

NO INFLUENCE OF ARTICULATORY SUPPRESSION ON THE WORD AND
PSEUDOWORD SUPERIORITY EFFECTS

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ABSTRACT

In this study, we explored the role of phonological recoding in word and pseudoword superiority effects, previously characterized as pure orthographic effects. Participants were asked to identify letters embedded in briefly presented words, pseudowords, and nonwords, with and without concurrent articulatory suppression. This manipulation had the purpose of occupying the participants' phonological loop and interfering with the phonological recoding of stimuli in working memory. We predicted that the presence of articulatory suppression would lower accuracy across stimuli, and that this decrease would be more dramatic for pseudowords if participants relied on phonological recoding to perform the task. Word and pseudoword effects were present in both conditions; furthermore, articulatory suppression caused a similar decrease in accuracy for the three types of stimuli. Therefore, word and pseudoword superiority effects were not affected by the lack of phonological recoding. These results suggest that these effects mainly reflect orthographic processing.

INTRODUCTION

The purpose of this study was to evaluate the contribution of phonology in the Reicher-Wheeler task. Recent research by Grainger and colleagues (Grainger, Bouttevin, Truc, Bastien, & Ziegler, 2003) has prompted a closer look at this task, its underlying processes, and the results. First, we addressed the Reicher-Wheeler task and the measures involved (word and pseudoword superiority effects); next, we discussed the role of phonology in reading; and finally, the issue of how we assessed the role of phonology on orthographic measures was addressed.

Research over the past 50 years has shown that during reading, words are identified through a series of steps (or stages) that, in expert readers, take place automatically, that is, proceed without voluntary control and do not require capacity or processing resources (La Berge, 1981; Logan, 1992; Posner & Snyder, 1975). Letter strings are first analyzed in terms of physical features and segments (the basic lines that make up the letters); then, single letters are identified and assigned a position; next, letter combinations are identified; and finally, letter strings are matched with lexical entries within our mental lexicon (Besner, Smith, & MacLeod, 1990). Therefore, we first process strings of letters based on the orthography of our language. Then, we access the lexical entry counterpart to the word, its meaning and sound.

There have been some attempts in devising experimental paradigms that allow us to isolate these cognitive processes. Here, we concentrate on what is now known as the Reicher-Wheeler paradigm (Reicher, 1969; Wheeler, 1970). Reicher and Wheeler (Reicher, 1969; Wheeler, 1970) explored the perception of letters in isolation (e.g., DXXX) and letters in context (e.g., DARK) in an attempt to understand the mechanisms involved in letter recognition. In their paradigm, a string of letters (word, pseudoword, or nonword) is presented briefly and then masked. Participants are then asked to identify which of two subsequently presented letters appeared in the initial stimulus in a given position. By using this paradigm, Reicher (1969) and Wheeler (1970) showed that letter

identification is contextual: it is optimal when letters are embedded in an orthographic context, compared to when they are presented in isolation or in letter strings that are orthographically illegal.

Word and Pseudoword Superiority Effects

In experiments using tachistoscopic presentation of stimuli and the Reicher-Wheeler task, participants are more accurate at identifying letters embedded in words than letters presented alone or letters embedded in scrambled words (Baron, 1974; Reicher, 1969). This effect has been named the Word Superiority Effect (WSE) by Reicher (1969). Accuracy in letter identification has also been observed to be higher with words than pronounceable nonwords (or pseudowords, e.g., *lape*; Grainger et al., 2003; Grossi, Murphy, & Boggan, in press; McClelland, 1976), although Baron and Thurston (1973) found that participants performed just as well whether the target letter was part of a pronounceable nonword or part of a word. These effects were later isolated and identified as two effects, the WSE and Pseudoword Superiority Effect (PSE). The WSE was redefined as the participant's higher accuracy in identifying letters embedded in words as compared to letters embedded in pseudowords (Grainger et al., 2003; Grainger & Jacobs, 1994; McClelland, 1976). The advantage of pseudowords over unpronounceable, illegal letter strings (or nonwords), was referred to as the Pseudoword Superiority Effect (PSE, Grainger & Jacobs, 1994). This advantage denotes the participant's higher accuracy in identifying letters embedded in pseudowords as compared to letters embedded in illegal nonwords (e.g., *xvdt*).

Word and pseudoword superiority effects have been considered behavioral indices of two different types of familiarity. The WSE is generally explained in terms of familiarity with the word meaning (the association of the word with a semantic representation) and/or the participants' familiarity with the word as a whole (a type of visual familiarity; Grainger et al., 2003; McClelland, 1976). The PSE has been

considered a measure of the familiarity with the orthography of a language, or the specific set of alphabetic symbols and letter combinations that characterize the arrangement of letters into sequences according to specific combinatorial rules of the language (Grainger et al., 2003; Grossi et al., in press; McClelland, 1976). Both familiarity with the meaning and orthography is present in words, while only familiarity with orthography is present in pseudowords. That is, what distinguishes between words and pseudowords is the presence of meaning and familiarity in the WSE. In the PSE, the distinguishing feature is the orthographic familiarity within pseudowords, which is missing in nonwords (Baron, 1974).

