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Journal of Memory and Language 53 (2005) 141–162
Journal of Memory and Language
www.elsevier.com/locate/jml

Serial position effects in nonword repetition ☆

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Received 21 May 2004; revision received 11 December 2004
Available online 14 March 2005

Abstract

A growing body of research has emphasized the linkage between performance in immediate serial recall of lists, nonword repetition, and word learning. Recently, it has been reported that primacy and recency effects are obtained in repetition of individual syllables within nonwords (Gupta, in press). Five experiments examined whether such within-nonword primacy and recency effects are attributable to common sequencing mechanisms that are shared with immediate list recall. Experiments 1 and 2 indicated that the primacy and recency effects are not simply due to greater morphological salience at the beginnings/endings of nonwords, and that the serial position effects generalize to different stimuli and across a variety of stimulus lengths. Experiment 3 indicated that the primacy and recency effects are similar to those obtained in list recall. Experiments 4 and 5 examined alternative hypotheses for the observed serial position effects, concluding that the alternative hypotheses fail to account for the obtained pattern of results. These results provide support for the common sequencing mechanisms hypothesis. The implications of these results are discussed in terms of the relationship between list recall and nonword repetition, and in terms of broader issues in word learning.

Keywords: Nonwords; Word learning; Immediate serial recall; Primacy; Recency

In recent years, investigation of verbal short-term memory as studied in immediate list recall tasks has acquired new directions, following the finding of relationships between list recall ability, nonword repetition ability, and the learning of new words. Evidence for such relationships has come from a wide variety of sources. In children, reliable correlations have been obtained between digit span, nonword repetition ability, and vocabulary achievement, even when other possible factors such as age and nonverbal intelligence have been factored out (e.g., Gathercole & Baddeley, 1989; Gathercole, Willis, Emslie, & Baddeley, 1992; Gathercole, Service, Hitch, Adams, & Martin, 1999; Gupta, MacWhinney, Feldman, & Sacco, 2003). Nonword repetition ability has been shown to be an excellent predictor of language learning ability in children learning English as a second language (Service, 1992; Service & Kohonen, 1995), and is also associated with more rapid learning of the phonology of new words by children in experimental tasks (Gathercole & Baddeley, 1990b; Gathercole, Hitch, Service, & Martin, 1997; Gupta et al., 2003; Michas & Henry, 1994). In addition, similar relationships between these abilities have been demonstrated in normal adults, both correlationally (Gupta, 2003) and in

☆ We thank Gary Dell for helpful comments on this work, and Matthew Brown, Sara Even, Naveen Khetarpal, James Malicki, Byron Murphy, Sarah Oakley, Millisa Reynolds, Ellen Samuel, Kathleen Schnitker, Sierra Spies, and Linda Wood for assistance in conducting and transcribing experiments.
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doi:10.1016/j.jml.2004.12.002

experimental investigation of factors that affect both list recall and the learning of new words (Atkins & Baddeley, 1998; Papagno, Valentine, & Baddeley, 1991; Papagno & Vallar, 1992). It also appears that there is a population of neuropsychologically impaired patients in whom language function is largely preserved, but who exhibit selective deficits in immediate serial recall and in nonword repetition and word learning ability (Baddeley, 1993; Baddeley, Papagno, & Vallar, 1988). These relationships have also been demonstrated under developmental language impairment (Gathercole & Baddeley, 1989, 1990a; Gupta et al., 2003). Overall, there is now a considerable body of evidence to suggest that word learning, immediate serial recall, and nonword repetition are a related triad of abilities. An emerging view of this relationship is that immediate serial recall and nonword repetition are both tasks that draw on the mechanisms of verbal short-term memory fairly directly, and that the learning of new words is also in some way supported by verbal short-term memory (e.g., Baddeley, Gathercole, & Papagno, 1998; Brown & Hulme, 1996; Gathercole et al., 1999; Gupta, 2003; Gupta & MacWhinney, 1997).

From the point of view of an individual learner, every new word is in effect a nonword when first encountered, and every known word was once a nonword to that learner. Greater facility in processing nonwords would therefore be expected to lead to greater facility in eventually learning them, thus providing intuition for why there might be a relationship between nonword repetition and word learning. But what of the relationship between nonwords and immediate serial memory? Why are these abilities correlated? In what sense might immediate repetition of a nonword be a verbal short-term memory task, as is commonly assumed? One possibility might be that a nonword is literally processed like a list (i.e., a sequence of sounds) when it is first encountered (Cumming, Page, & Norris, 2003; Gupta, 1996; Gupta, 2002, in press; Gupta & MacWhinney, 1997; Hartley & Houghton, 1996). If this were the case, it might make sense for sequencing mechanisms similar to those underlying list recall in a typical immediate serial recall task to also be engaged in recall of the sequence of sounds comprising a nonword. This would provide a simple explanation of the relationships observed between immediate serial recall and nonword repetition. The question then arises of how we might examine such a hypothesis. Before considering this question, however, let us consider why this hypothesis might be worth examining in the first place.

It is useful to distinguish four traditions of inquiry, each of which would view this hypothesis quite differently. One of these traditions of inquiry has already been described: it is the line of investigation that has been engendered by the numerous findings of relationships between nonword repetition, word learning, and immediate serial recall, starting with the results reported by Gathercole and Baddeley (1989, 1990a); this line of inquiry is located within the framework of Baddeley and Hitch's working memory model (Baddeley, 1986; Baddeley & Hitch, 1974). Within this tradition, the discovery of these relationships is viewed as being of considerable significance, because they are viewed as indicating a causal role for list memory in the process of learning new words, and this in turn suggests an evolutionary purpose for the mechanisms that subserve immediate serial recall (Baddeley et al., 1998; Gathercole & Baddeley, 1993). In the working memory model, of course, these mechanisms constitute what is termed the phonological loop. Thus, the phonological loop is posited to underlie performance in the immediate serial recall task, and also in nonword repetition. The emerging view has been, as noted previously, that nonword repetition is a verbal short-term memory task. However, there has been relatively little explicit discussion of the considerably more specific hypothesis that it might be the *maintenance of serial order of a novel sequence* that is critical to both list recall and nonword repetition (but see Cumming et al., 2003; Ellis & Sinclair, 1996; Gupta, 1995, 1996; Gupta, 2002, in press; Gupta & MacWhinney, 1997; Hartley & Houghton, 1996.) This hypothesis has not been highlighted even in several computational models. For instance, several computational accounts of immediate serial recall have proposed mechanisms for the serial ordering of lists, but were not designed to address sequencing *within* words or nonwords (e.g., Brown, Preece, & Hulme, 2000; Burgess & Hitch, 1992, 1999; Page & Norris, 1998). Other computational models have addressed sequencing within word forms, but were not designed to simulate immediate list recall (Hartley & Houghton, 1996; Vousden, Brown, & Harley, 2000). The only model that has addressed serial ordering at the level of lists and within word forms (Gupta, 1995, 1996; Gupta & MacWhinney, 1997) nevertheless treated the sequencing as being different at these two levels. Thus, none of these models has addressed the question of whether common mechanisms might be implicated. And certainly, there has been no direct empirical investigation of this question. The hypothesis that a nonword is processed like a list when it is first encountered is therefore of considerable interest and importance within this first tradition of inquiry.

