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The phonological similarity effect in serial recognition

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An experiment is reported examining the effect of consistent phonemic similarity among list items on memory retention in a task that is independent of overt speech production, the serial recognition task. Lists of consonant-vowel-consonant (CVC) words and nonwords were constructed such that although phoneme overlap was manipulated (i.e., shared vowel and final consonant [_VC], initial consonant and vowel [CV_], or the two consonants [C_C]), similarity remained constant. The results show that the influence of sub-syllabic mechanisms on STM performance is independent of speech production processes, and similarity in the pattern of results suggests that the same mechanisms subserve the recall of words and nonwords in STM. It is argued that the results are more consistent with psycholinguistic models than nonlinguistic models of STM, and implications for current STM models are discussed.

One of the most widely used measures of short-term memory (STM) is the immediate serial recall task which traditionally requires the verbal report of list items in the order of presentation (Baddeley, 1966). A robust effect in this task is that lists of words are recalled better than nonsense syllables (e.g., Hulme, Maughan, & Brown, 1991; Hulme, Roodenrys, Brown, & Mercer, 1995). Termed the lexicality effect, this performance advantage has been used as evidence to support the notion that unlike nonwords, words undergo a redintegration process (Brown & Hulme, 1995), where pre-existing long-term memory (LTM) representations aid in the recall of incomplete traces held in STM (Schweickert, 1993).

Another factor that has been found to influence STM performance is the phonological similarity of the list items. This is the finding that STM performance is worse if the words in a list sound similar to each other (e.g., Baddeley, Lewis, & Vallar, 1984; Coltheart, 1993; Conrad & Hull, 1964; Fallon, Groves, & Tehan, 1999; Gathercole, Gardiner, & Gregg, 1982). This finding of an order memory impairment has recently been extended to situations where the stimuli are nonwords (e.g., Fallon, Mak, Tehan, & Daly, 2005; Gathercole, Pickering, Hall, & Peaker, 2001).

Although the majority of STM models include mechanisms to account for the effects that phonemic similarity and lexicality have on STM performance (e.g., Brown, Preece, & Hulme, 2000; Burgess & Hitch, 1992, 1999; Gupta & MacWhinney, 1997; Henson, 1998; Nairne, 1988, 1990, 2002; Page & Norris, 1998; Tehan & Fallon, 1999), a point of difference between these models is in the locus at which they assume these effects occur.

A core assumption proposed to account for the lexicality effect is that the redintegration process operates at the lexical level and, according to some models, the effect that similarity has on order memory is a consequence of this process (e.g., Brown et al., 2000; Burgess & Hitch, 1992, 1999). By this view, pre-existing LTM representations are used to aid in the recall of degraded STM traces. Taken literally, this implies that word recall benefits from these LTM representations,

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whereas nonword recall does not.[1] As such, researchers have suggested that phonemic similarity should not influence nonword performance (e.g., Brown & Hulme, 1995). However, some research findings are inconsistent with this view. For example, Besner and Davelaar (1982) found an order memory impairment for phonemically similar as compared to dissimilar nonword lists. This finding is problematic for STM models that assume this effect arises purely from pre-existing lexical representations competing in redintegration (e.g., Brown et al., 2000; Burgess & Hitch, 1992, 1999). This is not to suggest that these models would deny that lexical representations held in LTM can aid serial recall attempts. However, the redintegration process is assumed to operate at the lexical level and the phonological similarity effect is assumed to be a byproduct of this process. Hence, clear evidence of a phonological similarity effect when the stimuli are nonwords would, in itself, need to be addressed by these models.

A number of STM models do provide an explanation for the effect of phonemic similarity when the stimuli are nonwords by assuming that similar processes operate for word and nonword recall (Gupta & MacWhinney, 1997; Hartley & Houghton, 1996; Nairne, 1988, 1990, 2002). According to this view, the difference between word and nonword recall is one of degree, with item familiarity being the influential variable. Two classes of STM models can provide an explanation for the effect of phonemic similarity on nonword recall: nonlinguistic (Nairne, 1988, 1990, 2002) and psycholinguistic (Gupta & MacWhinney, 1997; Hartley & Houghton, 1996) models of STM. Both classes of model predict an order memory impairment for phonemically similar lists of items. However, as described below, each proposes different mechanisms to account for this effect.

Like other nonlinguistic STM models (e.g., Brown et al., 2000; Burgess & Hitch, 1992, 1999), the feature model (Nairne, 1988, 1990, 2002) is based on the ratio rule or distinctiveness assumption. This is the idea that the likelihood of recalling a target item is relative to the similarity of the target item to all of the other items that were presented in the same list (Luce, 1959; Nosofsky, 1986). Accordingly, STM models that are based on the distinctiveness assumption argue that as phonemic similarity between list items increases, order memory should decrease.

In contrast, psycholinguistic models of STM (see Gupta & MacWhinney, 1997; Hartley & Houghton, 1996) assume that sub-syllabic linguistic processes are responsible for the effect that phonemic similarity has on order memory. One linguistic principle that has been incorporated into these models is sonority. Sonority refers to the energy of a speech trace, and the sonority principle to the idea that the energy of a speech trace increases to a peak at the vowel and then decreases (Treiman, 1984). Accordingly, the speech trace for vowels as compared to consonants will be stronger because the trace is both longer in duration and more acoustically intense than it is for consonants (see Service, Maury, & Luotoniemi, 2005, for a similar argument). Therefore, according to these models, any form of similarity should impair order memory but the greatest impairment will be seen when the vowel is shared, as this is the most strongly represented phoneme in a speech trace.