The precise mechanisms underlying these two effects are still a matter of discussion. Two theories were proposed by McClelland (1979), and explored by McClelland and Rumelhart (1981), to explain the WSE. They suggested that a letter based model of visual word recognition could capture the WSE. One way to do so is by the activation of word units, which can then be broken down to the letter levels of representation. In other words, the activation of word units also reinforces the letters within those words, leading to more accurate letter perception and recall (Grainger et al., 2003). This is not possible for pseudowords (unless the pseudoword is already familiar) as pseudowords are unfamiliar, and, therefore, unrecognizable as word units. Another theory proposed that these effects relied on the cascaded nature of activation and the flow in the interactive activation networks (McClelland, 1979). The theory of cascaded activation purports that activation at lower levels of representation occurs slower than at higher levels. Both theories seem to be counterintuitive when considering the left-to-right, individual letter reading strategy of novice readers (especially when learning to read- the process of sounding out letters and letter combinations in particular comes to mind). However, the perception of the word as a whole can provide information about the letters it contains before the information regarding letters is actually available.

The Role of Phonology in Reading

The above-mentioned studies started to clarify the role that orthography plays in reading. However, it was soon revealed that orthographic and phonological processes are intimately related (McClelland, 1976; Baron & Thurston, 1973). In most models, they are seen as separate, yet highly related and interacting, processes. Therefore, another factor that could facilitate performance on words and pseudowords, compared to nonwords, is the presence of phonology. While performing the Reicher-Wheeler task, participants could sound out the stimuli; these attempts would be successful with words and pseudowords, which consist of pronounceable letter strings, but not with nonwords. Therefore, phonology could be partially responsible for the PSE (though not for the WSE, given that a phonological structure is present in both words and pseudowords). Indeed, the original explanation of the higher accuracy for words and pseudowords compared to nonwords offered by Baron and Thurston (1973) was in terms of pronounceability.

Research has shown that phonology plays an important part in reading (Abramson & Goldinger, 1997; Baddeley, Eldridge, & Lewis, 1981). For example, phonological decoding, a slow and sequential process by which graphemes are mapped onto their corresponding phonemes, is a critical tool in reading development (Alario, De Cara, & Ziegler, 2007). Phonological decoding is central to reading acquisition because it provides a self-teaching device that allows children to decode novel words (Ziegler and Goswami, 2005). Research has also shown that readers rely more on phonological decoding when processing new written material as opposed to orthographic processing for familiar words. For example, Papagno and Vallar (1992) conducted a series of experiments investigating the role of the phonological short-term store and the rehearsal process in learning phonologically similar novel words and pseudowords. Their results indicated that both the phonological short-term store and the rehearsal subcomponents of

verbal short-term memory are involved in learning novel words. For instance, in one experiment, researchers studied “paired associate learning” of phonologically similar and dissimilar word and pseudoword items. The phonologically dissimilar items were recalled more accurately than similar ones, indicating that the phonologically similar items interfered with each other. Also, in a second experiment, a digit span task was completed between the presentation and recall of phonologically similar and dissimilar items; the phonological similarity effect was observed, showing that phonological short term memory is involved in pseudoword learning. Pseudowords could conceivably be novel words when simply considering their orthographic structure. Therefore, pseudowords are more likely to be processed phonologically than real, known words (which can be processed semantically) and nonwords, for which a phonological representation is not available (Papagno & Vallar, 1992).

Research on both adults and children has also shown that pronounceable letter strings automatically activate a phonological representation. For example, Ferrand and Grainger (1992, 1993) showed orthographic and phonological priming effects in a masked priming paradigm with adults. In a study with 6 to 12-year-old readers, Booth and colleagues (Booth, Perfetti, & MacWhinney, 1999) showed orthographic and phonological priming effects despite the fact that primes were presented so briefly that the children were not fully aware of the stimuli. In masked priming experiments, strategic activation of phonological information can be ruled out, given that the prime is presented too briefly to be consciously processed. Therefore, these data suggest that the extraction of phonology from print proceeds automatically, meaning that it is stimulus-driven and can be initiated without deliberate intention (LaBerge, 1981; Logan, 1992; Posner & Snyder, 1975), in both expert and young skilled readers.

In order to determine the role of phonology in the WSE and PSE, Grainger and colleagues tested the presence of these effects in dyslexic children with marked phonological deficits (Grainger et al., 2003). Since dyslexic children show poor

performance in reading pseudowords aloud, they are assumed to have a phonological deficit. This deficit is generally interpreted as the result of processing (or representation) impairment in the sublexical translation of spelling to sound. In the bimodal interactive activation model proposed by Grainger & Ferrand (1996), lexical and sublexical (e.g., letter combinations) processing levels of phonology and orthography are interconnected. The model allows information that is coded orthographically to activate phonological processes within a level. That is, units at the sublexical orthographic level activate units at the sublexical phonologic level and vice versa. Grainger et al. (2003; see also Frith, Wimmer, & Lanferl, 1998) proposed that prelexical mechanisms of orthography-to-phonology conversion might be responsible for the PSE. If so, it is reasonable to predict that the dyslexic children, who show a deficit in reading pseudowords aloud, would show a reduced PSE as compared to a control group of children without reading disabilities. However, the data failed to show significant differences between dyslexic children and control children for the PSE. The authors suggested that dyslexic children have skills at exploiting orthographic regularities in order to produce a similar PSE to control children, yet still have difficulty in reading pseudowords aloud. This result may indicate that 1) the cognitive mechanisms responsible for the PSE are different from the mechanisms involved in spelling to sound conversion, or 2) PSE performance is not mediated by phonology in this population.

Following in the vein of Grainger and colleagues (2003), this study aimed to test the role of phonology in the PSE by engaging participants in the Reicher-Wheeler task while concurrently engaging their phonological loop. To this end, an articulatory suppression paradigm was employed to prevent phonological recoding of the stimuli in working memory. In the next few sections, Baddeley and colleagues' model of working memory is described.