From the perspective of linguistics and psycholinguistics, however, the processing of nonwords is a very different matter. Within the domain of psycholinguistics, theories of speech production provide a relevant point of reference. Two of the most influential accounts have also been instantiated as computational models (Dell, 1986; Levelt, Roelofs, & Meyer, 1999). In both accounts, lexical knowledge is assumed to be a hierarchically structured system, with units at one level constituting abstract lexical representations (*lemmas*) that carry syntactic information, units at a second level representing morphemes, and units at a third level representing phonemes. A given lemma unit has connections to the relevant morpheme units; a morpheme unit has connections to the relevant phoneme units. Each unit encodes the serial order of its constituents, so that the serial order of the morphemes constituting a word is stored along with the lemma for that word, and the serial order of the phonemes constituting a morpheme is stored with that morpheme node.

What about nonwords? Neither the Dell nor Levelt models was intended as an account of word learning, and hence neither explicitly deals with the processing of novel word forms (i.e., nonwords). Thus, neither model explicitly addresses the question of how, in the absence of a lemma for the novel word form *flugwish*, repetition of this word form (and in particular, replication of the serial order of its constituents) would be achieved. From their treatments of the production of known words, however, it may be inferred that the repetition of nonwords would make similar use of structured representations, although the details of such an account are not clear. But in any case, there is not the slightest hint of a suggestion in these models that such processing has anything to do with the mechanisms of list recall. Thus, from the perspective of the most relevant and well-specified psycholinguistic accounts, the hypothesis that nonwords are processed like lists is at best counterintuitive.

Additionally, in standard *linguistic* traditions, theories of language incorporate hierarchical constructs to account for the highly structured nature of language. These constructs are similar in nature to the levels of representation and branching tree structures incorporated in the lexical network of the Dell and Levelt models. On such accounts, language learning requires the learning of these highly structured representational schemes, and such learning is viewed as necessitating specialized and structure-sensitive language-specific learning mechanisms. (See Chomsky, 1988 for a general exposition of this view. For one well-specified example of such an account in the domain of linguistic stress assignment, see Dresher & Kaye, 1990; see also Gupta & Touretzky, 1994 for an alternative account of learning in the same domain.) The notion that a foundational aspect of such learning (namely, the immediate repetition and hence the eventual learning of novel word forms) might in essence be based on a nonlinguistic mechanism such as that underlying list memory would thus be deeply antithetical to much of the thinking within such a tradition. (For example: "...Similar problems arise in the domain of vocabulary acquisition, and the solution to them must lie along the same lines: in the biological endowment that constitutes the human language faculty." Chomsky, 1988, p. 27.) As a result, the hypothesis that a nonword is processed like a list would be viewed as counterintuitive, implausible, or patently absurd, from many linguistic and psycholinguistic perspectives.

A third tradition of inquiry is perhaps best characterized as consisting of cognitive science models that address aspects of spoken word processing but do not fall within the mainstream of standard psycholinguistics. Numerous models in this tradition have examined the learning of new words (Grossberg, 1978; Houghton, 1990; Miikkulainen, 1990), or aspects of spoken word processing more generally but without learning (Dell, Schwartz, Martin, Saffran, & Gagnon, 1997; Elman & McClelland, 1986; Luce, Goldinger, Auer, & Vitevitch, 2000; Norris, 1994; Vousden et al., 2000). However, none of these models has posited a connection between the encoding of serial order within novel words, and the encoding of serial order within lists. From the perspective of cognitive science also, therefore, the hypothesis that a nonword is processed like a list is not a particularly obvious one.

A fourth relevant stream of inquiry is the broad tradition of memory research that remains outside the framework of the Baddeley and Hitch working memory model. Within this broader tradition of memory research, the hypothesis that a nonword is processed like a list would be viewed still differently. More than a century ago, Ebbinghaus (1885/1913) studied the learning of sequences of nonsense syllables that varied in length from 7 to 36 syllables each. For present purposes, what is most relevant is that lists of nonsense syllables were read out aloud multiple times, and eventually these lists were learned. From many perspectives within the broad tradition of memory research, therefore, it would appear obvious that a polysyllabic nonword is a list of syllables (just like Ebbinghaus's lists), and that immediate repetition of this sequence of syllables could not possibly be anything other than a list memory task (analogous to an attempt to recite a series of syllables following only one reading). From such a perspective, the hypothesis that a nonword is processed like a list appears trivial and tautological.

Where does this leave us? As we have seen, different traditions of inquiry regard the hypothesis that a nonword is processed like a list very differently: as being of great interest, as being improbable or absurd, or as being trite. This variety of perspectives suggests that the matter is not obvious to all within the study of memory and language—and that it is therefore in need of further study. An additional point regarding the fourth perspective is that, even though it might appear obvious that polysyllabic nonwords are lists, there are some nontrivial differences between the situations involved in immediate repetition of a sequence of separate syllables and in immediate repetition of an auditorily presented nonword. A spoken polysyllabic nonword is a stimulus that does not include systematic pauses between syllables, that incorporates coarticulation across syllables, and that incorporates a variable stress contour. In all these respects, it differs from a read-aloud list of syllables, which includes pauses between the list items, has greatly reduced coarticulation across syllables, and is typically presented with a monotone stress contour. Indeed, the linguistic salience of these differences may be one reason why the hypothesis that nonwords are lists does not appear particularly self-evident or likely within the psycholinguistic and linguistic traditions, and has not been pursued within these traditions. Thus, although the intuition that polysyllabic nonwords are lists may be plausible (from one perspective, at least), there is also need for empirical investigation of whether this intuition holds up despite these stimulus differences. For these various reasons, the hypothesis is well-worth examining, especially if the goal is to facilitate communication across the disciplines and subdisciplines of memory and language.

So let us return to the question of how we might examine such a hypothesis. One of the hallmark characteristics of performance in immediate serial recall tasks is the presence of primacy and recency effects that result in a bowed serial position curve. If mechanisms similar to those underlying immediate serial recall are operative in the repetition of nonwords, we would expect to observe serial position effects in repetition of the sequence of sounds comprising nonwords.

Following this reasoning, Gupta (in press) examined immediate repetition of individual auditorily presented polysyllabic nonwords, to determine whether repetition accuracy broken down by syllables within the nonwords would manifest primacy and recency; that is, whether the first and last syllables within the nonwords would be repeated more accurately than middle syllables. In three experiments, such primacy and recency effects were indeed obtained in repetition of individual four-syllable and seven-syllable nonwords. These novel results were consistent with the idea that common serial ordering mechanisms are operative in immediate serial recall of lists and in repetition of nonwords, especially when taken together with the considerable body of evidence indicating an association between nonword repetition and list recall.

There are a number of other reasons, however, why serial position effects might arise in repetition of individual nonwords. Nonwords of English often have beginnings and endings that are morpheme-like, which might make beginnings and endings more salient, leading to primacy and recency effects that would be unrelated to those obtained in list recall. Additionally, nonwords carry differing levels of stress on different syllables. Primacy and recency effects could conceivably arise from the placement of stress, rather than from list-like short-term memory effects. The goal of the present work was to systematically examine serial position effects in nonwords, to establish whether they arise from mechanisms that are shared with those of immediate list recall, or whether they arise for other reasons such as those discussed above. The importance of this question lies in its implications for the nature of the processing that underlies nonword processing, and ultimately word learning abilities. If common sequencing mechanisms underlie list recall and nonword repetition, this would provide insight not only into the pervasive commonalities that have been reported between list recall and nonword repetition, but also important insight into the nature of word learning.

