January 2002

Syllable frequency effects on phonological short-term memory tasks

L. M. Nimmo
University of Wollongong

Steven Roodenrys
University of Wollongong, steven@uow.edu.au

Syllable frequency effects on phonological short-term memory tasks

Abstract

Recent evidence suggests that phonological short-term memory (STM) tasks are influenced by both lexical and sublexical factors inherent in the selection and construction of the stimuli to be recalled. This study examined whether long-term memory (LTM) influences STM at a sublexical level by investigating whether the frequency with which one-syllable nonwords occur in polysyllabic words influences recall accuracy on two phonological STM tasks, nonword repetition and serial recall. The results showed that recall accuracy increases when the stimuli to be recalled consist of one-syllable nonwords that occur often in polysyllabic English words. This result is consistent with the notion that LTM facilitates phonological STM at both a lexical and sublexical level. Implications for models of verbal STM are discussed.

Disciplines

Arts and Humanities | Life Sciences | Medicine and Health Sciences | Social and Behavioral Sciences

Publication Details

This paper was originally published as Nimmo, LM and Roodenrys, S, Syllable frequency effects on phonological short-term memory tasks, Applied Psycholinguistics, 23, 2002, 643-659. Copyright Cambridge University Press. Original article available here.

Applied Psycholinguistics **23** (2002), 643–659
Printed in the United States of America
DOI: 10.1017.S0142716402004071

Syllable frequency effects on phonological short-term memory tasks

LISA M. NIMMO and STEVEN ROODENRYS
University of Wollongong

ADDRESS FOR CORRESPONDENCE
Lisa M. Nimmo, Department of Psychology, University of Wollongong, Northfields Avenue, Wollongong 2522, Australia. E-mail: lmn02@uow.edu.au

ABSTRACT
Recent evidence suggests that phonological short-term memory (STM) tasks are influenced by both lexical and sublexical factors inherent in the selection and construction of the stimuli to be recalled. This study examined whether long-term memory (LTM) influences STM at a sublexical level by investigating whether the frequency with which one-syllable nonwords occur in polysyllabic words influences recall accuracy on two phonological STM tasks, nonword repetition and serial recall. The results showed that recall accuracy increases when the stimuli to be recalled consist of one-syllable nonwords that occur often in polysyllabic English words. This result is consistent with the notion that LTM facilitates phonological STM at both a lexical and sublexical level. Implications for models of verbal STM are discussed.

Traditionally, short-term memory (STM) has been defined in relation to long-term memory (LTM). Whereas STM both holds information temporarily and is limited in capacity, LTM is neither limited in capacity nor temporally constrained. Recently, researchers have questioned the influence that LTM may have on phonological STM performance (Baddeley, Gathercole, & Papagno, 1998; Dollaghan, Biber, & Campbell, 1993, 1995; Gathercole, Frankish, Pickering, & Peaker, 1999; Hulme, Maughan, & Brown, 1991; Roodenrys, Hulme, & Brown, 1993). In light of recent evidence suggesting that performance on phonological STM tasks is influenced by phonological information stored in LTM, the current research examines whether the frequency with which one-syllable nonwords occur in polysyllabic English words influences recall accuracy on phonological STM tasks.

One of the most commonly used measures of verbal STM ability is the immediate serial recall (ISR) task. Immediately following the presentation of a sequence of items, a participant is required to recall the items in the correct order.

However, researchers interested in investigating language acquisition in children have used nonword repetition performance as a measure of verbal STM (Gathercole & Baddeley, 1989). When performing a nonword repetition task, participants are required to repeat a multisyllabic nonsense word back to the experimenter immediately after the nonword has been presented. The utility of the nonword repetition task derives from experimental evidence in the areas of reading, language development, and neuropsychology, which shows that individuals who exhibit deficits in performance on nonword repetition tasks also display performance deficits on conventional measures of STM (Baddeley, Papagno, & Vallar, 1988; Baddeley & Wilson, 1993; Bisiacchi, Cipolotti, & Denes, 1989; Gathercole, 1995b; Gathercole & Baddeley, 1990; Gathercole, Willis, Baddeley, & Emslie, 1994; Jorm, 1983; Wagner & Torgesen, 1987). The finding of a relationship between nonword repetition performance and digit span, such that as digit span increases nonword repetition accuracy increases, has also been replicated in numerous studies (e.g., Gathercole & Adams, 1993, 1994; Gathercole, Hitch, Service, & Martin, 1997; Gathercole, Service, Hitch, Adams, & Martin, 1999; Gathercole, Willis, & Baddeley, 1991; Metsala, 1999). Thus, converging evidence suggests that verbal STM abilities can be gauged by employing either nonword repetition or ISR tasks (Gupta & MacWhinney, 1997).

In a study designed to investigate the role that long-term knowledge of phonology may have in ISR, Hulme et al. (1991) found that participants were able to recall familiar words more accurately than either Italian words (e.g., *lago*) or nonwords with an English sound (e.g., *maffow*). This has been called the *lexicality effect* and reflects a performance advantage when the stimuli employed are words as compared to nonwords or unfamiliar words. These findings are consistent with the idea that LTM influences STM. The term redintegration has been used to describe the process by which, prior to output, incomplete phonological traces held in STM are reconstructed (redintegrated) by using phonological representations that are stored in LTM (Brown & Hulme, 1995; see also Schweikert, 1993). According to this view, recall accuracy is lower for nonwords than words because there is no stored representation available to assist in the reconstruction of the partial trace (Hulme et al., 1991, 1997).

