that this is an indication of learning the phonological forms of newly encountered word but remapping them back the wrong spellings when tested. For instance, participant 001 made 3 homophonic spelling errors and only 1 letter substitution error and participant 003 made 3 and 0 errors respectively at Time 2. In my view, this indicates that (1) these students have learned the phonological forms of these words and (2) this learning has considerably influenced the selection of the orthographic forms. Second, these results extend Share's model − which was originally proposed for beginning word readers − to university students who are skilled readers. Therefore, I speculate that university students also take advantage of the self-teaching hypothesis to learn new words through texts, that is, through mapping to the phonological form of words they self-teach when they read texts on their own and with no support.

An additional contribution of my thesis is bridging two independent lines of inquiry. The triangle model (Seidenberg & McClelland, 1989) suggests that vocabulary acquisition requires

learning both the orthographic and phonological forms of words. Above I have outlined how these data suggest that both forms are potentially being learned through independent reading. An additional contribution of this thesis is to consider the extent to which phonological STM, which has been suggested as a key mechanism underlying the acquisition of phonological forms (Gathercole, 2006), might support the acquisition of the orthographic form as well. This thesis is a first step in empirically evaluating the potential role of phonological STM in orthographic learning and the results suggest that it possible that phonological STM contributes to remembering the orthographic forms of new words in the long term. I make this speculation on the basis of the data from Time 2 which suggest a possible influence of phonological STM in the university students' orthographic learning. However, as this result failed to remain significant in the presence of control variables, future research continues to be needed.

The results of this study need to be taken into the context of certain methodological decisions such as sample size. One of the major limitations of this study was the small sample size that arose because data collection was disrupted when lock down measures were put in place because of COVID-19. I made every possible endeavor to expand my sample size, including adapting my study to an online format. Unfortunately, no participants volunteered for the online version of my study. Nevertheless, the small sample size provides clear indication of what might prove fruitful for future research, particularly in regards to exploring the impact of phonological short-term memory on orthographic learning in university students, a trend for which initial indications were observed in my study at Time 2. This suggests that more explorations with larger sample sizes are required to advance our understanding of the impact of phonological STM on university students' orthographic learning. It may also be fruitful to investigate the effect of semantic information on students' orthographic learning. As explained in Chapter 2,

there is no consensus on the role of semantic information on orthographic learning with some researchers emphasizing the influence of such information (e.g. Balota et al., 2004; Laing & Hulme, 1999; Strain et al., 1995) and others doubting this contribution (e.g., Cunningham, 2006; McKague et al., 2001; Nation et al., 2007).

6. Conclusion

In summary, the current thesis has begun to illustrate the nature of university students' orthographic learning. The results of this thesis not only provide further support for Share's (1995) self-teaching hypothesis, but extend this orthographic learning model to a different population. Although my findings demonstrate clear evidence of orthographic learning via self-teaching hypothesis in skilled readers (university students), they failed to clearly address the influence of phonological STM on learning the orthographic forms of newly encountered words. It is of crucial importance to understand the university students' orthographic learning process. It is also important to decipher the pattern by which they learn novel words through texts because university students, despite being fluent and skilled readers, need to deal with many new words especially discipline-specific jargons and students' success is tied to the successful acquisition of these vocabularies (Corson, 1997; Garcia, 1991; Snow & Kim, 2007; Nagy & Townsend, 2012). This thesis offers an important first attempt to connect the two language learning domains (spoken and written) which traditionally have been researched independently from each other. Further investigation of the potential contributions of university students' spoken language abilities and strengths to their orthographic learning merits further research.

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Appendix A: List of invented words in the orthographic learning task

Words from the orthographic learning task:

rejope	redurp	repabe	reglere
pefeap	peroop	pelurg	pesirt
revaif	remerl	retude	renoak
pezewl	peweef	peklig	pecreb

"Roots" that were included in the orthographic choice task:

jope	durp	pabe	glere
feap	roop	lurg	sirt
vaif	merl	tude	noak
zewl	weef	klig	creb

The original orthographic learning task (Mimeau et al., under review) was designed to determine if morphology can assist with orthographic learning, but this manipulation goes beyond the scope of this study. The invented words were either in the orthographic complex condition (e.g., peroop) or morphologically complex condition (e.g., rejope). It is important to mention that I analyzed morphologically complex and orthographically complex words together because the analysis revealed that they did not statistically impact accuracy and given the small sample size, I wanted to reduce the number of variables in my model.