Before describing the present investigations, it may be useful to consider what it would mean for similar or common serial ordering or sequencing mechanisms to be operative in both list recall and nonword repetition. This question was discussed by Gupta (2003) in the context of a computational model of list recall and nonword repetition (Gupta, 1995, 1996; Gupta & MacWhinney, 1997), shown in Fig. 1. This work incorporates a simple model of lexical and sublexical processing, and a *sequence memory.* The sequence memory in effect takes "snapshots" of the sequence of activations of linguistic representations that occurs at the lexical level as a result of presentation of a list, thereby encoding the serial order of the list. This encoding of serial order occurs via temporary learning in the short-term connection weights from the sequence memory to the lexical level. As long as these connection weights have not decayed too much, the sequence memory can cause that sequence of activations to be replayed and thus recalled. In simulations using the model, this recall exhibits typical serial position effects (Gupta, 1995,

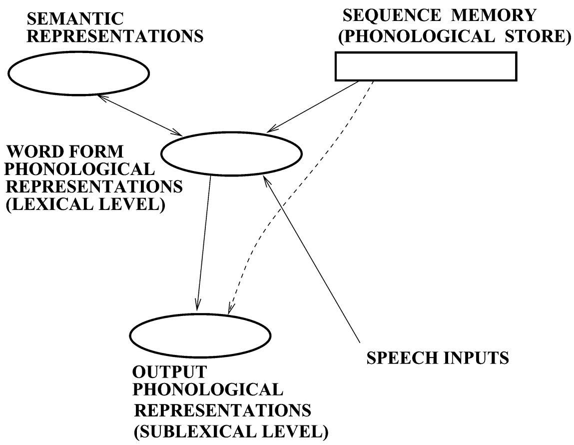

Fig. 1. Conceptual structure of the computational model proposed by Gupta (1995, 1996; Gupta & MacWhinney, 1997), and extended by Gupta, 2003 (dashed line).

1996).[1] In this model, the sequence memory is a specialized short-term sequencing mechanism, corresponding roughly to the working memory model's phonological store, but with the difference that it is not really a store into which items are entered, but rather a serial ordering device that sets up associations to a sequence of activations in the lexical system. The finding of syllable primacy and recency effects in repetition of individual polysyllabic nonwords was interpreted by Gupta (2003) in terms of an additional direct (short-term) connection from the sequence memory to the sublexical level of representation (depicted as the dashed line in Fig. 1), which introduces a direct role for the sequence memory in temporarily maintaining and repeating the sequence of syllables that comprise an individual nonword. This offers a simple account of how primacy and recency effects in repetition of individual polysyllabic nonwords might arise for the same reason as in serial recall of lists of lexical items: because of the involvement of the sequence memory at both levels.

Thus, there is a clear proposal for how within-nonword primacy and recency effects *could* arise from sequencing mechanisms that are shared with list processing. The question remains, however, of whether the within-nonword effects really are similar to those observed in list recall, or are simply due to morphological or other linguistic factors. Below we present five experiments that addressed this question.

Experiment 1

Experiment 1 had several aims related to the overall goal of investigating within-nonword primacy and recency effects. First, we wished to examine the generality of such primacy and recency effects. Second, we wished to examine these primacy and recency effects systematically across a range of syllable lengths. Third, we wished to investigate how the placement of linguistic stress interacts with serial position effects within nonwords.

Experiment 1 therefore examined syllable primacy and recency effects in nonwords which were completely different from the stimuli used in our previous investigations, thus allowing for a test of the generality of serial position effects. The nonwords ranged from two through seven syllables in length. For stimuli of each length, primary stress fell in one of two locations, so that the interaction of stress position and serial position could be examined.

As a fourth aim, we wished to examine the possibility that within-nonword primacy and recency effects might simply be the result of an uneven distribution of morphemic syllables at the beginnings and/or ends of the nonwords. In Experiment 3 of the Gupta (in press) study, for instance, the beginning or ending of some of the nonwords did in fact constitute morphemes (e.g, *BENTisippelanjevill*, *SPENTonymidderoxING*, *jedabuloskeramIC*; in IPA, /ˌbɛntɪsɪpəˈlænʤəvɪl/, /spɛnˌtoʊnɪmɪdɚˈrɑksɪŋ/, and /ʤɛdæbjulɑskəˈræmɪk/, respectively). Possibly, primacy and recency could arise from the morphemic character of such first and last syllables, in that experiment, and in general. Addressing this issue was made possible by the nature of the nonwords in the corpus from which stimuli were drawn in the present experiment. As described in greater detail in Method, the stimuli in this corpus have been generated in a manner that does not favor the presence of morphemes at the beginnings or ends of nonwords over other serial positions, and these stimuli do not have reduced vowels.

Method

Participants

A total of 30 undergraduate students at the University of Iowa participated in this experiment for course credit. All were native speakers of English who reported having normal hearing and normal or corrected-to-normal vision.

Materials and design

Nonwords were drawn from a corpus of nonwords we have created (Gupta et al., 2004) that includes 420 nonwords each of lengths two through seven syllables. These polysyllabic nonwords are all comprised of CV non-final syllables and a CVC final syllable. The nonwords were generated orthographically in sets of 10 by a computer algorithm. In each set of 10, onset consonants were drawn from the set {p, t, k, b, d, g} with a probability of 20% for each of {t, k, b, d}, and 10% for each of the other two consonants. All non-initial consonants (i.e., onsets of non-initial syllables, and codas of final syllables) were drawn from the orthographic set {b, k, d, f, g, l, m, n, p, r, s, t, v} with a probability of 3, 10, 9, 4, 6, 7, 4, 14, 4, 7, 15, 15, and 3%, respectively. All vowels were drawn from the orthographic set {a, e, i, o, u} with equal probability. Each orthographic string was converted to a phonological encoding, with consonant letters mapping onto the phonemes {b, k, d, f, g, l, m, n, p, r, s, t, v}, and vowel letters mapping onto

[1] Similar notions of serial ordering mechanisms are incorporated in several other recent models of immediate serial recall (e.g., Brown et al., 2000; Burgess & Hitch, 1992, 1999; Hartley & Houghton, 1996; Page & Norris, 1998; Vousden et al., 2000). Serial position effects in the Gupta (1996; Gupta & MacWhinney, 1997) model, as in the Burgess and Hitch (1992; Burgess, 1995; Burgess & Hitch, 1999) model, arise from two factors. First, the sequence memory by its nature encodes initial and final list items with less interference than middle list items. Second, decaying connection weights from the sequence memory to the lexical level of representation lead to a generally better encoding for earlier items in a list.

the phonemes {æ, eɪ, ɛ, ɪ, i, aɪ, oʊ, ɑ, u}. The nonwords were then recorded digitally at a sampling rate of 44.1 kHz by a single female native speaker of American English. For each nonword length, half the nonwords have primary stress on the penultimate syllable and half have primary stress on the antepenultimate syllable, except for the two-syllable nonwords, in which primary stress is placed on either the first or second syllable. Nonwords were pronounced without vowel reduction. Examples of the stimuli are given in Appendix A, which provides an IPA transcription as well as an English-like orthographic gloss for each nonword.

As these stimuli were generated by a computer algorithm that incorporates no morphological rules or knowledge, and as they have substantial symmetry across syllables, first or last syllables are no more likely to constitute morphemes than are syllables in middle positions. Additionally, as the stimuli were pronounced without vowel reduction, middle syllables are unlikely to be less distinct than first or last syllables simply because of having reduced vowels. One set of nonwords for use in the experiment was created by drawing 20 nonwords randomly without replacement from each of the pools of two- through seven-syllable nonwords. Thus, one set of materials consisted of 120 nonwords, 20 of each syllable length. Ten sets of materials were generated in this way, and were counterbalanced across the 30 participants. Each participant engaged in repetition of all 120 nonword stimuli in a particular set, thus constituting a repeated measures design.