Although empirical results support the idea that nonword repetition is a good predictor of reading development and vocabulary in both children (e.g., Gathercole, Willis, Emslie, & Baddeley, 1992; Service, 1992) and adults (e.g., Baddeley et al., 1988; Baddeley & Wilson, 1993), as yet, little is known about the cognitive mechanisms that underlie repetition performance (Gathercole, 1995a). In an attempt to measure the effect that linguistic familiarity may have on nonword repetition accuracy, Gathercole, Willis, Emslie, and Baddeley (1991), obtained subjective wordlikeness ratings of two-, four-, and five-syllable nonwords. They found that the more wordlike a nonword is rated, the more likely it is to be recalled correctly. Called the wordlikeness effect, this finding has been replicated in numerous studies (e.g., Gathercole, 1995a). The explanation offered to account for the recall advantage on repetition tasks for nonwords rated high, as compared to low, in wordlikeness is that phonological representations of nonwords rated high in wordlikeness are supplemented by stored lexical

knowledge, whereas recall is not facilitated by this stored lexical knowledge when nonwords are rated low in wordlikeness (Gathercole, 1995a).

However, Dollaghan et al. (1993, 1995) have suggested that the wordlikeness effect could be attributed to the proportion or number of nonwords that contain real English words. In an attempt to investigate this claim, Dollaghan et al. (1993) constructed pairs of multisyllabic nonwords. The pairs differed only with respect to one phoneme in the syllable that received primary stress. Thus, in each pair, the syllable receiving primary stress was either a word (e.g., *BATHesis*), or a nonword (e.g., *FATHesis*). They found that when the stressed syllable was lexical, as opposed to nonlexical, recall accuracy increased. Consistent with Hulme et al.'s (1991) findings of a lexicality effect on tasks that employ words as compared to nonwords, these results indicate that LTM does indeed influence nonword repetition performance (Dollaghan et al., 1993). The idea proposed to account for the influence of LTM on STM is that when stimuli are novel, as compared to familiar, an individual has to rely more heavily on the phonological loop (PL) component of working memory to support articulatory output (Baddeley et al., 1998). According to this view, if stored lexical knowledge is used to supplement phonological working memory, then the recall of nonwords that are subjectively rated as high in wordlikeness should have a stronger relationship with digit span than the recall of nonwords rated low in wordlikeness. To date, however, this issue has not been empirically addressed.

Given the performance advantage when the stimuli to be recalled consist of lexical units, researchers of late have questioned whether sublexical factors such as the phonotactics of the nonword stimuli also influence performance on such tasks. *Phonotactics* is a term used to describe "the sequential arrangement of phonetic segments in morphemes, syllables, and words" (Vitevitch & Luce, 1999, p. 374). Linguistic researchers have looked at the effect that various phonotactic constraints have on recall performance. For example, Kessler and Treiman (1997) found, using English syllables, that phonotactic constraints are stronger on vowel–consonant (VC) couplings than on consonant–vowel (CV) couplings. This finding is consistent with research indicating that when a recall error does occur, the majority of consonant–vowel–consonant (CVC) syllables retain the VC component (Treiman & Danis, 1988).

Researchers have also investigated the relationship between recall accuracy and the probabilistic phonotactics of nonwords (i.e., the frequency with which phonotactic segments and sequences occur in syllables and words; Vitevitch & Luce, 1999). For example, Gathercole, Frankish, et al. (1999) employed nonwords with a CVC structure in an ISR task consisting of four conditions: words and high, low, and very low probability nonwords. Not only was recall accuracy better for words as compared to nonwords, but it was also better for nonwords with a high, as compared to low, total biphone probability. Thus, when the stimuli to be recalled are nonwords, as the total biphone probability of nonwords increases, recall accuracy increases. Gathercole, Frankish, et al. (1999) also compared recall accuracy on sets of words and nonwords that were matched on total biphone probability. The results revealed that when the stimuli were matched on total biphone probability, recall accuracy was better for lexical than

nonlexical stimuli. Based on these results, Gathercole, Frankish, et al. (1999) proposed separate mechanisms to mediate the probabilistic phonotactic and lexicality effects. However, caution should be exercised if one is to accept the claim that separate mechanisms mediate sublexical and lexical effects on phonological STM performance. For instance, the finding of a lexical influence in both the ISR (e.g., Hulme et al., 1991; Roodenrys et al., 1993) and nonword repetition tasks (e.g., Dollaghan et al., 1993, 1995), raises doubt as to whether phonological memory can be separated from lexical operations (Dollaghan et al., 1995).

In a more recent study however, Roodenrys and Hinton (2002) found no biphone frequency effect when the number of lexical neighbors of the stimuli was controlled. In a follow-up experiment, Roodenrys and Hinton (2002) manipulated neighborhood size while controlling biphone frequency. A significant neighborhood size effect was observed. Based on these results, they suggested that lexical, rather than sublexical, factors influence phonological STM performance. However, these findings do not rule out the possibility that other sublexical factors influence phonological STM performance. For instance, better performance on nonwords that sound more wordlike could be a direct result of the frequency with which segments of the nonwords occur in the English language. Before performance on phonological STM tasks can be attributed to the influence of either lexical or sublexical factors, a more in-depth investigation of other sublexical factors that may influence recall accuracy must be conducted.

Based on current research investigating factors that may influence phonological STM performance, the current experiment was specifically designed to directly test the claim that LTM also influences phonological STM at the sublexical level. This is accomplished by examining the effect that the frequency with which one-syllable nonwords occur in polysyllabic English words has on recall accuracy. This study examines these effects in both the nonword repetition and serial recall tasks. On the basis of previous research, it is expected that a relationship should exist between recall accuracy on both the serial recall and repetition tasks and the digit span measure. It is also predicted that, regardless of the recall technique employed, a participant's performance should be better (i.e., fewer errors), when the stimuli to be recalled consist of syllables that occur often, as opposed to rarely, in polysyllabic English words.

METHOD

Participants

Forty undergraduate psychology students (8 males, 32 females) from the University of Wollongong participant pool, with an age range of 17–56 years, participated in compliance with a course requirement. Only participants with an Australian English accent and who also indicated having no prior problems with hearing were included in the present study.

Stimuli

Syllable frequency counts for 160 one-syllable nonwords, all with a CVC structure, were obtained using the CELEX lexical database (Baayen, Piepenbrock, & Van Rijn, 1993). CELEX has an English lexicon based on 17.7 million word

tokens. The syllable frequency counts used in the current experiment were words per million counts occurring in this database. Word form frequency was used, which includes every occurrence of that particular syllable in the English language (i.e., both speech and written forms). Based on these word form counts, the overall frequency of a syllable's occurrence in the English language was calculated.