Working Memory

According to the model of working memory formulated by Baddeley and colleagues over the past 40 years (Baddeley, 1990, 2002; Baddeley, Gathercole & Papagno, 1998; Salamé & Baddeley, 1982), incoming information is initially stored in the brain in limited capacity storage systems controlled by the central executive, a set of processes that acts as a limited capacity attentional controller (Baddeley, 2002). The two limited capacity storage systems are the phonological loop, dedicated to processing acoustic and verbal information, and the visuospatial sketchpad, dedicated to processing visual and spatial information (Baddeley & Hitch, 1974; see Figure 1). According to this model, information must be rehearsed within working memory in order to be stored and recalled accurately.

The phonological loop is assumed to comprise two components, an articulatory control process based on inner speech, and a phonological store that is capable of holding speech-based information (Gathercole & Baddeley, 1993; see Figure 2). Material within the phonological store will start to decay within 2 seconds unless it is refreshed via articulatory rehearsal. The articulatory control process is also capable of converting written material into a phonological representation, registering, and preserving it in the phonological store (Baddeley, 1990; Salamé & Baddeley, 1982). The phonological store relies heavily on articulatory rehearsal, for without it, information will decay in the phonological store and will be lost (Baddeley, 2002). The phonological loop seems to have many purposes; however, according to Baddeley and colleagues (Baddeley et al., 1998), the primary purpose of the phonological loop is assistance in learning new words.

Several studies have been found to support Baddeley's model of working memory. Experimental manipulations employed to test this model include phonological similarity, irrelevant speech, word length, and articulatory suppression (Baddeley, 1990).

Each manipulation taxes the phonological loop in a different way. For the purpose of the present study, we only focused on articulatory suppression, also known as concurrent articulation. In tasks using articulatory suppression, participants are asked to repeat irrelevant material while viewing material that is to be remembered. Participants are less accurate in recalling information when they engage in articulation of an irrelevant sound (or irrelevant words) while performing a task compared to when they do not engage in articulatory suppression. This effect, named the articulatory suppression effect (Baddeley, 1986), has been observed with both auditory and visual presentation of stimuli.

The articulatory suppression technique appears to be the favored technique when studying the role of phonology in reading. If suppression interferes with the reading task, it is assumed that the phonological processing is being interrupted, which would imply that the phonological processes are normally being used during reading (Baddeley, 1979; Baron, 1977; Barron & Baron, 1977; Besner & Davelaar, 1982; Kleiman, 1975). Within this model of working memory, articulatory suppression is assumed to block both subvocal rehearsal and the phonological encoding of visually presented material, and will therefore interfere with recall of information temporarily stored in the phonological store. Baddeley and colleagues (Baddeley, Thomson, & Buchanan, 1975) suggest that the suppression serves to prevent visual information from being translated into a phonemic code. Indeed, previous research has shown that articulatory suppression impairs memory performance (Larsen & Baddeley, 2003). In their study, Larsen and Baddeley (2003) tested several techniques (i.e., articulatory suppression, and others) purported to impact performance on serial recall of strings of phonologically similar and dissimilar letters. Articulatory suppression was the most successful at causing a substantial degree of impairment across all three experiments. In this study, articulatory suppression was employed to prevent the subvocal rehearsal process from creating a phonological representation of the tachistoscopically presented written stimuli.

The Present Study

To our knowledge, Articulatory Suppression had not been previously used as a concurrent task to clarify the nature of the processes at work in the Reicher-Wheeler paradigm. Previous research on Articulatory Suppression has focused on learning and word recognition (Baddeley, 1979; Besner, 1987; Gupta & MacWhinney, 1995; Tenjovic & Lalovic, 2005), while in this study, we focused on Letter Identification in different orthographic contexts. Participants were asked to perform a Forced-Choice Letter Identification Task (the Reicher-Wheeler paradigm) in two conditions: With and Without Articulatory Suppression. Based on previous research, we hypothesized that Articulatory Suppression would tax the phonological loop and prevent the Stimuli from being recoded phonologically into working memory. As a consequence, the Stimuli would be preferentially processed based on non-phonological representations (Baddeley et al., 1998; Salamé & Baddeley, 1986). The following predictions were made:

- Prediction 1. Reicher-Wheeler task without Articulatory Suppression (Control Task): Based on previous research, participants were expected to be more accurate in performing the Letter Identification Task with real Words compared to Pseudowords (WSE), and with Pseudowords compared, to Nonwords (PSE).
- Prediction 2. The presence of Articulatory Suppression would lower accuracy across stimuli compared to the Reicher-Wheeler task without Articulatory Suppression (main effect of task). This prediction was justified based on previous work showing that the addition of a secondary task lowers performance on the primary task (Broadbent, 1982; Pashler, 1994). Given that illegal Nonwords are unlikely to be coded phonologically, we considered the decrease in accuracy with Nonwords an estimate of a general interference effect due to the presence of a secondary task.

- Prediction 3. If phonology plays a role in the Reicher-Wheeler task and participants rely on phonological recoding to perform the Letter Identification Task, accuracy should decrease more dramatically for Pseudowords than for Words and Nonwords (interaction between Task and Stimulus; see Figure 3). This prediction was justified based on previous studies showing that Pseudowords are more likely to be processed phonologically than real Words (which, aside from being processed phonologically, can be processed semantically or lexically) and, Nonwords (for which a phonological representation is not available; Papagno & Vallar, 1992). We predict that if phonology does not play a role in the Reicher-Wheeler task, then we would expect Words, Pseudowords, and Nonwords to be equally impacted by Articulatory Suppression (main effect of Task without Task x Stimulus interaction; see Figure 4).