Procedure

Participants listened to the stimuli through headphones at a comfortable listening level. Each nonword was presented auditorily on a Macintosh PowerPC G3 computer using the PsyScope experiment control system (Cohen, MacWhinney, Flatt, & Provost, 1993). Participants were instructed to repeat each nonword as soon as a fixation cross appeared on the computer display, 500 ms after offset of the nonword. The next nonword was presented following the participant's response. To avoid presenting the difficult five-, six-, and seven-syllable nonwords at the beginning, stimulus presentation was blocked by nonword length, starting with two-syllable nonwords, progressing to three-syllable nonwords, and so on. A rest pause was provided between blocks. Three practice trials preceded the experimental trials at each nonword length. Stimulus presentations and participant responses were audiotaped for subsequent offline scoring of repetition accuracy, in which the individual syllables in the participant's repetition response were rated as correct or incorrect with respect to a syllable-by-syllable transcription of each presented stimulus. The taped responses could be replayed as necessary, so that the scoring of responses was not itself a memory-based task, and so any serial position effects would not be an artifact of the scoring procedure itself. For each syllable, a strict scoring criterion was used, so that all phonemes had to be correct and unreduced and in the correct serial order, for the syllable as a whole to be considered correct.

Results and discussion

For each nonword length, planned comparisons were made to assess (a) primacy, (b) recency, and (c) the effect of stress at the two specific serial positions at which primary stress was placed. The results of an omnibus within-participants 2-way (Stress Location × Serial Position) ANOVA were also examined at each nonword length. Primacy was assessed by comparing first position accuracy with second position accuracy. Following the procedure adopted in Gupta (in press), recency was assessed by comparing final position accuracy with middle position accuracy. Primacy and recency were also assessed separately for the two different stress types at each nonword length.

As noted previously, primary stress was placed on either the antepenultimate syllable or the penultimate syllable of the nonwords (except for the two-syllable nonwords, in which primary stress fell on either the first or second syllable). We will refer to these as the StressN and StressN+1 patterns, respectively. In addition, for six- and seven-syllable nonwords, a secondary stress was also present. For seven-syllable nonwords, the secondary stress fell on the first syllable for most Stress5 nonwords, and on the second syllable for most Stress6 nonwords. For six-syllable nonwords the secondary stress fell on the second syllable for most Stress4 nonwords and on the first syllable for most Stress5 nonwords. To examine the effect of stress, two planned comparisons were made between the StressN and StressN+1 stimuli at each nonword length: repetition accuracy was compared for the StressN and StressN+1 stimuli at syllable serial position N; and repetition accuracy was compared for the StressN and StressN+1 stimuli at syllable serial position $N + 1$. For the six- and seven-syllable nonwords, repetition accuracy for the StressN and StressN+1 stimuli was additionally compared at the first syllable serial position, and at the second syllable serial position, to examine the effects of secondary stress. At each nonword length, significant differences in these comparisons would indicate a modulation of serial position effects by primary and/or secondary stress.

Table 1 summarizes the results of the various analyses. The entries marked Primacy and Recency are self-explanatory. For the StressN stimuli at each stimulus length, PrimStress indicates whether accuracy was greater for the StressN than the StressN+1 stimuli at serial position N. For the StressN+1 stimuli, PrimStress indicates whether accuracy was greater for the StressN+1

Table 1
Results of Experiment 1

	7-Syllable nonwords	4-Syllable nonwords
	All stimuli	All stimuli
Primacy	$F(1,29) = 63.2, p < .0005, MSE = 104.7$	$F(1, 29) = 32.7, p < .0005, MSE = 15.6$
Recency	$F(1,29) = 32.7, p < .0005, MSE = 135.1$	$F(1,58) = 0.9, p > .3, MSE = 33.4$
	Stress5 stimuli	Stress2 stimuli
Primacy	$F(1,29) = 156.4, p < .0005, MSE = 119.8$	$F(1,29) = 23.8, p < .0005, MSE = 47.4$
Recency	$F(1,29) = 33.6, p < .0005, MSE = 271.5$	$F(1,58) = 7.9, p < .01, MSE = 63.7$
PrimStress	$F(1,29) = 46.8, p < .0005, MSE = 169.5$	$F(1,29) = 8.7, p < .01, MSE = 92.9$
SecStress	$F(1,29) = 18.7, p < .0005, MSE = 149.9$	
	Stress6 stimuli	Stress3 stimuli
Primacy	$F(1,29) = 2.4, p > .1, MSE = 246.5$	$F(1,29) = 3.5, p = .07, MSE = 38.4$
Recency	$F(1,29) = 6.7, p < .05, MSE = 180.5$	$F(1,58) = 2.0, p > .15, MSE = 63.3$
PrimStress	$F(1,29) = 3.0, p = .09, MSE = 241.9$	$F(1,29) = 10.0, p < .005, MSE = 60.3$
SecStress	$F(1,29) = 11.3, p < .005, MSE = 312.9$	
	Omnibus ANOVA	Omnibus ANOVA
Serial Position	$F(6, 174) = 46.3, p < .0005, MSE = 271.5$	$F(3, 87) = 7.1, p < .0005, MSE = 63.3$
Stress	$F(1,29) = 2.7, p > .1, MSE = 295.5$	$F(1,29) = 7.1, p < .05, MSE = 113.6$
Interaction	$F(6, 174) = 13.9, p < .0005, MSE = 203.1$	$F(3, 87) = 4.2, p < .01, MSE = 51.1$
	6-Syllable nonwords	3-Syllable nonwords
	All stimuli	All stimuli
Primacy	$F(1,29) = 23.5, p < .0005, MSE = 149.9$	$F(1,29) = 1.9, p > .15, MSE = 8.1$
Recency	$F(1,58) = 24.6, p < .0005, MSE = 101.6$	$F(1,29) = 8.5, p < .01, MSE = 11.0$
	Stress4 stimuli	Stress1 stimuli
Primacy	$F(1,29) = 4.9, p < .05, MSE = 210.6$	$F(1,29) = 2.7, p = .1, MSE = 29.9$
Recency	$F(1,58) = 21.8, p < .0005, MSE = 167.5$	$F(1,29) = 9.0, p < .01, MSE = 22.4$
PrimStress	$F(1,29) = 40.0, p < .0005, MSE = 176.1$	$F(1,29) = .8, p > .3, MSE = 33.6$
SecStress	$F(1,29) = 3.6, p = .07, MSE = 133.4$	
	Stress5 stimuli	Stress2 stimuli
Primacy	$F(1,29) = 36.4, p < .0005, MSE = 205.8$	$F(1,29) = 0.1, p > .7, MSE = 15.5$
Recency	$F(1,58) = 4.5, p < .05, MSE = 189.8$	$F(1,29) = 2.1, p > .15, MSE = 12.9$
PrimStress	$F(1,29) = 2.9, p > .1, MSE = 188.3$	$F(1,29) = 1.0, p > .3, MSE = 26.7$
SecStress	$F(1,29) = 14.3, p < .001, MSE = 72.7$	
	Omnibus ANOVA	Omnibus ANOVA
Serial Position	$F(5, 145) = 26.1, p < .0005, MSE = 228.4$	$F(2, 58) = 4.6, p < .05, \mathrm{MSE} = 20.9$
Stress	$F(1,29) = 5.0, p < .05, MSE = 250.4$	$F(1,29) = 0.1, p > .7, MSE = 52.1$
Interaction	$F(5, 145) = 15.4, p < .0005, MSE = 152.6$	$F(2, 58) = 1.1, p > .3, MSE = 28.8$
	5-Syllable nonwords	2-Syllable nonwords
	All stimuli	All stimuli
Primacy	$F(1,29) = 22.6, p < .0005, MSE = 66.4$	$F(1,29) = 0.1, p > .7, MSE = 4.7$
Recency	$F(1,29) = 1.4, p > .2, MSE = 67.9$	
	Stress3 stimuli	Stress1 stimuli
Primacy	$F(1,29) = 18.8, p < .0005, MSE = 94.5$	$F(1,29) = 0.0, p = 1.0, MSE = 10.3$
Recency	$F(1,29) = 0.3, p > .5, MSE = 123.5$	
PrimStress	$F(1,29) = 31.4, p < .0005, MSE = 149.6$	$F(1,29) = 0.0, p = 1.0, MSE = 13.8$
	Stress4 stimuli	Stress2 stimuli
Primacy	$F(1,29) = 10.3, p < .005, MSE = 102.5$	$F(1,29) = 1.0, p > .3, MSE = 6.7$
Recency	$F(1,29) = 4.4, p < .05, MSE = 149.8$	
PrimStress	$F(1,29) = 4.3, p < .05, MSE = 221.7$	$F(1,29) = 0.4, p > .5, MSE = 17.0$
	Omnibus ANOVA	Omnibus ANOVA
Serial Position	$F(4, 116) = 12.4, p < .0005, MSE = 135.1$	$F(1,29) = 0.3, p > .5, MSE = 10.2$
Stress	$F(1,29) = 10.8, p < .005, MSE = 209.1$	$F(1,29) = 0.1, p > .7, MSE = 24.0$
Interaction	$F(4, 116) = 11.0, p < .0005, MSE = 121.0$	$F(1,29) = 0.5, p > .4, MSE = 6.8$