The stimuli selected for the current study had a syllable frequency count that was either above 44 (i.e., high frequency syllable count, $M = 403.68$) or below 10 (i.e., low frequency syllable count, $M = 2$; see Appendixes A and B). For nonwords with CVC structure, this translated into the top and bottom thirds of the stimulus pool, respectively. The high and low nonword conditions differed significantly from one another in syllable frequency ($z = -10.9775$, $p < .05$). Syllables selected for the high and low frequency conditions were matched in such a way that a similar number of phonemes from the same phonetic class (e.g., ŋ, *n*, and *m* phoneme sounds) occurred in each condition. For example, *affricates* (i.e., the phoneme sounds *tʃ*, as in *ch*eap and *dʒ* as in *j*eep) occurred a total of nine times in both the high- and low-frequency sets of stimuli. Following from Dollaghan et al. (1995), this experiment used two trained listeners to transcribe the stimuli from the audiocassette recording, using a broad phonetic transcript with a percentage of agreement at 100% for the serial recall and 96.25% for the nonword repetition stimuli.

In the current experiment, each participant completed three tasks: digit span, serial recall, and nonword repetition. Forty lists, each consisting of four one-syllable nonwords were constructed such that the syllables presented were identical, regardless of task (i.e., serial recall or nonword repetition). Half of the lists consisted of stimuli with high syllable frequency and the other half with low. There were constraints placed on the construction of the stimuli such that consonants were not repeated in the same position in a syllable for any list. Also, where possible, vowels were not repeated in the same list. Last, for both the high and low syllable frequency conditions, the number of times a phonemic class occurred in any one position in a list was controlled for.

Using an Arista Cardioid dynamic microphone (model DM-904D) and a Marantz portable cassette recorder (model CP430), the stimuli were recorded in a sound attenuated booth by a female speaker with an Australian English accent. The stimuli for the digit span task consisted of the digits 1–9. Although the same stimuli were used in the repetition and serial recall tasks, the recording of the stimuli was not identical. The four one-syllable nonwords were recorded separately for the serial recall task and as one continuous, four-syllable nonword for the repetition task.

Each stimulus was randomly presented to participants through a Sony MDR head set (model CD 250), with presentation controlled by a Macintosh computer. While the order of the lists was randomized for each participant, stimuli presentation within each list for the repetition and serial recall tasks did not vary across positions. To counterbalance any practice effects, half of the participants completed the serial recall task first and the other half the repetition task. In order to control for the effects of fatigue, participants always completed the digit span task between the two nonword recall tasks.

Short-term phonological memory tasks

Digit span. Each digit was presented to participants at a rate of one/s. On each trial, the participant heard a sequence of randomly generated digits and was asked to repeat the sequence back to the experimenter in the correct serial order. Presentation started with lists of three digits in length. Participants were given one list at a time and asked to recall them as soon as the last digit was heard. If a participant correctly recalled two consecutively presented lists of the same length, testing continued with two lists that were increased in length by one digit. If, however, a participant made an error when recalling one of the two lists, a third list was presented. If a participant made an error on this list, testing was discontinued. Span was scored as the maximum length at which a participant correctly recalled at least two lists. If a participant was able to correctly recall one of the succeeding three lists that was presented, an extra half score was recorded.

Serial recall. On each trial in the serial recall task, a participant heard four one-syllable nonwords, presented at a rate of one/s. The task was to repeat these nonwords back to the experimenter exactly as they were heard, after the last item had been presented.

Nonword repetition. On each trial in the nonword repetition task, a participant heard one four-syllable nonword. The participant's task was to repeat the nonword back to the experimenter exactly as it was heard.

Procedure

Each participant was tested individually in a single session, in a quiet room. The number of lists correctly recalled at each length for the digit span task was recorded on a response sheet. Recall accuracy for the nonword repetition and serial recall tasks was also recorded on computer by the experimenter. Each participant's recall attempts for the serial recall and nonword repetition tasks were recorded onto audiotapes. The audio recordings were later transcribed by the same experimenter using a broad phonetic transcription. The time taken for each participant to complete all three tasks was approximately 30 min.

Scoring

In the serial recall tasks, items were scored as correct only if the correct phonemes were recalled in the positions in which they were presented. For the nonword task, each syllable was scored as correct only if all three phonemes were recalled correctly. Where the trained listeners heard a different target phoneme in any given stimulus, either phoneme was scored as correct when recalled by a participant (Dollaghan et al., 1995). Whole syllables that were either omitted by participants or were uninterpretable were scored as incorrect but not included in the phoneme error analysis. When an error occurred, the retained portion of the target syllables was recorded. In cases where multiple attempts

Table 1. *Means (*M*) and standard deviations (*SD*) for three measures of short-term memory scored in items correct (*N*)*

Task	*M*	*SD*	*N*
Serial recall	103.25	20.31	40
Nonword repetition	104.93	17.97	40
Digit span	6.83	0.93	40

were made to pronounce a nonword, the most complete and correct attempt was scored.

Reliability

Tapes from five randomly selected subjects were transcribed and scored independently by a research assistant who was trained in both broad phonetic transcription and in the scoring rules used in the current study. Interrater reliability scores for the serial recall (95.6%) and nonword repetition (92.5%) tasks were obtained.

RESULTS

The following analyses present the correlations between digit span, nonword repetition, and serial recall. Comparisons between performance on the nonword recall tasks when the stimuli to be recalled occur often, as opposed to rarely, in polysyllabic English words are also presented. Last, error analyses were performed on the data to determine whether the nature of recall errors is related to task type.

Phonological STM tasks

The data from the three phonological STM tasks, scored in terms of the number of items or syllables correctly recalled, are presented in Table 1. As depicted in Table 1, recall accuracy was similar across the serial recall and nonword repetition tasks.