METHOD

Participants

The participants were 27 graduate and undergraduate students from the State University of New York at New Paltz who received partial course credit, or credit towards their major, for taking part in the study. The data of two students were excluded due to incomplete recording by the computer. The students were between 19-29 years of age, with the average age of 21.64 years. There were 17 female and 8 male students, 22 of which were right-handed, 2 left-handed and one ambidextrous. The participants used their dominant hand during the task (the ambidextrous participant used their right hand). All participants were native American-English speakers, and only one participant claimed fluency in another language (Ukrainian). Ten other participants reported having taken foreign languages classes, but indicated that they did not know the language enough to be fluent. Participants were recruited via campus-wide email, the psychology subject pool, advertisements posted around campus and online bulletin boards specific to the SUNY New Paltz student population. It was explained in these postings that students with neurological problems were excluded from the study. There were no participants that admitted dyslexia or any other reading disorder. All participants claimed to have normal or corrected to normal vision.

Stimuli and materials

The stimuli employed in this experiment were similar to the one described in Chase and Tallal (1990) and Rumelhart and McClelland (1982). Words and pseudowords were selected from Chase and Tallal (1990). The 4-letter words were selected based on the Kucera and Francis' database (1967). These words had a written frequency of 12 or more per million (Kucera and Francis, 1967). Words that differed by a single letter position were selected as word pairs. Forty word pairs were chosen, 10 pairs

for each letter position (e.g., DARK-PARK, LOVE-LIVE, LIFE-LIKE, MILE-MILK). The position where each pair differed was referred to as the target position and the letter in that position was referred to as the target letter. In the forced-choice test, the alternatives were the two target letters for each word pair (i.e., D-P for DARK-PARK). Two lists of stimuli were employed. List 1 was comprised of 40 words, 40 pseudowords, and 40 nonwords, while list 2 was comprised of the alternate stimuli (in other words, “DARK” in list 1 was replaced by “PARK” in list 2). The lists of words can be found in Appendix A.

Pseudowords that matched each pair of words were constructed by (most often) changing the letter most distant from the target letter to produce a pronounceable nonword (e.g., DARB-PARB). Some of the pseudowords used in Chase and Tallal (1990) were changed for several reasons: 1. Some are considered real words (e.g. JAIN), names (e.g., CHAN), or words/anagrams used commonly in American-English slang (e.g., YOUS), 2. Some sounded too much like real words (e.g., WORT, DILE), or 3. They are real words in other, familiar, languages (e.g., COMO). In addition, some of the nonwords included in the original list by Chase and Tallal (1990) were changed because they were pronounceable, and were therefore categorized as pseudowords. Nonwords were constructed by substituting consonants for vowels, and rearranging the letters of the corresponding words. Despite these changes, the identity of the target letter remained consistent across stimulus type and letter position.

As a measure of orthographic complexity, bigram frequency values were computed for words and pseudowords through the program N-Watch- a Windows program that provides a broad range of statistics concerning the properties of word and nonword stimuli, including measures of word frequency and orthographic similarity (Davis, 2005). In N-Watch, bigram frequency is defined as the number of times a pair of adjacent letters (a bigram) appears, in the same position, in a same length word. For example, the stimulus edge contains three bigrams (ed, dg, and ge). For the first of these

(ed), the corresponding bigram frequency is based on the number of four-letter words that begin with ed. Therefore, the type frequency for ed is 4. These bigram frequencies were computed on the basis of the COBUILD/CELEX word frequency corpus. An independent sample *t*-test showed that words in list 1 and list 2 did not differ in terms of bigram frequency ($P=.114$); moreover, words and pseudowords within each list were also characterized by similar bigram frequencies ($P=.308$ in list 1 and $P=.67$ in list 2).

In each condition, participants were presented with 40 words, 40 pseudowords, and 40 nonwords, totaling 120 trials for that condition. Participants were run in both conditions, for a total of 240 trials.

Participants' basic demographics (age, gender, language experience) and brief neurological history were taken via a questionnaire. The neurological history was based on two questions within the demographics. The questions were yes or no questions and did not involve the patient divulging personal medical diagnoses or specific history (e.g., "Do you suffer or have you suffered from any neurological disorder or condition including, but not limited to, brain surgery, dyslexia, epilepsy, brain tumor, and schizophrenia?"). In addition, all participants were required to fill out the Edinburgh Assessment of Handedness.

Procedures

Procedures were similar to the ones followed by Chase and Tallal (1990) and Rumelhart and McClelland (1982). After giving informed consent and being randomly assigned to one of the two possible list orders (experimental condition first or control condition first), participants were tested in a sound-attenuating and dimly lit room; they were seated 100 cm directly in front of a 19-inch monitor on which stimuli were presented, such that each stimulus subtended 2.5° of horizontal visual angle and 0.5° of vertical visual angle. A trial began with a fixation point presented for 500 ms, after which the four-letter target string was presented (word, pseudoword, or nonwords) for 33 ms. A

mask, consisting of four pound signs, appeared superimposed on the letter field immediately after the offset of the string presentation for 500 ms, after which the letter choices appeared above and below the target serial position. These letters remained on screen until the participant pressed the appropriate button regarding their letter decision. Participants were asked to perform a forced-choice letter identification task and decide which of the two letters was presented in a given position in the previous stimulus. They made their decision by pressing one of two buttons positioned vertically on a Microsoft Sidewinder joystick, which was connected to the computer monitor (top button for top letter and bottom button for bottom letter). Accuracy was stressed.