stimuli than for the StressN stimuli at serial position $N+1$. That is, for each nonword length, PrimStress indicates the comparison of accuracy for the two types of stress patterns at that length, at the serial position where one of them received primary stress. SecStress indicates the analogous comparisons for secondary stress, for the seven- and six-syllable nonwords. The results of the omnibus ANOVA are also indicated for each nonword length.

Fig. 2 displays syllable serial position curves for each nonword length. For each plot, the thick line represents repetition accuracy across serial positions, collapsed across stress location. The two thinner lines plot repetition accuracy across serial positions broken down by stress location, i.e., they represent the serial position functions for the StressN and StressN+1 stimuli.

As can be seen from Table 1, primacy (collapsed across stress type) was significant for seven-, six-, five-, and four-syllable nonwords, and recency (collapsed across stress type) was significant for seven- and six-syllable nonwords. The PrimStress entries indicate that for lengths seven through four syllables, accuracy was generally greater for the StressN than the StressN+1 stimuli at serial position N, and conversely was generally greater for the StressN+1 stimuli than for the StressN stimuli at serial position N. The analogous effect was generally true for secondary stress, as shown by SecStress entries for those stimuli where there was a secondary stress (the seven- and six-syllable nonwords). The omnibus ANOVAs were of less direct interest for present purposes, but were generally consistent with the results of the planned comparisons, indicating generally significant main effects of syllable serial position and stress location, and a generally significant interaction, for seven- through four-syllable nonwords.

The analysis broken down by stress type provides additional insight into recency effects. For example, in the case of the five-syllable Stress3 stimuli (see Fig.

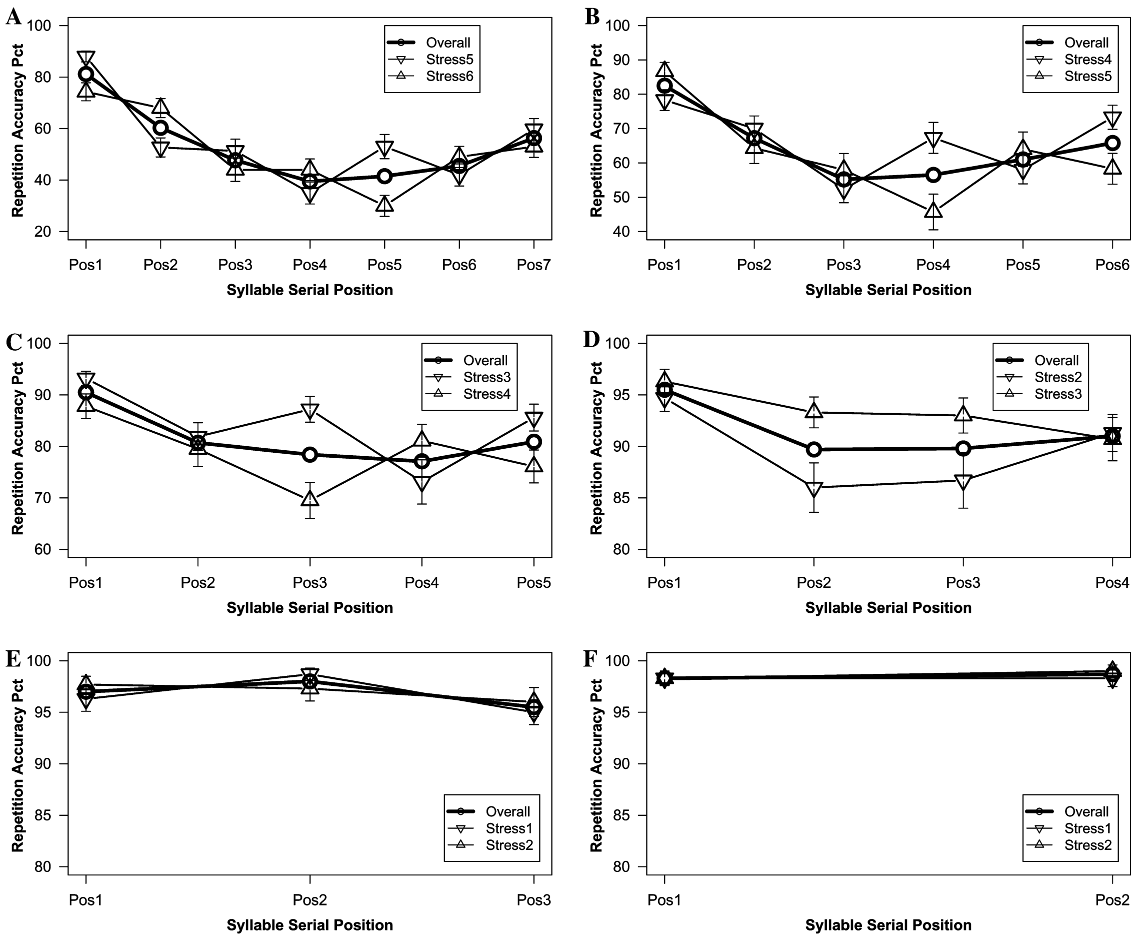

Fig. 2. Experiment 1: Serial position curves in repetition of (A) 7-syllable, (B) 6-syllable, (C) 5-syllable, (D) 4-syllable, (E) 3-syllable, and (F) 2-syllable nonwords (with standard error bars).