As expected, digit span was highly correlated with performance on both serial recall, $rs\ (39) = .6119$, $p < .05$, and nonword repetition, $rs\ (39) = .5264$, $p < .05$. Also as expected, performance on the serial recall and repetition tasks were highly correlated, $rs\ (39) = .7541$, $p < .05$. These results suggest that all three tasks have some component processes in common.

Syllable frequency analyses

Interestingly, regardless of the task, digit span was more highly correlated with performance on stimuli with a high syllable frequency: serial recall, $rs\ (39) = .605$, $p < .01$, repetition, $rs\ (39) = .632$, $p < .01$, as opposed to a low syllable

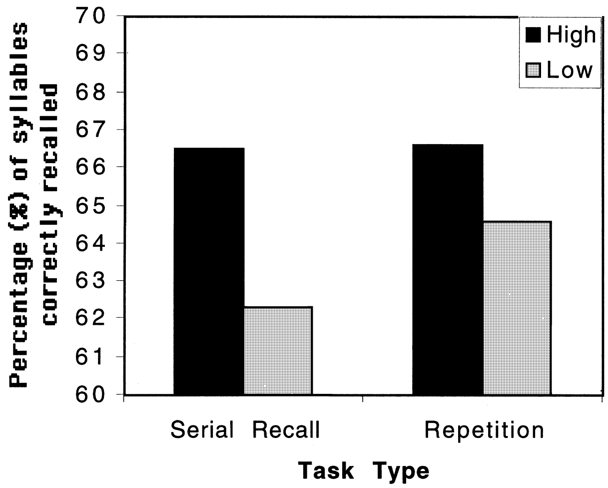

Figure 1. Mean number of one syllable nonwords correctly recalled in the serial recall and repetition tasks as a function of syllable frequency.

frequency, serial recall = *rs* (39) = .559, $p < .01$, repetition = *rs* (39) = .336, $p < .05$. However, when the differences in the relationships between digit span and recall accuracy on the high- versus low-frequency syllables were statistically analyzed, these relationships failed to reach significance for either serial recall, $t(37) = 0.302$, $p > .05$, or nonword repetition, $t(37) = 1.800$, $p > .05$.

The average numbers of syllables correctly recalled are presented in Figure 1. The data were analyzed using a 2×2 repeated measures analysis of variance (ANOVA). The first factor was task (serial recall vs. nonword repetition) and the second factor was syllable frequency (high vs. low).

The analysis revealed a significant effect of frequency, $F(1, 39) = 8.567$, $p < .05$, but not task, $F(1, 39) = .882$, $p > .05$, *ns*, and a nonsignificant Task × Frequency interaction, $F(1, 39) = 1.652$, $p > .05$, *ns*. What these results suggest is that the effect of frequency on the mean number of syllables correctly recalled, is independent of which task is being performed (refer to Figure 1). Thus, as expected, regardless of the task to be performed, recall is better when the stimuli to be recalled consist of syllables that occur often in polysyllabic English words.

Because the serial recall and repetition tasks were constructed so that each stimulus did not occur in each position, an interpretation of any results obtained across positions within each of these tasks would be both troublesome and meaningless because of the differential influence that individual stimuli may have on recall accuracy. That is, because particular syllables only occur in one position, differences in performance between positions may reflect item difficulty rather than position per se. It is still possible, however, to compare performance across tasks for each position. Thus, to analyze these results further, comparisons were performed on the differences in recall accuracy between the

tasks, for each of the four positions. On average, participants were more accurate at recalling syllables in the first position, when the task was serial recall (M = 30.83), as compared to the repetition task (M = 27.13, z = –4.40, p < .0125). Analysis also revealed no difference between tasks when the syllables to be recalled were in position 2, $t(39) = -.73$, p > .0125, *ns*. Finally, contrary to the effects found for position 1, on average, participants were more accurate when the task was repetition for syllables in both position 3, M = 25.78; $t(39) = 3.27$, p < .0125, and position 4, M = 26.93; $t(39) = 5.26$, p < .0125, than when the task was serial recall (M = 23.65 for position 3 and 23.08 for position 4).

Error analysis

Error analyses when recalling high compared to low frequency syllables revealed no distinguishing differences. Thus, only results that differ from previous studies or that show differences in the types of errors when participants are performing the serial recall task, as opposed to the repetition task, will be reported here.

As can be seen in Table 1, overall performance level was not influenced by task (serial recall = 65.78%, nonword repetition = 66.85%). Also, when a recall error occurred, the CV, as opposed to the C_C (first and third phoneme) or VC structures, was the most commonly retained two-phoneme structure, regardless of whether the task was serial recall (42.17% of all errors) or repetition (43.11% of all errors). Last, the most common error for the serial recall (96.01%) and repetition (93.51%) tasks was a phoneme substitution error.

DISCUSSION

The primary aim of this study was to investigate the nature of phonological STM tasks and, specifically, to examine whether recall accuracy on such tasks is influenced by the frequency with which one-syllable nonwords occur in polysyllabic English words. However, the results also provide interesting data relevant to the construction of future models of STM. Briefly, the major findings of the current study are that, as expected, a positive relationship between digit span, serial recall, and nonword repetition was observed. Also, regardless of the task, recall accuracy increased when the stimuli to be recalled consist of one-syllable nonwords that occur often, as opposed to rarely, in polysyllabic English words.

The finding of a relationship between digit span and both the repetition and serial recall tasks replicates previous research in showing a correlation across subjects between the digit span, serial recall, and nonword repetition scores (e.g., Bisiacchi et al., 1989; Gathercole & Adams, 1993). Also as predicted, a positive relationship between recall accuracy on the repetition and serial recall tasks was observed. Hence, the current study lends support to the idea that nonword repetition measures phonological STM (Gathercole, 1995a).