Stimulus presentation was controlled by the software Presentation run on a PC in the adjoining room with Windows 2000 operating system. The 4-letter strings appeared as white uppercase letters against a black background and were presented in Courier font.

Each participant was randomly assigned and participated in both conditions: without articulatory suppression (control condition) and with articulatory suppression (experimental condition). The order of presentation was counterbalanced among participants. In the articulatory suppression condition, participants were instructed to repeat the word “two” twice a second along with a ticking metronome. The researcher stood behind the participants during the task and ensured that they complied with the timing of articulation. The researcher (and ticking metronome) was present in the room in the control condition as well, but did not interact with the participants. Within each list, the order of presentation of the stimuli was randomized for each participant. Control and experimental tasks were separated by with a 10-minute break so that participants could rest their eyes and drink some water.

Participants were given 12 practice trials (not included in the lists of stimuli for the actual experiment) before starting the experiment. At the end of the study, they were debriefed and thanked for their participation. The entire experimental session lasted approximately one hour.

RESULTS

A two-way within-subjects analysis of variance was conducted to evaluate the effect of articulating conditions and Stimulus Type on accuracy in the Letter Identification Task. The dependent variable was the mean percentage of correct responses (accuracy) in each condition. The within-subject factors were Task (no task, Articulatory Suppression) and Stimulus type (Word, Pseudoword, Nonwords). Word and Pseudoword superiority effects in the two conditions were assessed by two separate one-way analyses of variance. A summary of the data is presented in Figure 5.

Prediction 1. Based on previous research (Besner, 1987; Chase & Tallal, 1990; Grainger et al., 2003; Grossi et al., in press), it was predicted that WSE and PSE would be present in the control condition (without Articulatory Suppression). Stimulus type was significant as main effect ($F(2,48)=21.01, p<.0001$). Planned comparisons revealed that participants were more accurate with Words ($M=91.90, SD=9.69$), compared to Pseudowords ($M=87.70, SD=10.20$) (WSE, $t(24)=3.83, p=.001$, two-tailed); similarly, participants were more accurate with Pseudowords, compared to Nonwords ($M=82.88, SD=9.20$) (PSE, $t(24)=3.53, p=.002$, two-tailed) in the control condition.

Prediction 2. Based on previous research (Broadbent, 1982; Pashler, 1994), it was predicted that the presence of Articulatory Suppression would lower accuracy across stimuli as compared to the control task (main effect of task). The omnibus ANOVA revealed that task was a significant main effect ($F(1,24)=20.21, p<.0001$): participants were more accurate in the control compared to the experimental task ($M=87.33, SD=8.85$; $M=80.53, SD=11.17$, respectively).

Prediction 3. Task did not interact with Stimulus type ($F(2,48)=.02, p=.978$). The decrease in accuracy due to Articulatory Suppression was similar for the three Stimulus conditions (6.8%, 6%, 6.88% for Words, Pseudowords and Nonwords, respectively). WSE and PSE were also present in the Articulatory Suppression task: Stimulus type was significant as main effect ($F(2,48)=8.70, p=.002$). Planned comparisons revealed that

participants were more accurate with Words ($M=85.10$, $SD=13.02$) compared with Pseudowords ($M=81.70$, $SD=12.31$) (WSE, $t(24)=2.38$, $p=.026$, two-tailed); similarly, participants were more accurate with Pseudowords compared with Nonwords ($M=76.00$, $SD=11.86$) (PSE, $t(24)=3.13$, $p=.005$, two-tailed). These results suggest that phonology does not play a prominent role in the Reicher-Wheeler task.¹

¹ Results did not change significance when left handed and ambidextrous data were removed.

DISCUSSION

Based on the results of our analyses, our first prediction was confirmed: participants were more accurate in performing the Letter Identification Task with real Words as compared to Pseudowords (WSE) and with Pseudowords as compared to Nonwords (PSE). Therefore, our data confirm the robustness of both superiority effects that have been observed across a variety of stimuli and languages (Chase & Tallal, 1990; Grainger et al., 2003; Grossi et al., in press).

Our second prediction, that articulatory suppression, as a secondary task would lower participants' accuracy, compared to the control condition, was also confirmed. This effect replicates previous data (e.g., Broadbent, 1982; Pashler, 1994) showing attentional limitations during the performance of concurrent multiple tasks.

In terms of our third prediction, the decrease in accuracy due to Articulatory Suppression was similar for the three types of stimuli. In fact, numerically speaking, Pseudowords showed the smallest drop in accuracy, an average of 6% as compared to 6.8% and 6.88% for Words and Nonwords, respectively. Given that illegal Nonwords were unlikely to be coded phonologically, we considered the decrease in accuracy with Nonwords an estimate of a general interference effect due to the presence of a secondary task. This effect was similar for the three types of stimuli. Moreover, both WSE and PSE were present in both task conditions. Therefore, the present results suggest that interfering with the phonological recoding of stimuli in the Letter Identification Task does not affect the WSE and the PSE. We conclude that these two effects can be considered indices of familiarity with the Words and the orthography of a language, respectively (Grainger et al., 2003). Future research is needed to clarify what specific mechanisms are responsible for such effects. Although many researchers (e.g., Dehaene, Cohen, Sigman, & Vinckier, 2005; Grainger et al., 2003) propose the PSE, or even both effects, reflect sublexical processes at the level of orthographic representations, there is no agreement on how such processes are cognitively and neurally implemented.