2C), the primary stress-related accuracy enhancement at serial position three accounts for why recency was not significant for these stimuli, and also accounts for why recency was not significant when collapsing across stress type. The effect of stress also explains why recency was not significant for the four-syllable nonwords collapsed across stress type. For the four-syllable Stress3 stimuli, the primary stress at serial position 3 (see Fig. 2D) enhanced accuracy at that position. It is less clear why accuracy in these stimuli was so high at serial position 2. But as a result of the high accuracy at serial positions 2 and 3, recency was not significant for these stimuli, nor for the four-syllable nonwords collapsed across stress type. Additionally, because of the high position 2 accuracy in the Stress3 stimuli, primacy was only marginally significant for these stimuli. For three-syllable nonwords collapsed across stress type, there was no significant primacy effect but there was a significant negative recency effect (see Fig. 2E). The negative recency effect for the three-syllable stimuli was likely due to a combination of accuracy being near ceiling and the fact that the final syllable was a CVC, with greater possibility for error than for the second syllable.[2] Finally, there were no significant effects for two-syllable nonwords.

Overall, these results indicate several things. First, they replicate the main findings reported by Gupta (in press), extending the investigation to a different set of stimulus materials, and across a range of stimulus lengths. They thus indicate that primacy and recency effects in repetition of nonwords are quite robust. Second, they indicate that these serial position effects are unlikely to be merely an artifact of morphemic endings or beginnings for the nonwords, given that the present stimuli did not incorporate a bias for morphemic syllables to be at the beginnings or ends, and that they are not simply an artifact of middle-syllable vowel reduction, given that there were no reduced vowels in the stimuli. Third, the present findings indicate that serial position effects are stronger in longer nonwords, decreasing steadily as the nonwords become shorter. This is what would be expected if the observed serial position effects are due to the engagement of verbal short-term memory sequencing mechanisms: in the same way that serial position effects in lists of known words or digits decrease steadily from list lengths 7 through 2, so did serial position effects in nonwords decrease steadily from nonword lengths 7 through 2 syllables.

Fourth, the present results indicate that the location of stress interacts with the effect of serial position, suggesting that underlying serial position effects are modulated by the placement of stress. It is therefore interesting that the modulation of serial position effects by stress has also been demonstrated in immediate serial recall of lists, by Reeves, Schmauder, and Morris (2000). These authors compared immediate serial recall of auditorily presented 9-item lists with either uniform stress on all list items, greater stress on the first, fourth, and seventh list items, or greater stress on the third, sixth, and ninth list items. They found that recall accuracy was higher in the lists with varying stress than in lists with uniform stress, at serial positions corresponding to the greater stress. The modulation of underlying serial position effects by stress within nonwords is thus quite consistent with effects observed in list recall, and is consistent with the notion of common underlying sequencing mechanisms.

Thus, the present results provide support for the common sequencing mechanisms hypothesis. One possible difficulty is that, as described above, the distribution of onsets was different for initial and non-initial syllables in the nonwords. This difference is thus confounded with the primacy effect at the first two serial positions. However, even if this difference played some role in the accuracy difference between the first and second serial positions, it is clear from the serial position functions that primacy extends well beyond the second serial position. Thus, the present results provide clear evidence for primacy over and above any contribution from the first-syllable onset difference. A potentially more serious difficulty is that the final syllables in the present stimuli differed from all prefinal syllables in that they had a CVC structure, whereas all prefinal syllables had a CV structure. Conceivably, the recency effects that were obtained (which were generally strongest at the last two serial positions) could simply have been an artifact of this final-syllable difference. Experiment 2 aimed to examine this possibility.

Experiment 2

To control for the possibility that recency in Experiment 1 was simply an artifact of the CVC structure of final syllables, a new set of seven-syllable stimuli was created consisting entirely of CV syllables. Additionally, to avoid any possibility of recency effects arising as an artifact of near final-syllable stress, the stimuli were created so that primary stress was at least two syllables removed from the final syllable, falling on either the fourth or the fifth syllable.

Method

Participants

A total of 30 undergraduate students at the University of Iowa participated in this experiment for course credit. All were native speakers of English who reported having normal hearing and normal or corrected-to-normal vision.

[2] We thank one of the reviewers of this article for pointing this out.

Materials and design

Nonwords were created using the same computer algorithm and procedure as for the stimuli used in Experiment 1 except that no codas were generated, so that all syllables had a CV structure. A total of 60 seven-syllable nonwords were created in this manner, 30 with primary stress on the fourth syllable and secondary stress on the second syllable (for example, *teesohrayfeckaytoatee* /tiˌsoʊreɪˈfɛkeɪtoʊti/ and *keegainysannogeeray* /kiˌgeɪniˈsænogireɪ/), and 30 with primary stress on the fifth syllable and secondary stress on the first syllable (for example, *baydigimidaysuru* /ˌbeɪdigimiˈdeisuru/ and *doogyloomylonnydai* /ˌdugilumiˈlɑnidaɪ/). A further 10 nonwords of each of these types were generated for use as practice stimuli. All nonwords were recorded digitally at a sampling rate of 44.1 kHz by the same speaker as in Experiment 1.

One set of nonwords for use in the experiment was created by randomly assigning the 60 nonwords to three blocks of 20 each, with the constraint that each block of 20 contained an equal number of stress4 and stress5 stimuli. Ten sets of materials were created in this way, and were counterbalanced across the 30 participants. Each participant engaged in repetition of all 60 nonword stimuli in a particular set, thus constituting a repeated measures design.

Procedure

The procedure was identical to that in Experiment 1, except that nonwords were presented in three blocks of 20 stimuli each, with 10 stimuli of each stress type in each block. A rest pause was provided between blocks. Scoring was as in Experiment 1.

Results and discussion

Fig. 3 plots results broken down by serial position and stress, and Table 2 summarizes statistics. In the analysis by subjects, there was significant primacy as well as recency for the stimuli collapsed across stress type. Primacy and recency were also significant for the Stress4 and Stress5 stimuli. Repetition accuracy was significantly higher for the Stress4 than for the Stress5 stimuli at the fourth syllable serial position (where Stress4 stimuli received primary stress), and significantly higher for the Stress5 than for the Stress4 stimuli at the fifth serial position (where Stress5 stimuli received primary stress). Analogously, accuracy was significantly higher for the Stress4 stimuli at the second syllable serial position (secondary stress) and for the Stress5 stimuli at the first syllable serial position (secondary stress). Of less interest, the omnibus ANOVA indicated significant main effects of syllable serial position, stress location, and a significant interaction. All these effects were also significant in an analysis by items, except the effect of secondary stress for Stress4 stimuli, which was not significant in the item analysis, and the main effect of stress in the omnibus ANOVA, which was only marginally significant in the item analysis.

Two points are worth noting from these results. First, the clear recency effects could not have been due to differential salience for the last syllable. This in turn indicates that the recency effects in Experiment 1 were unlikely to have arisen from the final syllable having a CVC structure.

Additionally, the present recency effects could not have been due to the presence of a stressed syllable at a later serial position, because they were obtained even for the Stress4 stimuli, in which stress occurred three serial positions away from the final position. This in turn indicates that the recency effects in Experiment 1 are unlikely to have been an artifact of the primary stress that fell on the penultimate or antepenultimate syllable. Second, although as just noted, the placement of stress was not the cause of recency effects, Experiment 2 does provide further confirmation that stress modulates underlying serial position effects. This is clearly visible from the opposite patterns of accuracy at serial positions 4 and 5 for the Stress4 and Stress5 stimuli, with both differences having been significant. Overall, the present results

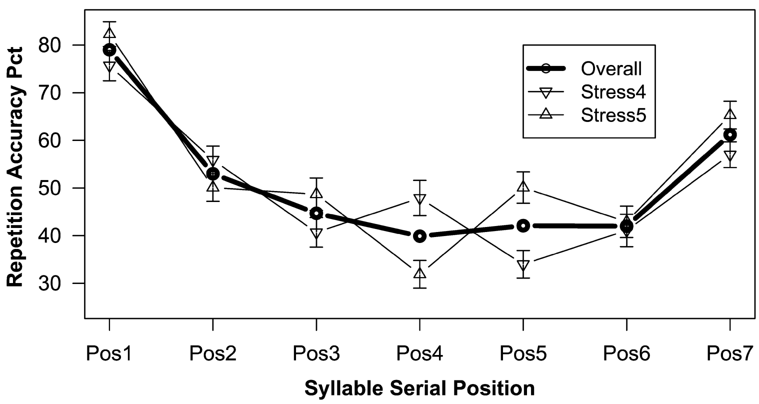

Fig. 3. Experiment 2: Serial position curves in repetition of 7-syllable nonwords (with standard error bars).