Baddeley et al. (1998) suggested that because digit span tasks employ familiar stimuli, a stronger relationship should exist between this task and nonwords that are rated high, as opposed to low, in wordlikeness. This suggestion is based on

the idea that LTM representations facilitate phonological STM recall at both a lexical and sublexical level. The current research did not investigate the relationship between wordlikeness ratings and digit span directly. However, the pattern of relationships among digit span and recall accuracy on stimuli with a high rather than low syllable frequency was consistent with Baddeley et al.'s (1998) suggestion, although differences between the correlations failed to reach significance.

The finding of a facilitative syllable frequency effect on phonological STM tasks that employ nonword stimuli is consistent with previous research that also found that recall accuracy on phonological tasks is influenced by sublexical factors such as the probabilistic phonotactics of the stimuli to be recalled (Gathercole, Frankish, et al., 1999). These results clearly suggest that, although LTM representations facilitate performance on phonological STM tasks that employ lexical stimuli (Hulme et al., 1991; Roodenrys et al., 1993), LTM also facilitates phonological STM performance at a sublexical level.

Error analyses were performed to investigate recall performance on both the serial recall and repetition tasks more closely. The current study found that, when a recall error occurred, phonemic substitutions were the most common error type. Thus, in accordance with previous research, insertion (i.e., adding an extra phoneme) and deletion errors (i.e., omitting a phoneme) are relatively infrequent when the stimuli to be recalled are nonwords (e.g., Ellis, 1980; Treiman & Danis, 1988).

An interesting finding in the current study was that participants were more accurate at recalling one-syllable nonwords presented in the first position in a list when the task was serial recall as compared to nonword repetition. However, when recalling one-syllable nonwords presented in the fourth position in a list, participants were more accurate when the task was nonword repetition as compared to serial recall. A possible explanation for the differences across positions observed in the current experiment is that recall accuracy may be confounded by the rate at which the serial as opposed to repetition stimuli are presented. For instance, in serial recall, pauses exist between the items, whereas continuous phonemic sequences are presented and recalled in the nonword repetition task (Hartley & Houghton, 1996). When the task is serial recall, there is approximately a 4-s latency from the time when participants hear the initial item to when the last item is presented and recalled. When the task is nonword repetition, however, there is only approximately a 2-s latency between stimulus presentation and recall. Thus, the differences in errors observed between the two recall tasks in the current study may reflect a difference in decay rate. Accordingly, as the duration from presentation to recall increases, recall accuracy decreases due to the rate at which the representation in phonological STM decays. However, in the current study, this explanation fails to account for why recall accuracy was better on nonword stimuli presented in the first position in a list, when the task was serial recall as compared to nonword repetition.

Gathercole, Willis, Baddeley, and Emslie (1994) suggested that because subvocal rehearsal operates in real time, it is unlikely that nonword stimuli are rehearsed prior to output when the task is repetition. However, because pauses exist between each of the presented items in the serial recall task, participants

may actively rehearse the first items presented in each list. Hence, if participants actively rehearsed the first items presented in each list, we would expect recall accuracy on the items to be better when the task was serial recall as opposed to nonword repetition. Thus, the results of the current study are consistent with the idea that, whereas recall accuracy on phonological STM tasks is influenced by the rate at which phonological representations in STM decay, when the task is serial recall, accuracy on the initial item may be facilitated by subvocal rehearsal.

Recent models of STM lack the ability to account for the different error types that occur when participants serially recall lists of nonwords (i.e., recombination errors), as compared to those that occur when recalling words (i.e., whole word substitution errors; Burgess, 1995; Burgess & Hitch, 1992; Hartley & Houghton, 1996; Houghton, 1990, 1993, 1994). However, a new STM model developed by Gupta and MacWhinney (1997), based on the work of Burgess and Hitch (1992) and Hartley and Houghton (1996), provides mechanisms to account for both differences in recall accuracy when recalling words as compared to nonwords and differences in the types of errors that occur when the stimuli to be recalled are lexical rather than nonlexical items. Also, the proposal of separate lexical and sublexical mechanisms is well accommodated within this STM model (Gupta & MacWhinney, 1997). In this model, the phonological store and semantic template mechanisms facilitate recall accuracy at a lexical level, whereas the phonological chunk layer, syllable template, syllable layer, and phoneme layer facilitate recall accuracy at a sublexical level. Therefore, this model can also offer a plausible explanation for the syllable frequency effect observed in the current study.

According to the model, a nonword is represented phoneme by phoneme. Due to the competitive queuing mechanism, activation of these phonemes is graded, which establishes a representation of the nonword. Phonotactic constraints are placed on articulation from the activation of the syllable template to the phoneme layer. These phonotactic constraints are assumed to have been acquired through previous experience and, as such, represent more permanent weights (Gupta & MacWhinney, 1997). There is also a syllable layer node, which receives activation from both the phoneme layer and the syllable template and sends activation to the phonological chunk layer. These activations are assumed to be bound by a Hebbian adjustment of weights (Gupta & MacWhinney, 1997). In other words, when nodes are active at the same time, connections between the nodes are strengthened. Thus, the syllable frequency effect observed in the current study can be explained by the stronger connections between the whole syllable as a node in the syllable layer and between phonemes in the phoneme layer, both of which are constrained by the syllable template. The more frequently syllables occur in polysyllabic English words, the stronger are the connections between the syllable layer and the phonological chunk layer. Hence, the more likely it is that the syllable will be recalled correctly. Also, as with nonwords that occur often in polysyllabic English words, these connections would be strengthened each time a nonword is rehearsed. However, when syllables occur rarely in polysyllabic English words, the connections are weaker; hence, there is more chance that the representation will decay. Therefore, the

weaker the connections between the syllable layer and the phonological chunk layer, the less likely it is that the syllable will be recalled correctly. Also, the longer the duration from initial presentation to recall, the greater the decay from the chunk node to the phoneme layer. Therefore, the current finding that participants are less accurate at recalling one-syllable nonwords presented in the final position, when the task is serial recall as compared to nonword repetition, is well accommodated by the view that differences between tasks may reflect differences in the strength of phonological representations in STM due to decay (refer to Gupta & MacWhinney, 1997, for an in-depth discussion of their STM model).