The present data show that Articulatory Suppression decreased the participants' accuracy dramatically with respect to the control task. In line with previous research on the effects of Articulatory Suppression on memory and reading, we attribute this decrease in performance to two sources: the addition of a secondary task (Broadbent, 1982; Pashler, 1994) and the interference with the phonologic recoding of stimuli (Baddeley, 1990). As mentioned, the size of the PSE did not vary with the presence of Articulatory Suppression. Our conclusion that the PSE does not reflect phonological processing can be drawn with confidence only inasmuch as by taxing the phonological loop, we have effectively blocked the phonological recoding process. It is certainly possible that in the present study Pseudowords were not processed phonologically, and that, therefore, Articulatory Suppression did not block any phonological recoding process. This would contrast sharply with data from research employing rapid presentation tasks that show that phonological representation of stimuli are automatically activated during reading (e.g., Booth et al., 1999). Another possibility is that phonological representations are activated but not used to perform the Letter Identification Task. In any case, our results show that even including a task that may have blocked phonological recoding of stimuli, the WSE and PSE did not change in size. Therefore, these effects seem not to reflect phonological processing.

Limitations

There are some limitations in the present study that are worth discussing. As mentioned earlier, while it is clear from previous research that articulatory suppression limits the functionality of working memory in information recall (Baddeley, 1990), this methodology has not been used previously in conjunction with the Reicher-Wheeler task (to our knowledge). Therefore, it is unclear whether the articulatory suppression was successful at occupying the phonological loop and preventing the phonological recoding process. It may have been that the repetition of the word "two" was not enough to engage

the loop or recoding process (though was certainly enough to establish a secondary task effect), or that the timing of the articulatory repetition (as prompted by the metronome) and the timing of phonological recoding were not always overlapping. If this were the case, it is possible that participants were sometimes able to create a phonological representation of the stimuli; in turn, this representation might have helped in performing the letter identification task. A more precise control of participants' articulation should be devised in the future.

Our sample was also quite homogeneous (it predominantly included right-handed females whose ages spanned only 10 years); this can raise external validity issues. However, our findings replicate several other studies on word and Pseudoword superiority effects (e.g., Chase & Tallal, 1990; Grainger et al., 2003; Grossi et al., in press; McClelland, 1976; Grossi, Thierry, Thomas, & Di Pietro, unpublished data), which span a broad spectrum of individuals (children through adults) and several languages (English, French, Italian, Welsh).

Future Research

Data on masked priming suggest that phonological representations can be activated even in the absence of awareness (Reicher, 1969, Wheeler, 1970). Therefore, some phonological processing can take place without a controlled act of articulation (overt or silent). For this reason, future research should investigate different avenues of blocking the phonological recoding process during reading. In a follow-up experiment, we are exploring the effectiveness of phonological interference in occupying the phonological loop during the Reicher-Wheeler task. In the phonological interference condition, participants perform the letter identification task while listening to a story. Phonological interference prevents phonological information purportedly activated by the stimuli from being consolidated in the phonological store (Baddeley, 2002). The interference is created by the competition of the phonological representations with the

story in working memory. If there is automatic phonological recoding of the stimuli during the letter identification task and if this recoding is necessary for the task, then phonological interference should lower participants' performance, especially for stimuli whose processing mostly relies on phonology, such as pseudowords.

These studies are important to establish whether behavioral effects purportedly measuring orthographic processing do partially reflect other types of processes (e.g., phonology). If not, these effects can be used to study a variety of phenomena such as development of orthography in children learning to read and in second language learners.

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Figure Captions

Figure 1.

This diagram (derived from Baddeley & Hitch, 1974) shows working memory as a multiple-component model.

Figure 2.

A representation of the phonological loop model taken from Gathercole and Baddeley (1993).

Figure 3.

Predicted results if performance on the Reicher-Wheeler task relies on the phonological recoding of the stimuli (stronger articulatory suppression effects for pseudowords compared to words and nonwords).

Figure 4.

Predicted results if performance on the Reicher-Wheeler task does not rely on the phonological recoding of the stimuli (the decrease in accuracy due to articulatory suppression is similar across stimuli).

Figure 5.

Accuracy for Words, Pseudowords and Nonwords in the Reicher-Wheeler Letter Identification Task with and without Articulatory Suppression. Standard errors of the means are also displayed.