One difficulty in evaluating STM model accounts of the phonological similarity effect is the inconsistency of findings in the research literature. Although the standard order memory impairment for phonemically similar lists of words is observed for correct-in-position performance (i.e., scored as correct if a participant recalls the correct item in the correct position; e.g., Baddeley, 1966; Nimmo & Roodenrys, 2004), when the stimuli are nonwords, an order memory advantage has been found (e.g., Fallon et al., 2005). These findings suggest either that different STM processes are involved when recalling words as compared to nonwords (Brown & Hulme, 1995), or that other factors inherent in verbal recall tasks, such as speech production processes, influence the findings from nonword studies.

A number of studies have recently examined the phonological similarity effect with the serial recognition task—a task that does not require the verbal recall of presented list items, yet is similar to the standard serial recall task.[2] In one study,

[1] This view has recently been tempered with the suggestion that nonwords that are high in wordlikeness may also undergo a redintegration process (see Saint-Aubin & Poirier, 2000).

[2] This task involves presenting a list of items to participants and then re-presenting either the same items in the same order, or the same items in a different order (Campbell & Butterworth, 1985; Martin & Breedin, 1992; Martin, Lesch, & Bartha, 1999). A participant's task is to say whether the items that were re-presented were in the "same" or a "different" order (e.g., log, bog, hog, and then bog, log, hog).

Gathercole et al. (2001; see also Henson, Hartley, Burgess, Hitch, & Flude, 2003; Thorn, Gathercole, & Frankish, 2002) found the standard phonological similarity effect (i.e., better recognition of dissimilar than similar lists) regardless of whether the stimuli were words or nonwords (Experiments 3B & 4B). Although Lian, Karlsen, and Winsvold (2001) found an identical pattern of results for word lists, when nonwords were rated low in associative value (i.e., low in wordlikeness), they found no differences between phonemically dissimilar and similar nonword lists. However, Lian et al. (2001) did not define what they meant by similarity.[3] This is important, in that recent research suggests that different results are found as a consequence of how similarity has been defined (Fallon et al., 1999; Nimmo & Roodenrys, 2004, in press). To further complicate this issue, contrary to the results reported by Gathercole et al. (2001), Lian and Karlen (2004) recently found no differences between rhyming and phonemically dissimilar lists, and an order memory advantage for nonword lists that shared the consonants (i.e., C_C lists) as compared to phonemically dissimilar nonwords. Hence, one aim of the current study was to elucidate the effect of phonological similarity for order memory with a task that is independent of overt speech production.

Given that previous research (e.g., Nimmo & Roodenrys, 2004, in press) suggests that the phonemic similarity effect is influenced by sub-syllabic linguistic mechanisms, similarity was defined in a number of different ways. For example, lists of CVC words and nonwords were constructed that shared the rhyme (_VC), the initial consonant and vowel (CV_) or both consonants (C_C)—thus changing the position of the overlapping phonemes across conditions, yet keeping the amount of phonemic overlap constant.

A further aim for conducting the current study was to clarify the nature of the phonological similarity effect on order memory for words and nonwords. An incongruent pattern of results for words and nonwords would suggest that different STM processes are operating when recalling these types of stimuli. Alternatively, an identical pattern of results would suggest that similar processes are involved in recall, and that the inconsistent results that have been reported in the research literature using the correct-in-position criterion (see Fallon et al., in press; Nimmo & Roodenrys, 2004), are due to differences in overt speech production demands between words and nonwords. Finally, the primary reason for conducting the current study was to distinguish between the predictions that nonlinguistic and psycholinguistic STM models generate for the effect of phonemic similarity on order memory with a task that does not require oral recall.

As outlined above, two types of STM models (nonlinguistic and psycholinguistic) provide explanations for the effect of phonological similarity on nonword recall. According to nonlinguistic STM models (e.g., Nairne, 1988, 1990) as similarity increases, order memory should decrease. Hence, these models predict an order memory impairment for phonemically similar (i.e., sharing some phonemic overlap) as compared to dissimilar lists, and an even greater impairment for lists that are consistently similar (i.e., _VC, CV_ and C_C conditions) as these items share a greater number of overlapping phonemes than do phonemically similar lists. Importantly, these models predict that order memory should be impaired to the same extent for the consistently similar lists, as these lists share the same amount of phonemic overlap. In contrast, psycholinguistic models of STM (Gupta & MacWhinney, 1997; Hartley & Houghton, 1996) predict that any form of phonemic similarity should impair order memory (i.e., phonemically similar as compared to dissimilar lists), but the greatest impairment will be seen when the overlapping phoneme is the vowel (i.e., _VC, CV_ and the phonemically similar lists in the C_C condition).

METHOD

Participants

A total of 216 undergraduate psychology students from the University of Wollongong participant pool (54 males and 162 females), with an age range from 17 to 49 years ($M = 21$), participated in compliance with a course requirement. Only native Australian English speakers who indicated having no prior problems with hearing participated in the study.