Table 2
Results of Experiment 2

	Analysis by subject	Analysis by item
	All stimuli	All stimuli
Primacy	$F1\,(1,29) = 309.0$, $p < .0005$, $MSE = 32.8$	$F2(1,118) = 88.0$, $p < .0005$, $MSE = 230.6$
Recency	$F1\,(1,29) = 89.4$, $p < .0005$, $MSE = 75.6$	$F2(1,118) = 45.0$, $p < .0005$, $MSE = 300.4$
	Stress4 stimuli	Stress4 stimuli
Primacy	$F1\,(1,29) = 64.1$, $p < .0005$, $MSE = 91.5$	$F2(1,58) = 23.3$, $p < .0005$, $MSE = 251.7$
Recency	$F1\,(1,29) = 8.5$, $p < .01$, $MSE = 146.0$	$F2(1,58) = 4.5$, $p < .05$, $MSE = 274.7$
PrimStress	$F1\,(1,29) = 27.2$, $p < .0005$, $MSE = 141.1$	$F2(1,58) = 15.3$, $p < .0005$, $MSE = 248.3$
SecStress	$F1\,(1,29) = 6.8$, $p < .05$, $MSE = 73.9$	$F2(1,58) = 1.7$, $p > .15$, $MSE = 281.5$
	Stress5 stimuli	Stress5 stimuli
Primacy	$F1\,(1,29) = 281.6$, $p < .005$, $MSE = 55.3$	$F2(1,58) = 79.0$, $p < .0005$, $MSE = 197.3$
Recency	$F1\,(1,29) = 126.0$, $p < .0005$, $MSE = 133.1$	$F2(1,58) = 65.8$, $p < .0005$, $MSE = 253.3$
PrimStress	$F1\,(1,29) = 52.6$, $p < .0005$, $MSE = 74.0$	$F2(1,58) = 13.3$, $p < .001$, $MSE = 292.3$
SecStress	$F1\,(1,29) = 8.2$, $p < .01$, $MSE = 80.8$	$F2(1,58) = 4.1$, $p < .05$, $MSE = 167.5$
	Omnibus ANOVA	Omnibus ANOVA
Serial Position	$F1\,(6,174) = 76.6$, $p < .0005$, $MSE = 158.4$	$F2(6,406) = 45.4$, $p < .0005$, $MSE = 267.4$
Stress	$F1\,(1,29) = 7.8$, $p < .01$, $MSE = 100.1$	$F2(1,406) = 3.0$, $p = .08$, $MSE = 267.4$
Interaction	$F1\,(6,174) = 20.5$, $p < .0005$, $MSE = 82.6$	$F2(6,406) = 6.3$, $p < .0005$, $MSE = 267.4$

strengthen the case that the serial position effects obtained in Experiments 1 and 2 and in previous investigations are unlikely to have been due to morphological characteristics of the nonword stimuli, and thus strengthen the case for the "common sequencing mechanisms" account.

Experiment 3

Although Experiments 1 and 2 provide further evidence of serial position effects within nonwords, the question arises of whether these effects are really comparable to those observed in immediate serial recall of lists. The classic serial position curves obtained in immediate serial recall of auditorily presented lists of words or digits exhibit recency effects that are almost as strong as primacy effects (e.g., Conrad & Hull, 1968; Corballis, 1966). More precisely, the finding is that final-position accuracy is virtually as good as first-position accuracy, in immediate serial recall of auditory lists of known verbal items. In Experiments 1 and 2, however, final-position accuracy was much lower than first-position accuracy, so that the serial position functions were less typically bowed. If the increase in accuracy in the recency portion is different in immediate repetition of nonwords than in immediate serial recall of lists, where does this leave the argument for common sequencing mechanisms? To examine this question, it is instructive to examine more carefully what kind of serial position effects are or are not obtained in immediate list recall.

In particular, let us consider immediate serial recall of lists of auditorily presented monosyllabic *nonwords.* This is clearly a list recall task. Moreover, as noted in the introduction, this list recall task would in the tradition of Ebbinghaus be viewed as plausibly equivalent to the repetition of a polysyllabic nonword—and hence as a highly relevant comparison with the repetition of polysyllabic nonwords. A considerable amount is now known about immediate serial recall of nonword lists. For one thing, overall performance is worse for lists of nonwords than for lists of known words (Hulme, Maughan, & Brown, 1991), which can be seen as a particular instance of the more general finding that the accuracy of immediate serial recall of verbal items is strongly influenced by the degree of prior knowledge of those items (e.g., Brener, 1940; Hulme et al., 1991, 1997; Hulme, Roodenrys, Brown, & Mercer, 1995; Thorn, Gathercole, & Frankish, 2002). The error types are also very different: for lists of known words, item order errors predominate, i.e., errors in which list items appear in the wrong position, often with interchanging of position (e.g., Aaronson, 1968; Bjork & Healy, 1974). In immediate serial recall of lists of nonwords, however, the predominant error type involves, not the misordering of items in the list, but transposition of parts of the nonword items from one item in the list to another; these errors preserve the syllable structure of the target list, and obey the phonotactic constraints of the language (Treiman & Danis, 1988; Treiman, 1995).

What kinds of serial position effects would be expected in recall of auditorily presented nonword lists? We have been unable to find any published data that address this question. Although a number of studies have examined immediate serial recall of auditory nonword lists (Hulme et al., 1995; Roodenrys & Hinton, 2002; Thorn et al., 2002; Treiman & Danis, 1988; Treiman, 1995), none of these studies reported serial position data. However, there is some unpublished evidence to suggest that final-position accuracy in recall of these lists is markedly lower than first-position accuracy (N. Martin, unpublished data, personal communication, August 2004; R. Treiman, unpublished data from Treiman & Danis, 1988, personal communications, August 1996, August 2004). This suggests that the serial position effects obtained within polysyllabic nonwords in the present Experiments 1 and 2 may in fact be quite similar to those obtained in immediate serial recall of lists, when the lists are comprised of items that are not highly overlearned, and are thus more comparable with polysyllabic nonwords.

However, as these are unpublished data, Experiment 3 aimed to directly examine the serial position function in immediate serial recall of auditorily presented nonword lists. If recall of these lists yielded clearly weaker last-position than first-position accuracy, this would mirror the findings of Experiments 1 and 2 for serial position effects within polysyllabic nonwords, providing further support for the common sequencing mechanisms hypothesis. If, on the other hand, recall of the nonword lists yielded last-position accuracy as good as first-position accuracy, this would differ from the findings of Experiments 1 and 2. Although not necessarily fatal to the common sequencing mechanisms hypothesis, such a finding would be less consistent with it. As a manipulation check, Experiment 3 also included immediate serial recall of auditorily presented digit lists, which were expected to yield the classic near-equivalence of last- with first-position accuracy typically obtained with auditory word/digit recall.