FIGURE 1

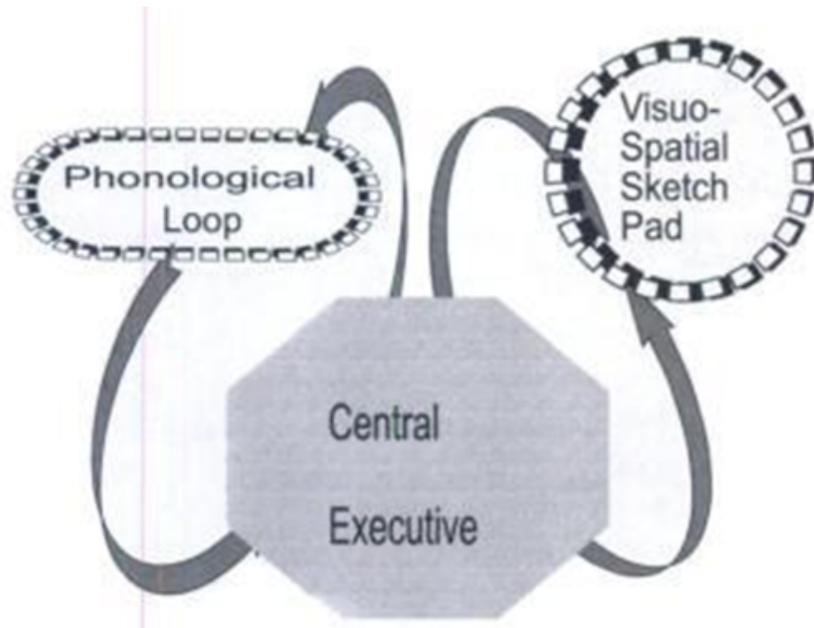


FIGURE 2

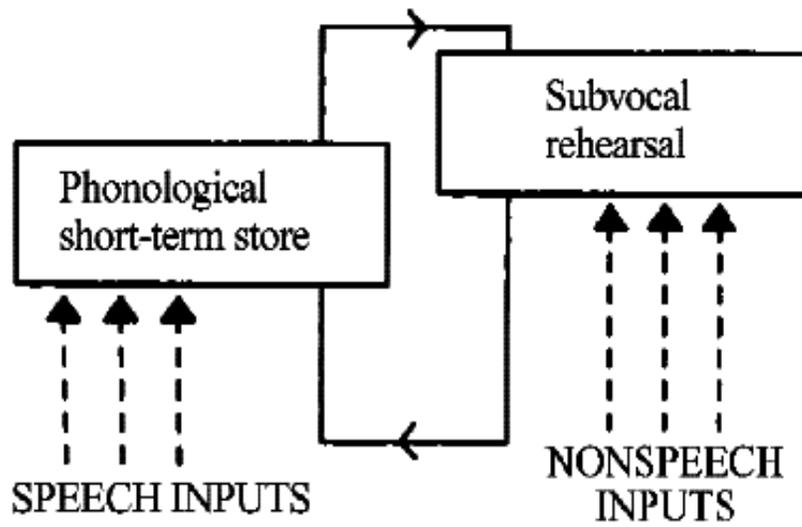


FIGURE 3

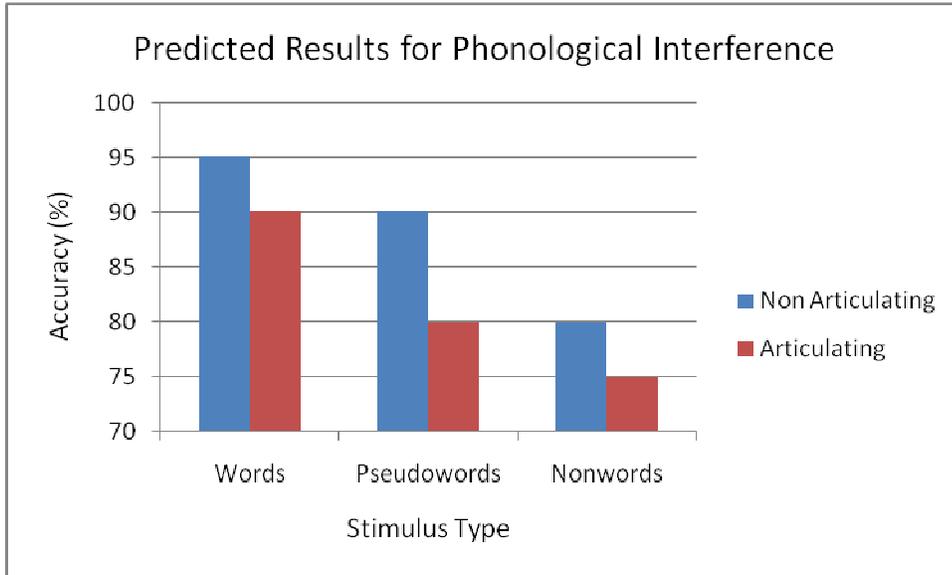


FIGURE 4

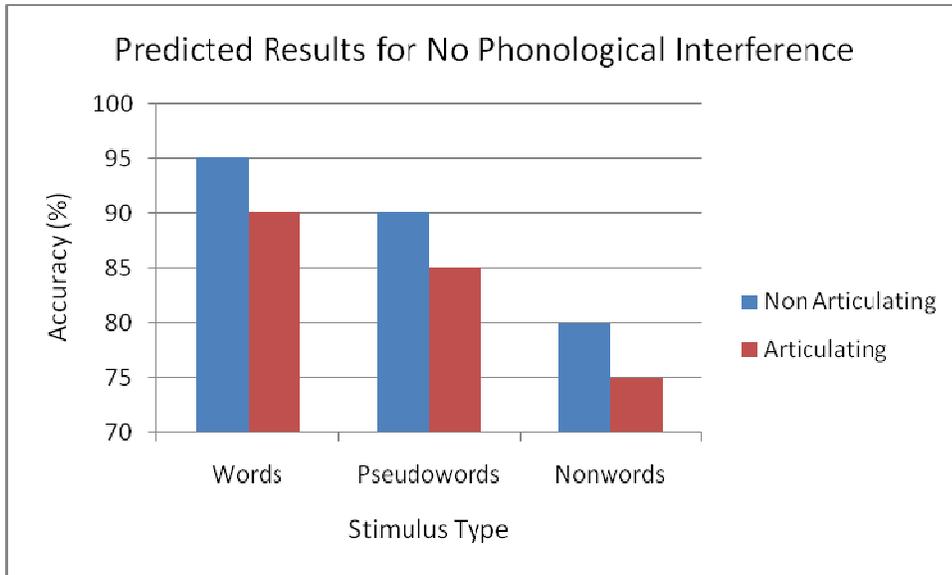
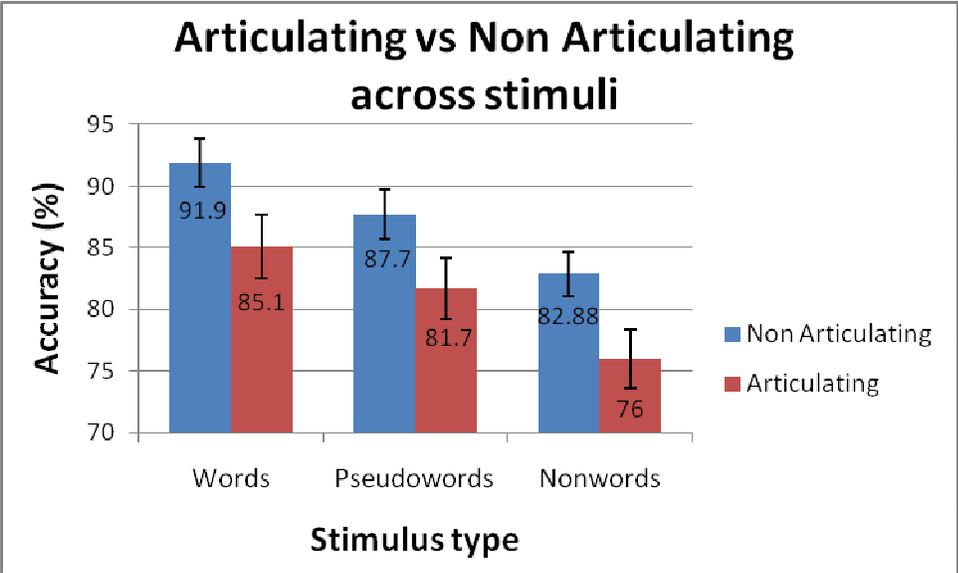


FIGURE 5



Appendix A

Real Words- List 1

<u>Serial 1</u>	<u>Serial 2</u>	<u>Serial 3</u>	<u>Serial 4</u>
DARK	CAME	FEET	BAND
DATE	FALL	FINE	COOL
DEEP	FIRM	HAND	HEAR
FOUR	GAVE	HOME	MAIL
LOOK	HELD	KNEW	MARK
LORD	LIST	LIFE	MILE
MUCH	LOVE	MADE	PAIN
TEST	MASS	MORE	POOL
WERE	MOST	RACE	RICH
WHAT	POST	THEN	WALL

Real Words- List 2

<u>Serial 1</u>	<u>Serial 2</u>	<u>Serial 3</u>	<u>Serial 4</u>
PARK	COME	FELT	BANK
LATE	FULL	FIRE	COOK
KEEP	FORM	HARD	HEAT
YOUR	GIVE	HOPE	MAIN
TOOK	HOLD	KNOW	MARY
WORD	LOST	LIKE	MILK
SUCH	LIVE	MAKE	PAIR
REST	MISS	MOVE	POOR
HERE	MUST	RATE	RICE
THAT	PAST	THAN	WALK

Pseudowords- List 1