[3] Please note that Lian et al. (2001, Experiment 1A), did not provide enough detail as to how the phonemically similar stimulus sets were constructed (i.e., list items that shared a vowel, an initial, or final consonant, or a mixture of phonemes in different positions).

Stimuli

Two stimulus sets were constructed that comprised either 540 words or 540 nonwords with a consonant-vowel-consonant (CVC) structure.

Word pool. Three stimulus sets were constructed from the chosen 540 words (see Figure 1). The stimuli were used to create 90 six-word lists that were consistently similar where all of the stimuli in a list shared two phonemes (i.e., 30 _VC, 30 CV_ and 30 C_C lists). Thus, each word pool comprised 180 words (see Nimmo & Roodenrys, 2004).

The 180 stimuli from each set were used to create a further 30 phonemically similar and 30 phonemically dissimilar six-word lists (see Figure 1). Thus, each word in a stimulus set was sampled three times, such that each appeared in one consistently similar, one phonemically similar, and one phonemically dissimilar list.

For the consistently similar conditions all of the stimuli in a particular list shared the _VC (e.g., Name, Came, Maim, Lame, Dame, and Shame), the CV_ (e.g., Time, Ties, Tight, Type, Tide, and Tile), or the C_C (e.g., Bought, Bet, Boot, But, Bat, and Bait) component. For the phonemically similar conditions, each stimulus in each list shared two phonemes with at least one other stimulus in the same list (e.g., Name, Knock, Need, Knees, Gnome, and Not). Finally, for the dissimilar conditions, each stimulus in each list did not share any phonemes with any other stimulus in that list (e.g., Name, Cot, Soul, Died, Pig, and Hub).

Nonword pool. Construction of the nonword pools and subsequent lists was identical to the method outlined for the words, except that the stimuli were nonsense syllables (see Appendix, Tables A1–A3).

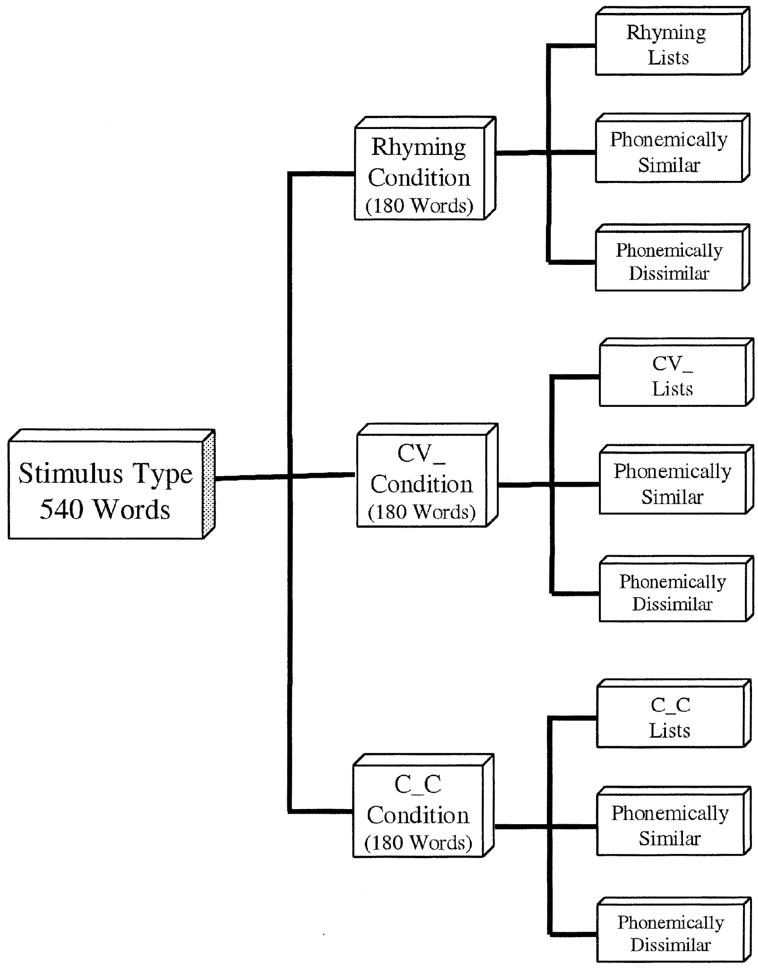

Figure 1. Flow chart of the experimental conditions and stimuli lists used in the current study.

Using an Arista Cardioid dynamic microphone (Model number DM-904D), the stimuli were recorded using a Sony Minidisc Deck (Model Number: MDS-JE640) in a sound-attenuated booth by a female speaker with an Australian English accent. Each stimulus was transferred digitally onto a Macintosh computer and normalised to control for possible amplitude effects on recognition performance.

Procedure

A total of 90 participants were presented with lists of words. The remaining 126 participants were presented with stimulus lists comprising nonwords. One third of the participants in each group were assigned to the rhyming stimulus set, one third to the CV_ set, and the remainder to the C_C set (i.e., 30 participants in each group for the words and 42 when the stimuli were nonwords). Thus, lexicality and stimulus set were between-subjects factors. Across all conditions, two practice lists were given to each participant prior to the presentation of the first experimental list. The stimulus sets for each condition were presented in three blocks of 30 trials. The order of the blocks within the experimental session was counterbalanced across participants. The order of the trials in each block and the order in which the items occurred in each list were randomised for all participants.