A surprising finding in the current research was that, when a recall error did occur, a greater number of responses retained the CV component than any other phoneme pair. Linguistic research on syllable structure has consistently lent support to the idea that syllables have a hierarchical internal structure, which consists of an onset, comprising the initial phoneme or phoneme cluster, and the rime, which includes the final VC phonemes (MacKay, 1972; Treiman, 1983). Although not all researchers agree about where the internal boundaries of a syllable are (e.g., MacNeilage & DeClerk, 1969), recent research supports the idea that when a recall error occurs, the VC component is retained (Kessler & Treiman, 1997). This is based on the assumption that phonotactic constraints are stronger on VC than CV couplings (Kessler & Treiman, 1997). Therefore, the current findings are in direct contrast to contemporary research that has consistently found that when a recall error does occur, the VC rather than the CV component of a CVC syllable is commonly retained (Kessler & Treiman, 1997; Treiman & Danis, 1988).

A possible explanation for these inconsistent findings might be found in linguistic research conducted by Treiman (1984). Based on the sonority principle, the segments that make up a syllable are grouped according to their sounds. While investigating the status of the final consonant clusters within English syllables, Treiman (1984) found that postvocalic liquids (e.g., *1, h*, and *r*) are linked more closely to the vowel than either nasals (e.g., *m, n*, and ŋ), or obstruents, which includes both stops and fricatives (e.g., *p, t, k*, and *f*). Although the stimuli used in the current experiment were matched across frequency on the number of liquids that occurred in the first position of a syllable, a larger proportion of initial consonants consisted of liquids than did final consonants (i.e., 42.5 and 10%, respectively). So far, research on the degree to which the coarticulation of obstruents, nasals, or liquids influences syllable structure has not been conducted (Treiman, 1995). Hence, when recall errors do occur, it is unclear as to exactly how coarticulation may affect the structure of the retained portion of a CVC syllable.

Based on the sonority principal, newly proposed models of STM (e.g., Gupta & MacWhinney, 1997; Hartley & Houghton, 1996) have incorporated a syllable template to account for the fact that when recall errors are made, they most commonly retain the VC component. Hence, these models would predict that when a recall error does occur, the majority of the time, the recalled item should retain the VC not the CV component. Therefore, these models would be at a loss to explain the current research findings that suggest that it is the CV

rather than the VC component that is retained (for an in-depth discussion of the syllable template mechanism refer to Hartley & Houghton, 1996). Future research will need to examine the possible effects of coarticulation on syllable structure if these models, as well as future models of verbal STM, are to explain these contradictory results. Although the syllable template mechanism utilized by currently proposed models of STM (e.g., Gupta & MacWhinney, 1997; Hartley & Houghton, 1996) can be used to model the effects of general linguistic constraints on articulation, such as phoneme ordering (e.g., the phonemes /tl/ cannot occur in the initial or onset part of a syllable), based on the results of future coarticulation research, new STM models may need to include some type of mechanism that takes into account the effects that coarticulation may have on both recall accuracy and the structure of the retained portion of CVC syllables (when an error occurs).

Currently, factors that have been found to influence phonological STM tasks include the lexicality of either the whole item (Hulme et al., 1991) or lexical items embedded within nonwords (Dollaghan et al., 1993), the rated wordlikeness of the stimuli (Gathercole, 1995a), the number of lexical neighbors of a nonword (Roodenrys & Hinton, 2002), and, based on the results of the current experiment, the frequency with which one-syllable nonwords occur in polysyllabic English words. The current findings of a facilitative frequency effect on phonological STM tasks, even when the stimuli to be recalled are nonwords, suggests that caution should be exercised when interpreting results obtained from such tasks. Thus, future research should seek to explore the relationship between sublexical factors such as the probabilistic phonotactics and the syllable frequency of nonword segments that have been found to facilitate performance on phonological STM tasks (Dollaghan et al., 1993, 1995; Snowling, Chiat, & Hulme, 1991; Wells, 1995).

A major outcome of this study is the finding of a facilitative syllable frequency effect on phonological STM recall tasks when the stimuli employed on such tasks are one-syllable nonwords with a CVC structure. Separate mechanisms have been proposed to account for both lexical and sublexical factors that influence phonological STM performance. Although recent verbal STM models have incorporated a syllable template mechanism to account for phonotactic constraints on syllable structure, other factors such as coarticulation may influence both recall accuracy and, when recall errors occur, the component of the syllable that is retained.

APPENDIX A

Stimuli for serial recall and repetition tasks with CELEX high syllable frequency counts

	Position 1		Position 2		Position 3		Position 4	
High frequency stimuli	IPA code	Syllable freq.	IPA code	Syllable freq.	IPA code	Syllable freq.	IPA code	Syllable freq.
Chizlisrownmung	tʃɪz	390	lɪs	571	raʊn	88	mʌŋ	306
Fingvulchaymzik	fɪŋ	233	vʌl	53	tʃeɪm	54	zɪk	134
Genriznislun	gɛn	768	rɪz	536	nɪs	1182	lʌn	313
Hanvitdizful	hæn	222	vɪt	221	dɪz	255	fʌl	81
Hoscharnditpid	hɒs	137	tʃɑːn	77	dɪt	47	pɪd	145
Jekshingrishpoyn	dʒɛk	248	ʃɪŋ	304	rɪʃ	82	pɔɪn	154
Kaydsigmarnvik	keɪd	63	sɪg	224	mɑːn	121	vɪk	223
Kownfaktidsem	kaʊn	393	fæk	301	tɪd	5259	sɛm	95
Lanhuzfisjid	læn	169	hʌz	159	fɪs	360	dʒɪd	45
Nishponcheavris	nɪʃ	162	pɒn	308	tʃiːv	88	rɪs	103
Rupzurvsenving	rʌp	81	zɜːv	71	sɛn	1182	vɪŋ	1405
Sidgevenpulnuyz	sɪdʒ	114	vɛn	357	pʌl	58	naɪz	85
Sulningfeklish	sʌl	67	nɪŋ	2054	fɛk	287	lɪʃ	83
Taynsepkalforch	teɪn	179	sɛp	400	kæl	74	fɔːʃ	109
Tidgelifvarnses	tɪdʒ	180	lɪf	60	vɑːn	142	sɛs	477
Tisfuydsizkun	tɪs	398	faɪd	242	sɪz	3118	kʌn	654
Vismemfikgan	vɪs	200	mɛm	725	fɪk	257	gæn	409
Zarmtishnufreaz	zɑːm	278	tɪʃ	398	nʌf	495	riːz	84
Ziznaytgingdop	zɪz	580	neɪt	47	gɪŋ	84	dɒp	47
Zuynduslektiv	zaɪn	87	dʌs	181	lɛk	695	tɪv	1453