DARB	PAME	REET	PAND
DATS	JALL	BINE	SOOL
DEEW	FIRP	MAND	JEAR
FOUT	GARE	BOME	MARL
LOOG	HELf	PNEW	SARK
LORB	BIST	SIFE	JILE
MUCE	LOGE	GADE	PALN
TAST	RASS	JORE	ZOOL
WURE	FOST	TACE	PICH
WHAL	BOST	SHEN	WARL

Pseudowords- List 2

PARB	POME	RELT	PANK
LATS	JULL	BIRE	SOOK
KEEW	FORP	MARD	JEAT
YOUT	GIRE	BOPE	MARN
TOOG	HOLF	PNOW	SARY
WORB	BOST	SIKE	JILK
SUCE	LIGE	GAKE	PALR
RAST	RISS	JOVE	ZOOR
HURE	FUST	TATE	PICE
THAL	BAST	SHAN	WARK

Nonwords- List 1

DRKW	MACZ	FTEG	NBRD
DTVR	FALW	FVND	HCFL
DMKZ	RIFM	HDNJ	JHVR
FTRS	VAGM	BHMT	ZQWL
LHKF	LEHF	WNEK	HRMK
LRDK	TISL	LMFQ	NLME
MCHP	VOLZ	MWDV	BPGN
TSCG	SAFM	MZRK	TPKL
WRVG	SOPM	RMCL	TKPH
WLCH	KOTP	TNEH	WRPL

Nonwords- List 2

PRKW	MOCZ	FTLG	NBRK
LTVR	FULW	FVRD	HCFK
PMKZ	ROFM	HDRJ	JHVT
YTRS	VIGM	BHPT	ZQWN
THKF	LOHF	WNOK	HRMY
WRDK	TOSL	LMKQ	NLMK
SCHP	VILZ	MWKV	BPGR
RSCG	SIFM	MZVL	TPKR
HRVG	SUPM	RMTL	TKPE
TLCH	KATP	TNAH	WRPK