Each participant was auditorily presented with either six words or nonwords (target list) at a rate of one item per second. The same six items were then re-presented to each participant (comparison list). Stimulus presentation rate was controlled using Hypercard (version 2.4.1). One second after the presentation of the last item in a list, participants heard a 200 ms, 500 Hz tone, which was used as a response signal. The participant's task was to say whether the items in the comparison list were in the same (15 lists) or a different order (15 lists) to the target list. Hence, the only difference between the two list presentations was whether the items in the comparison list were presented in exactly the same order as the target list or whether two of the list items had been transposed. The number of transpositions was counterbalanced across each condition. Thus, of the 15 comparison lists where two of the items had been transposed, three transpositions occurred at each position (i.e., position 1 with 2, 2 with 3, 3 with 4, 4 with 5 and 5 with 6). The participant's response was scored immediately after each comparison list was presented. The time taken for each participant to complete all three conditions was approximately 40 minutes.

RESULTS

The mean numbers of correct responses were collated for words and nonwords when the stimuli were phonemically dissimilar, similar, or consistently similar for the three stimulus sets (see Table 1). To control for potential shifts in bias, or levels of attention for each participant, hits and false alarm rates were collated and used to calculate a *d* prime (d') value. The d' data were analysed using a 2 (lexicality) × 3 (stimulus set) × 3 (phonemic similarity) mixed design analysis of variance (ANOVA). Figure 2 summarises the resulting d' values for the three stimulus sets and similarity conditions. Unless otherwise specified, alpha was set at .05 (two-tailed), and an identical pattern of results was found regardless of whether the analyses were performed on the number of correct trials or the mean d' values obtained.

The d' analysis revealed a main effect of Phonological Similarity, $F(2, 420) = 60.775$, $MSe = .342$, but no effect of Lexicality $F(1, 210) = 2.456$, $MSe = .695$, *ns*, or Stimulus Set, $F(2, 210) = 0.314$, $MSe = .695$, *ns* (see Figure 2). The interaction between Similarity and Stimulus Set was significant, $F(4, 420) = 6.189$, $MSe = .342$, however no other interactions reached significance: Similarity × Lexicality, $F(2, 420) = 1.786$, $MSe = .342$, *ns*;

TABLE 1
Mean proportions (with SD) of lists correctly recognised as a function of lexicality, stimulus set, and similarity condition

	Words		Nonwords	
Stimulus set	*M*	*SD*	*M*	*SD*
Rhyming				
Consistently similar	0.62	0.09	0.60	0.10
Similar	0.63	0.07	0.63	0.10
Dissimilar	0.70	0.10	0.68	0.12
*CV_*				
Consistently similar	0.57	0.13	0.58	0.08
Similar	0.65	0.09	0.64	0.10
Dissimilar	0.71	0.13	0.68	0.10
C_C				
Consistently similar	0.66	0.11	0.62	0.11
Similar	0.61	0.10	0.59	0.08
Dissimilar	0.73	0.11	0.68	0.10

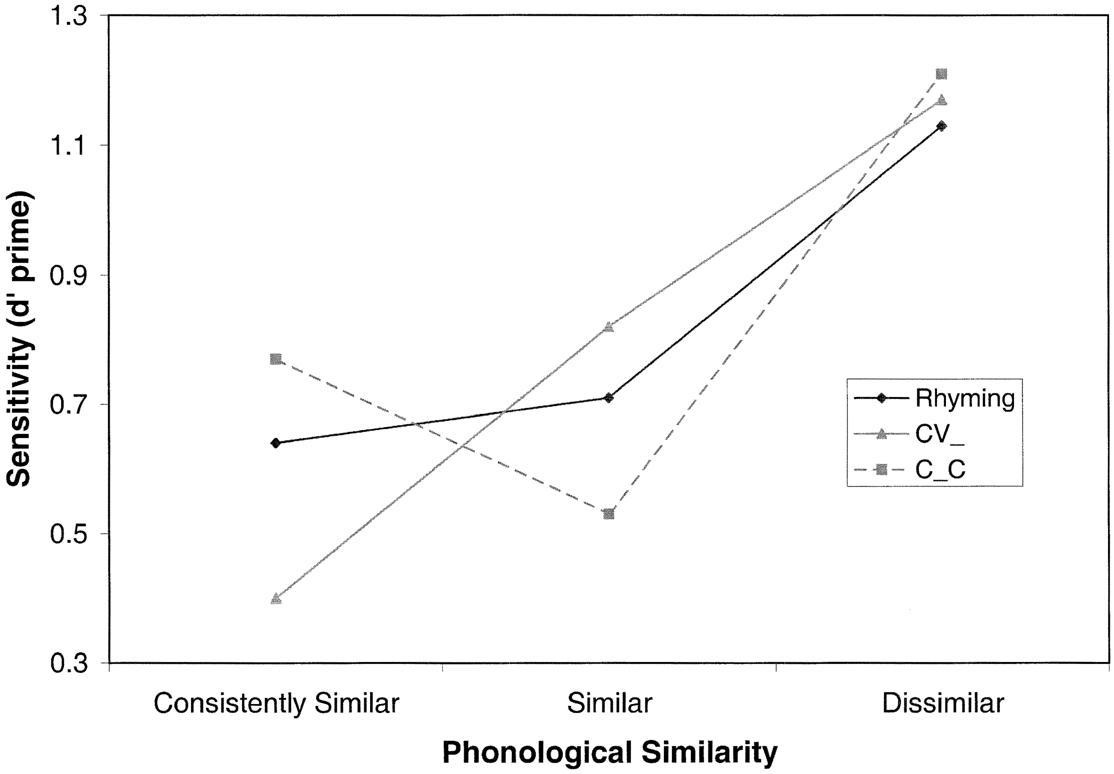

Figure 2. Mean d′ values for the three stimulus sets as a function of phonemic similarity.