APPENDIX B

Stimuli for serial recall and repetition tasks with CELEX low syllable frequency counts

	Position 1		Position 2		Position 3		Position 4	
Low frequency stimuli	IPA code	Syllable freq.	IPA code	Syllable freq.	IPA code	Syllable freq.	IPA code	Syllable freq.
Bowchdeshthizsorp	baʊtʃ	0	dɛʃ	3	θiːz	2	sɔːp	4
Chishetnupfam	tʃɪs	4	hɛt	0	nʌp	1	fæm	0
Divzurkfeafcharl	dɪv	0	zɜːk	2	fiːf	0	tʃɑːl	2
Durnlichrovtes	dɜːn	0	lɪtʃ	0	rɒv	2	tɛs	0
Fetchungloyzgik	fɛt	3	tʃʌŋ	1	lɔɪz	1	gɪk	0
Gispoydlufshen	gɪs	0	pɔɪd	0	lʌf	0	ʃɛn	2
Hodzetgimvung	hɒd	0	zɛt	4	gɪm	0	vʌŋ	1
Juynrasfeamgel	dʒaɪn	0	ræs	1	fiːm	0	gɛl	0
Kangtarkhebvurz	kæŋ	3	tɑːk	1	hɛb	0	vɜːz	0
Lepzayzhortbim	lɛp	2	zeɪz	0	hɔːt	1	bɪm	0
Lumteavezandib	lʌm	9	tiːv	1	zæn	7	dɪb	0
Nardreszidgegorp	nɑːd	3	rɛs	7	zɪdʒ	9	gɔːp	0
Nukrithsengchuyz	nʌk	0	rɪθ	8	sɛŋ	1	tʃaɪz	3
Pishlownzumrard	pɪʃ	4	laʊn	4	zʌm	0	rɑːd	2
Regsondarzmish	rɛg	0	sɒn	1	dɑːz	0	mɪʃ	7
Tarfkormvurdhean	tɑːf	3	kɔːm	0	vɜːd	0	hiːn	1
Theatnigmuydrof	θiːt	0	nɪg	6	maɪd	1	rɒf	4
Tolgifveschut	tɒl	0	gɪf	8	vɛs	2	tʃʌt	3
Vasfidketnoyn	væs	0	fɪd	0	kɛt	4	nɔɪn	2
Zoyzligfoktas	zɔɪz	0	lɪg	5	fɒk	7	tæs	8

REFERENCES

Baayen, R. H., Piepenbrock, R., & Van Rijn, H. (1993). *The CELEX lexical database.* Philadelphia, PA: University of Pennsylvania, Linguistic Data Consortium.
Baddeley, A., Gathercole, S., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review, 105,* 158–173.
Baddeley, A. D., Papagno, C., & Vallar, G. (1988). When long-term learning depends on short-term storage. *Journal of Memory and Language, 27,* 586–596.
Baddeley, A. D., & Wilson, B. A. (1993). A developmental deficit in short-term phonological memory: Implications for language and reading. *Memory, 1,* 65–78.
Bisiacchi, P. S., Cipolotti, L., & Denes, G. (1989). Impairment in processing meaningless verbal material in several modalities: The relationship between short-term memory and phonological skills. *The Quarterly Journal of Experimental Psychology, 41A,* 293–319.
Brown, G. D. A., & Hulme, C. (1995). Modeling item length effects in memory span: No rehearsal needed? *Journal of Memory and Language, 34,* 594–621.
Burgess, N. (1995). A solvable connectionist model of immediate recall of ordered lists. In G. Tesauro, D. Touretzky, & J. Alspector (Eds.), *Advances in neural information processing* (Vol. 7). San Mateo, CA: Kaufmann.
Burgess, N., & Hitch, G. J. (1992). Toward a network model of the articulatory loop. *Journal of Memory and Language, 31,* 429–460.

Dollaghan, C., Biber, M., & Campbell, T. (1993). Constituent syllable effects in a nonsense word repetition task. *Journal of Speech and Hearing Research, 36,* 1051–1054

Dollaghan, C. A., Biber, M. E., & Campbell, T. F. (1995). Lexical influences on nonword repetition. *Applied Psycholinguistics, 16,* 211–222.

Ellis, A. W. (1980). Errors in speech and short-term memory: The effects of phonemic similarity and syllable position. *Journal of Verbal Learning and Verbal Behaviour, 19,* 624–634.

Gathercole, S. E. (1995a). Is nonword repetition a test of phonological memory or long-term knowledge? It all depends on the nonwords. *Memory and Cognition, 23,* 83–94.

Gathercole, S. E. (1995b). Nonword repetition: More than just a phonological output task. *Cognitive Neuropsychology, 12,* 857–861.

Gathercole, S. E., & Adams, A. (1993). Phonological working memory in very young children. *Developmental Psychology, 29,* 770–778.

Gathercole, S. E., & Adams, A. (1994). Children's phonological working memory: Contributions of long-term knowledge and rehearsal. *Journal of Memory and Language, 33,* 672–688.

Gathercole, S. E., & Baddeley, A. D. (1989). Evaluation of the role of phonological STM in the development of vocabulary in children: A longitudinal study. *Journal of Memory and Language, 28,* 200–213.