Stimulus Set × Lexicality, $F(2, 210) = 1.462$, $MSe = .695$, *ns*; Similarity × Lexicality × Stimulus Set, $F(4, 420) = 0.452$, $MSe = .342$, *ns*.

As no effect of Lexicality was observed, the following analyses combined the word and nonword data. Post-hoc paired samples *t*-tests were used to analyse the main effect of phonological similarity for each stimulus set. Further, alpha was set at .0167 (two-tailed) to control for the increased probability of committing a Type I error as a function of the number of comparisons performed, thus keeping the family-wise error rate at .05.

For the rhyming (_VC) set, the analyses revealed that order memory was better for phonemically dissimilar compared to either of the similar conditions—rhyming, $t(71) = 4.602$, $p < .0167$; phonemically similar, $t(71) = 4.246$, $p < .0167$—which did not differ, $t(71) = 0.843$, *ns.* For the CV_ set, the analyses revealed that order memory was better for phonemically dissimilar compared to the phonemically similar lists, $t(71) = 3.839$, $p < .0167$, which was better than when the experimental lists consisted of items that shared the CV_ component, $t(71) = 4.385$, $p < .0167$. Finally, for the C_C set, the post-hoc analyses revealed that order memory was better when the stimuli were phonemically dissimilar compared to lists that shared the C_C component, $t(71) = 5.176$, $p < .0167$, which was better than when the stimuli were phonemically similar, $t(71) = 2.458$, $p < .0167$ (please note that no difference between the C_C and phonemically similar conditions was found when the analysis was performed using the mean proportions of correct responses).

DISCUSSION

Although some researchers suggest that the same processes are involved in word and nonword recall (e.g., Fallon et al., 2005), others have argued that different STM processes are involved (e.g., Brown & Hulme, 1995). Therefore, one aim of conducting the current research was to examine whether the differences observed in the literature for words (Nimmo & Roodenrys, 2004) as compared to nonwords (Fallon et al., 2005) when order memory is measured using the correct-in-position criterion are a product of different STM processes. The current findings go a long way towards clarifying this issue. For instance, the current study found no lexicality effect for order recognition judgements. In other words, a participant's ability to recognise that a list was in the "same" or a "different" order was unaffected by whether the stimuli were words or nonwords.

The finding of no performance differences between words and nonwords observed in the current study is not entirely surprising. Although Gathercole et al. (2001, Experiment 1) found an overall lexicality effect, no differences in serial recognition performance were observed for lists that contained fewer than six items. According to Gathercole et al. (2001), the lexicality effect should be evident whenever the task requires the retention of item information, and attenuated or absent when the task does not. As such, the results observed in the current study lend strong support to the idea that similar STM processes are involved in both word and nonword recall (Fallon et al., 2005) and that it is the articulatory ability of participants that influences the results obtained when participants are required to orally recall nonword lists (Gathercole, Service, Hitch, Adams, & Martin, 1999).

In line with previous research (Gathercole et al., 2001; Henson et al., 2003; Thorn et al., 2002), the current study found an order memory impairment for phonemically similar lists of items. In other words, order memory was better for dissimilar compared to any of the consistently or phonemically similar stimulus lists (although see Lian & Karlsen, 2004, for the reverse effect). Hence, these findings suggest that the effect of phonemic similarity on order memory persists, once the demands that overt speech production has on STM performance are removed.

The main impetus for conducting the current study was to discriminate between the predictions of nonlinguistic (Nairne, 1988, 1990, 2002) and psycholinguistic (Gupta & MacWhinney, 1997; Hartley & Houghton, 1996) STM models for the effect of phonological similarity on order memory. This is important in that the effect that sub-syllabic linguistic mechanisms have on STM performance and the implications of this for extant STM models have previously only been demonstrated with the serial recall task which requires spoken recall (Nimmo & Roodenrys, 2004, in press).

According to nonlinguistic STM models (Nairne, 1988, 1990, 2002), as similarity increases, order memory should decrease. Hence, the predictions generated by these models are consistent with the finding that order memory was poorer for CV_ as compared to the phonemically similar lists. However, the finding of no order memory differences between phonemically similar and rhyming lists of stimuli, and an order memory advantage for C_C as compared to the phonemically similar lists, despite the greater similarity in the rhyming and C_C conditions, is problematic for nonlinguistic models of STM that are based on the distinctiveness assumption.

In contrast, psycholinguistic models of STM (Gupta & MacWhinney, 1997; Hartley & Houghton, 1996) suggest that any form of phonemic similarity should have a detrimental effect on order memory, but the greatest impairment will be seen when the vowel is shared. These predictions are consistent with the current findings, in that order memory was impaired to a greater extent when list items shared the vowel (i.e., _VC,[4] CV_, and the phonemically similar lists in the C_C condition) compared to when they did not.