Gathercole, S. E., & Baddeley, A. D. (1990). Phonological memory deficits in language disordered children: Is there a causal connection? *Journal of Memory and Language, 29,* 336–360.

Gathercole, S. E., Frankish, C. R., Pickering, S. J., & Peaker, S. (1999). Phonotactic influences on short-term memory. *Journal of Experimental Psychology: Learning, Memory and Cognition, 25,* 84–95.

Gathercole, S. E., Hitch, G. J., Service, E., & Martin, A. J. (1997). Phonological short-term memory and new word learning in children. *Developmental Psychology, 33,* 966–979.

Gathercole, S. E., Service, E., Hitch, G. J., Adams, A., & Martin, A. J. (1999). Phonological short-term memory and vocabulary development: Further evidence on the nature of the relationship. *Applied Cognitive Psychology, 13,* 65–77.

Gathercole, S. E., Willis, C., & Baddeley, A. D. (1991). Differentiating phonological memory and awareness or rhyme: Reading and vocabulary development in children. *British Journal of Psychology, 82,* 387–406.

Gathercole, S. E., Willis, C. S., Baddeley, A. D., & Emslie, H. (1994). The Children's Test of Nonword Repetition: A test of phonological working memory. *Memory, 2,* 103–127.

Gathercole, S. E., Willis, C., Emslie, H., & Baddeley, A. D. (1991). The influences of syllables and wordlikeness on children's repetition of nonwords. *Applied Psycholinguistics, 12,* 349–367.

Gathercole, S. E., Willis, C., Emslie, H., & Baddeley, A. D. (1992). Phonological memory and vocabulary development during the early school years: A longitudinal study. *Developmental Psychology, 28,* 887–898.

Gupta, P., & MacWhinney, B. (1997). Vocabulary acquisition and verbal short-term memory: Computational and neural bases. *Brain and Language, 59,* 267–333.

Hartley, T., & Houghton, G. (1996). A linguistically constrained model of short-term memory for nonwords. *Journal of Memory and Language, 35,* 1–31.

Houghton, G. (1990). The problem of serial order: A neural network model of sequence learning and recall. In R. Dale, C. Mellish, & M. Zock (Eds.), *Current research in natural language generation.* New York: Academic Press.

Houghton, G. (1993). Inhibitory control of neuridynamics: Opponent mechanisms in sequencing and selective attention. In M. Oaksford & G. D. A. Brown (Eds.), *Neurodynamics and psychology.* New York: Academic Press.

Houghton, G. (1994). Spelling and serial recall: Insights from a competitive queuing model. In G. D. A. Brown & N. C. Ellis (Eds.), *Handbook of normal and disturbed spelling.* New York: Wiley.

Hulme, C., Maughan, S., & Brown, G. D. A. (1991). Memory for familiar and unfamiliar words: Evidence for a longer term memory contribution to short-term memory span. *Journal of Memory and Language, 30,* 685–701.

Hulme, C., Roodenrys, S., Schweikert, R., Brown, G. D. A., Martin, S., & Stuart, G. (1997). Word frequency effects on short-term memory tasks: Evidence for a redintegration process in im-

mediate serial recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23,* 1217–1232.

Jorm, A. (1983). Specific reading retardation and working memory: A review. *British Journal of Psychology, 74,* 311–342.

Kessler, B., & Treiman, R. (1997). Syllables structure and the distribution of phonemes in English syllables. *Journal of Memory and Language, 37,* 295–311.

MacKay, D. G. (1972). The structure of words and syllables: Evidence from errors in speech. *Cognitive Psychology, 3,* 210–227.

MacNeilage, P. R., & DeClerk, J. L. (1969). On the motor control of coarticulation in CVC monosyllables. *Journal of the Acoustical Society of America, 45,* 1217–1233.

Metsala, J. L. (1999). Young children's phonological awareness and nonword repetition as a function of vocabulary development. *Journal of Educational Psychology, 91,* 3–19.

Roodenrys, S., & Hinton, M. (2002). Sublexical or lexical effects on serial recall of nonwords? *Journal of Experimental Psychology: Learning, Memory and Cognition, 28,* 29–33.

Roodenrys, S., Hulme, C., & Brown, G. (1993). The development of short-term memory span: Separable effects of speech rate and long-term memory. *Journal of Experimental Child Psychology, 56,* 431–442.

Schweikert, R. (1993). A multinomial processing tree model for degradation and redintegration in immediate recall. *Memory and Cognition, 21,* 168–175.

Service, E. (1992). Phonology, working memory, and foreign-language learning. *Quarterly Journal of Experimental Psychology, 45A,* 21–50.

Snowling, M., Chiat, S., & Hulme, C. (1991). Words, nonwords and phonological processes: Some comments on Gathercole, Willis, Emslie and Baddeley. *Applied Psycholinguistics, 12,* 369–373.

Treiman, R. (1983). The structure of spoken syllables: Evidence from novel word games. *Cognition, 15,* 49–74.

Treiman, R. (1984). On the status of final consonant clusters in English syllables. *Journal of Verbal Learning and Verbal Behaviour, 23,* 343–356.

Treiman, R. (1995). Errors in short-term memory for speech: A developmental study. *Journal of Experimental Psychology: Learning, Memory and Cognition, 21,* 1197–1208.

Treiman, R., & Danis, C. (1988). Short-term memory errors for spoken syllables are affected by the linguistic structure of the syllables. *Journal of Experimental Psychology: Learning, Memory and Cognition, 14,* 145–152.

Vitevitch, M. S., & Luce, P. A. (1999). Probabilistic phonotactics and neighborhood activation in spoken word recognition. *Journal of Memory and Language, 40,* 374–408.

Wagner, R. K., & Torgesen, J. K. (1987). The nature of phonological processing and its causal role in the acquisition of reading skills. *Psychological Bulletin, 101,* 192–212.

Wells, B. (1995). Phonological considerations in repetition tasks. *Cognitive Neuropsychology, 12,* 847–855.