One criticism that could be levelled at the conclusions drawn from the current study derives from the finding that although _VC and CV_ lists shared both a common vowel and the same amount of phonemic overlap, order memory was not impaired to the same extent for _VC as compared to CV_ lists (see Figure 2). However, as Nairne and Kelly (2004, p. 113) suggest, "... memory tests are not 'process pure'." Further, Nimmo and Roodenrys (2004a) have found that item recall is higher for rhyming and poorer for CV_ lists of words. Hence, these differences may be a result of differences in item recall levels across conditions rather than due to differing levels of order memory impairment.

A second criticism that may emerge from the conclusions drawn from this study is what some may consider the unfair treatment of nonlinguistic STM models. For instance, one could argue that it is not the case that nonlinguistic models of STM deny the importance of sub-syllabic linguistic mechanisms for recall, but rather that by not making specific claims as to what is meant by similarity, these models remain mute on the subject. Moreover, taken to its extreme, one could argue that slight modifications to any number of nonlinguistic STM models may provide these models with plausible mechanisms in which to account for these linguistic effects. This last

[4] Although non-significant, the findings were in the direction predicted, with poorer order memory for rhyming as compared to phonemically similar lists.

criticism may even be true. However, the main impetus for the current study was not to show that these models cannot be modified to include linguistic constraints on STM performance, but merely to illuminate the inadequacies of STM models that are based on the distinctiveness assumption, and in doing so, highlight an area of research (i.e., linguistics) that has been neglected by STM modellers.

To reiterate, the novel finding of a sub-syllabic influence on order memory, with an STM task that is independent of overt speech production, lends further support to the claim that the influence of sub-syllabic mechanisms on STM performance is a genuine memory effect and not simply due to speech production processes or factors such as the ease of the articulatory transitions between lists items (see Murray & Jones, 2002). Importantly, the findings from the current study are clearly consistent with the predictions generated by psycholinguistic models of STM (Gupta & MacWhinney, 1997; Hartley & Houghton, 1996), and argue against STM models that rely on the distinctiveness or ''phonemic overlap'' assumption to explain the effect of phonological similarity on order memory (e.g., Brown et al., 2000; Burgess & Hitch, 1992, 1999; Nairne, 1988, 1990, 2002). Hence, future STM models will need to incorporate the mechanisms necessary to deal with linguistic processes that operate at the sub-syllabic level to constrain STM performance.

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APPENDIX

TABLE A1
Nonword lists and IPA codes for the rhyming condition

Stimuli	*IPA codes*	*Stimuli*	*IPA codes*	*Stimuli*	*IPA codes*	*Stimuli*	*IPA codes*	*Stimuli*	*IPA codes*	*Stimuli*	*IPA codes*
vame	veɪm	hame	heɪm	yame	jeɪm	wame	weɪm	zame	zeɪm	rame	reɪm
hace	heɪs	zace	zeɪs	tace	teɪs	nace	neɪs	wace	weɪs	yace	jeɪs
taych	teɪtʃ	naych	neɪtʃ	waych	weɪtʃ	yaych	jeɪtʃ	gaych	geɪtʃ	paych	peɪtʃ
payb	peɪb	fayb	feɪb	nayb	neɪb	wayb	weɪb	hayb	heɪb	rayb	reɪb
shiep	ʃaɪp	fiep	faɪp	kiep	kaɪp	diep	daɪp	liep	laɪp	miep	maɪp
shied	ʃaɪd	kied	kaɪd	mied	maɪd	zied	zaɪd	yied	jaɪd	chied	tʃaɪd
chiet	tʃaɪt	yiet	jaɪt	giet	gaɪt	ziet	zaɪt	viet	vaɪt	diet	daɪt
fieb	faɪb	hieb	haɪb	mieb	maɪb	gieb	gaɪb	kieb	kaɪb	lieb	laɪb
boke	bəʊk	doke	dəʊk	shoke	ʃəʊk	noke	nəʊk	hoke	həʊk	roke	rəʊk
gome	gəʊm	pome	pəʊm	lome	ləʊm	chome	tʃəʊm	bome	bəʊm	shome	ʃəʊm
yone	jəʊn	vone	vəʊn	pone	pəʊn	chone	tʃəʊn	wone	wəʊn	rone	rəʊn
wole	wəʊl	chole	tʃəʊl	nole	nəʊl	lole	ləʊl	vole	vəʊl	yole	jəʊl
gin	gɪn	zin	zɪn	hin	hɪn	rin	rɪn	min	mɪn	vin	vɪn
shid	ʃɪd	gid	gɪd	nid	nɪd	fid	fɪd	vid	vɪd	zid	zɪd
hig	hɪg	chig	tʃɪg	nig	nɪg	vig	vɪg	kig	kɪg	shig	ʃɪg
ning	nɪŋ	hing	hɪŋ	ging	gɪŋ	ming	mɪŋ	fing	fɪŋ	shing	ʃɪŋ
neech	nɪːtʃ	geech	gɪːtʃ	heech	hɪːtʃ	veech	vɪːtʃ	cheech	tʃɪːtʃ	yeech	jɪːtʃ
teep	tɪːp	veep	vɪːp	feep	fɪːp	geep	gɪːp	yeep	jɪːp	meep	mɪːp
deek	dɪːk	heek	hɪːk	neek	nɪːk	feek	fɪːk	yeek	jɪːk	veek	vɪːk
weeb	wɪːb	teeb	tɪːb	heeb	hɪːb	cheeb	tʃɪːb	veeb	vɪːb	reeb	rɪːb
boz	bɒz	moz	mɒz	toz	tɒz	voz	vɒz	zoz	zɒz	poz	pɒz
shog	ʃɒg	pog	pɒg	chog	tʃɒg	tog	tɒg	mog	mɒg	zog	zɒg
chot	tʃɒt	zot	zɒt	mot	mɒt	fot	fɒt	vot	vɒt	bot	bɒt
mun	mʌn	yun	jʌn	kʌn	kvn	zun	zʌn	lun	lʌn	hun	hʌn
wug	wʌg	zug	zʌg	vug	vʌg	shug	ʃʌg	kug	kʌg	gug	gʌg
lub	lʌb	fub	fʌb	gub	gʌb	shub	ʃʌb	mub	mʌb	wub	wʌb
wut	wʌt	vut	vʌt	zut	zʌt	yut	jʌt	chut	tʃʌt	fut	fʌt
vang	væŋ	mang	mæŋ	nang	næŋ	dang	dæŋ	wang	wæŋ	shang	ʃæŋ
bam	bæm	nam	næm	fam	fæm	cham	tʃæm	vam	væm	gam	gæm
fap	fæp	vap	væp	wap	wæp	bap	bæp	dap	dæp	shap	ʃæp

TABLE A2
Nonword lists and IPA codes for the CV_ condition

Stimuli	*IPA codes*	*Stimuli*	*IPA codes*	*Stimuli*	*IPA codes*	*Stimuli*	*IPA codes*	*Stimuli*	*IPA codes*	*Stimuli*	*IPA codes*
mayp	meɪp	mayv	meɪv	mayg	meɪg	mayf	meɪf	maych	meɪtʃ	maysh	meɪʃ
says	seɪs	sayp	seɪp	sayg	seɪg	sayng	seɪŋ	saych	seɪtʃ	saysh	seɪʃ
waysh	weɪʃ	ways	weɪs	waych	weɪtʃ	waym	weɪm	wayb	weɪb	wayg	weɪg
raych	reɪtʃ	raysh	reɪʃ	rayg	reɪg	rayng	reɪŋ	raym	reɪm	rayf	reɪf
lieg	laɪg	lieng	laɪŋ	liech	laɪtʃ	liesh	laɪʃ	liedge	laɪdʒ	lieb	laɪb
riech	raɪtʃ	riedge	raɪdʒ	riesh	raɪʃ	riev	raɪv	rieng	raɪŋ	rieg	raɪg
tiech	taɪtʃ	tiesh	taɪʃ	tieng	taɪŋ	tieg	taɪg	tiev	taɪv	tiedge	taɪdʒ
wieb	waɪb	weish	waɪʃ	wieng	waɪŋ	wies	waɪs	wiem	waɪm	wieg	waɪg
birsh	bɜːʃ	birf	bɜːf	birng	bɜːŋ	birm	bɜːm	birv	bɜːv	birdge	bɜːdʒ
pirsh	pɜːʃ	pirg	pɜːg	pirng	pɜːŋ	pirb	pɜːb	pirf	pɜːf	pirp	pɜːp
kav	kæv	kas	kæs	kaz	kæz	kang	kæŋ	kag	kæg	kadge	kædʒ
taf	tæf	tadge	tædʒ	tas	tæs	tach	tætʃ	tam	tæm	taz	tæz
nang	næŋ	nav	næv	naz	næz	nadge	nædʒ	nam	næm	nas	næs
waz	wæz	waf	wæf	wadge	wædʒ	wach	wætʃ	wav	wæv	was	wæs
lig	lɪg	lish	lɪʃ	lidge	lɪdʒ	lif	lɪf	lis	lɪs	lib	lɪb
pish	pɪʃ	piv	pɪv	pim	pɪm	pidge	pɪdʒ	pib	pɪb	pif	pɪf
bish	bɪʃ	bim	bɪm	biv	bɪv	bis	bɪs	bidge	bɪdʒ	bing	bɪŋ
seeb	sɪːb	seech	sɪːtʃ	seesh	sɪːʃ	seef	sɪːf	seeg	sɪːg	seev	sɪːv
weesh	wɪːʃ	wees	wɪːs	weef	wɪːf	weem	wɪːm	weeg	wɪːg	weedge	wɪːdʒ
beev	bɪːv	beesh	bɪːʃ	bees	bɪːs	beeg	bɪːg	beeb	bɪːb	beedge	bɪːdʒ
kuz	kʌz	kung	kʌŋ	kuv	kʌv	kuch	kʌtʃ	kug	kʌg	kun	kʌn
lus	lʌs	lum	lʌm	luz	lʌz	lub	lʌb	lun	lʌn	luch	lʌtʃ
mup	mʌp	muv	mʌv	mus	mʌs	mun	mʌn	mudge	mʌdʒ	muz	mʌz
ruch	rʌtʃ	rudge	rʌdʒ	rus	rʌs	ruv	rʌv	rup	rʌp	ruz	rʌz
loz	lɒz	loch	lɒtʃ	lon	lɒn	lom	lɒm	lof	lɒf	lov	lɒv
hodge	hɒdʒ	hon	hɒn	hob	hɒb	hoch	hɒtʃ	hos	hɒs	hoz	hɒz
tog	tɒg	tov	tɒv	todge	tɒdʒ	tosh	tɒʃ	toch	tɒtʃ	toz	tɒz
porv	pɔːv	porp	pɔːp	porg	pɔːg	porf	pɔːf	pors	pɔːs	porm	pɔːm
worb	wɔːb	worg	wɔːg	worch	wɔːtʃ	worv	wɔːv	wors	wɔːs	worsh	wɔːʃ
harb	hɒːb	harn	hɒːn	hardge	hɒːdʒ	hars	hɒːs	harz	hɒːz	harch	hɒːtʃ

TABLE A3
Nonword lists and IPA codes for the C_C condition

Stimuli	*IPA codes*	*Stimuli*	*IPA codes*	*Stimuli*	*IPA codes*	*Stimuli*	*IPA codes*	*Stimuli*	*IPA codes*	*Stimuli*	*IPA codes*
bech	bɛtʃ	barch	bɑːtʃ	borch	bɔːtʃ	baych	beɪtʃ	biech	baɪtʃ	buch	bʌʃ
bidge	bɪdʒ	bedge	bɜdʒ	birdge	bɜːdʒ	baydge	beɪdʒ	biedge	baɪdʒ	bodge	bɒdʒ
bish	bɪʃ	borsh	bɔːʃ	biesh	baɪʃ	barsh	bɑːʃ	baysh	beɪʃ	bush	bʌʃ
biv	bɪv	bav	bæv	barv	bɑːv	birv	bɜːv	bayv	beɪv	bov	bɒv
chaf	tʃæf	chof	tʃɒf	charf	tʃɑːf	chirf	tʃɜːf	chief	tʃaɪf	chorf	tʃɔːf
cheg	tʃɛg	chog	tʃɒg	charg	tʃɑːg	chirg	tʃɜːg	chag	tʃæg	chorg	tʃɔːg
didge	dɪdʒ	dedge	dɛdʒ	dadge	dædʒ	dudge	dʌdʒ	dardge	dɑːdʒ	diedge	daɪdʒ
div	dɪv	dav	dæv	dov	dɒv	darv	dɑːv	dirv	dɜːv	dorv	dɔːv
diz	dɪz	dez	dɛz	daz	dæz	doz	dɒz	darz	dɑːz	dirz	dɜːz
gim	gɪm	girm	gɜːm	garm	gɑːm	gorm	gɔːm	geem	gɪːm	gem	gɛm
gin	gɪn	geen	gɪːn	garn	gɑːn	gen	gɛn	girn	gɜːn	gon	gɒn
haf	hæf	heef	hɪːf	hirf	hɜːf	hayf	heɪf	hief	haɪf	hof	hɒf
han	hæn	hon	hɒn	hirn	hɜːn	hayn	heɪn	hien	haɪn	harn	hɑːn
hees	hɪːs	hos	hɒs	hars	hɑːs	hays	heɪs	hies	haɪs	hus	hʌs
hom	hɒm	heem	hɪːm	hirm	hɜːm	haym	heɪm	hiem	haɪm	horm	hɔːm
larv	lɑːv	lev	lɛv	lorv	lɔːv	lav	læv	layv	leɪv	lov	lɒv
lef	lɛf	laf	læf	lof	lɒf	lirf	lɜːf	layf	leɪf	luf	lʌf
lidge	lɪdʒ	liedge	lardʒ	lordge	lɔːdʒ	ladge	lædʒ	laydge	leɪdʒ	ludge	lʌdʒ
lish	lɪʃ	lesh	lɛʃ	liesh	laɪʃ	lirsh	lɜːʃ	laysh	leɪʃ	larsh	lɑːʃ
res	rɛs	ras	ræs	rars	rɑːs	rors	rɔːs	rirs	rɜːs	rus	rʌs
riz	riz	rez	rɛz	raz	ræz	rarz	rɑːz	rirz	rɜːz	ruz	rʌz
tas	tæs	tus	tʌs	tors	tɔːs	tays	teɪs	ties	taɪs	tees	tɪːs
tog	tɒg	targ	tɑːg	torg	tɔːg	tayg	teɪg	tieg	taɪg	teeg	tɪːg
wadge	wædʒ	wudge	wʌdʒ	wirdge	wɜːdʒ	wardge	wɑːdʒ	wiedge	waɪdʒ	wodge	wɒdʒ
wem	wɛm	wum	wʌm	weem	wɪːm	warm	wɑːm	wiem	waɪm	waym	weɪm
wesh	wɛʃ	wash	wæʃ	wush	wʌʃ	waysh	weɪʃ	wiesh	waɪʃ	warsh	wɑːʃ
yeb	jɛb	yeeb	jɪːb	yarb	jɑːb	yab	jæb	yieb	jaɪb	yirb	jɜːb
yeg	jɛg	yeeg	jɪːg	yog	jɒg	yarg	jɑːg	yag	jæg	yayg	jeɪg
yek	jɛk	yeek	jɪːk	yock	jɒk	yark	jɑːk	yiek	jaɪk	yayk	jeɪk
yem	jɛm	yeem	jɪːm	yorn	jɒm	yarm	jɑːm	yim	jɪm	yirm	jɜːm