Method

Participants

A total of 15 individuals participated in this experiment for payment. All were native speakers of English who reported having normal hearing and normal or corrected-to-normal vision. Each participant engaged in an immediate serial recall task.

Materials, design, and procedure

One token of each of the digits *one* through *nine* spoken by a female native speaker of English was recorded as 16-bit digitized sound at a sampling rate of 22.05 kHz. Random 6-element sequences of these tokens were generated. Eight such lists were generated randomly for each participant. Twenty lists of 6 nonwords each were created by randomly permuting a set of 120 monosyllabic nonwords drawn from the corpus used in Experiment 1. A different set of lists was generated for each participant. The design was a single-factor repeated measures design, with list type (Digit/Nonword) as the within-subject factor. Presentation of lists was blocked by condition, with the order of conditions counterbalanced across participants.

Each digit or nonword list was presented auditorily by computer at the rate of one digit or nonword per second. The participant was required to repeat the list immediately after its presentation. The digit lists were preceded by two practice trials, as were the nonword lists. The participant's responses were audiotaped for later scoring of accuracy.

Results and discussion

Fig. 4 shows serial position functions for digit lists and nonword lists. The serial position function for six-syllable nonwords from Experiment 1 is also included for comparison.

Planned comparisons indicated that final-position accuracy was significantly lower than first-position accuracy for the nonword lists $F(1,14) = 83.3$, $p < .0005$, $MSE = 32.5$ but not the digit lists $F(1,14) = 0.0$, $p = 1.0$, $MSE = 11.2$. (The same comparison for the six-syllable nonwords from Experiment 1 indicated that

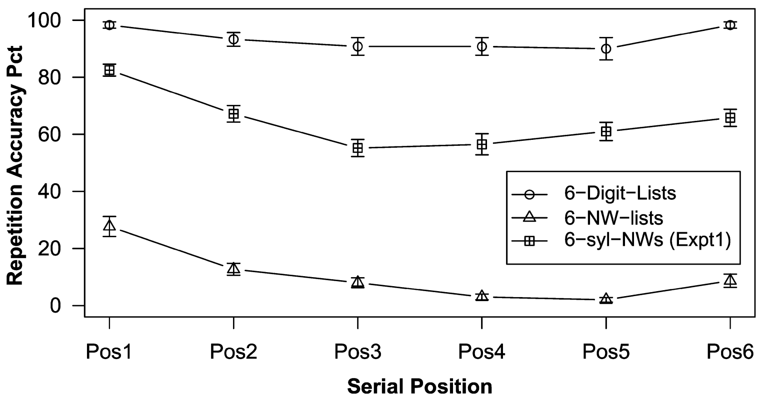

Fig. 4. Experiment 3: Serial position curves in recall of 6-digit lists and 6-nonword lists.The serial position function for 6-syllable nonwords from Experiment 1 is also included for comparison. All error bars indicate standard error.

final-position accuracy was significantly lower than first-position accuracy $F(1,29) = 27.0$, $p < .0005$, $MSE = 145.4$.) An omnibus 2×6 (list type × serial position) repeated measures ANOVA indicated a significant effect of list type $F(1,14) = 3216.9$, $p < .0005$, $MSE = 97.0$, serial position $F(5,70) = 26.8$, $p < .0005$, $MSE = 43.2$, and a significant interaction $F(5,70) = 5.8$, $p < .0005$, $MSE = 65.1$.

The main effect of list type in the omnibus ANOVA and the very low accuracy rates for the nonword lists indicate the difficulty of maintaining the serial order of novel items over the six-second duration of the lists. Of most direct relevance for present purposes, the planned comparisons indicate that recall accuracy was lower at the last position than at the first position for the nonword lists, as it was for the six-syllable nonwords in Experiment 1. This result suggests that the serial position effects within nonwords obtained in Experiments 1 and 2 are not atypical of list recall, and in fact, are quite similar to the effects obtained in a standard immediate serial list recall task, when the lists are comprised of nonwords. Recall accuracy for digit lists, however, displayed the equivalence of first and last position accuracy typically obtained for auditory lists of known items, providing a manipulation check of the list recall procedure. The results of Experiment 3 therefore lend further support to the common sequencing mechanisms hypothesis.

However, the results of Experiments 1, 2, and 3 do not entirely rule out the morphological account. Although unlikely, it is still conceivable that in Experiments 1 and 2, morphological properties of the stimuli led to systematic differences at the beginnings and ends of the nonwords as compared with the middles, thus giving rise to serial position effects. Alternatively or additionally, middle syllables might have been perceptually less distinct than final syllables as a result of masking: if masking were operative, then middle syllables would be both forward masked (by the preceding syllable or syllables) and backward masked (by the succeeding syllable or syllables), rendering them more indistinct than initial syllables (which would only be backward masked) and final syllables (which would only be forward masked). This would constitute an additional alternative account of the serial position effects. To test these alternative accounts against the common sequencing mechanisms account, we conducted two further experiments.

Experiment 4

Before describing Experiment 4, let us consider the masking account in greater detail. According to such a hypothesis, syllables in a nonword are perceptually masked at the time of presentation by preceding and succeeding syllables. For example, under the assumption that any given syllable is masked by the two preceding and two succeeding syllables, masking in a four-syllable nonword would be as follows: the first syllable would be backward masked by the second and third syllables, so what we might term the *degree* of backward masking would be two. The first syllable would be forward masked by no syllables, so the degree of forward masking would be zero. The total degree of masking that applied to the first syllable would be the sum of forward and backward masking, which in this case would work out to be two. This would also be true of the final syllable. However, each of the two middle syllables would have a total degree of masking of three (forward masking of degree one and backward masking of degree two for the second syllable; forward masking of degree two and backward masking of degree one for the third syllable). Thus, the distribution of total masking across different serial positions predicts serial position effects, and this holds across a range of stimulus lengths. The within-nonword serial position effects observed in Experiments 1 and 2 could thus potentially have arisen from such perceptual masking effects, operating at the time of auditory presentation of the nonwords.[3]

This brings us to the present Experiment 4. If the within-nonword serial position effects obtained in Experiments 1 and 2 reflect the operation of sequencing mechanisms similar to those in immediate serial recall (rather than morphological properties of the stimuli, or masking) then participants' performance in the nonword repetition task should be related to their performance in an immediate serial recall task. It is already well-established, of course, as noted in the introduction, that overall nonword repetition accuracy is correlated with digit span in a variety of populations including normal children (e.g., Gathercole & Baddeley, 1989; Gathercole et al., 1999; Gathercole et al., 1992) and normal adults (Gupta, 2003). These previous investigations did not, however, examine syllable serial position effects within nonwords. Moreover, in these studies, repetition accuracy was scored for each nonword as a whole, and was not broken down by syllable.

The goal of Experiment 4 was therefore to establish the presence of syllable primacy and recency effects in a nonword repetition task, and then determine whether syllable-by-syllable repetition accuracy in the same task was related to digit span in the same participants. If serial position effects were obtained, and if they are related to short-term memory mechanisms, then the proportion of syllables repeated correctly should be related to list

[3] It is worth noting that the backward masking part of this account is essentially the same as that proposed by Crowder and colleagues (Crowder, 1978; Crowder & Morton, 1969; Watkins, Watkins, & Crowder, 1974) as an explanation of last-position recency in auditory presentation of lists. The addition of forward masking in the present account enables it to predict primacy effects as well, at least within nonwords.

recall performance. If on the other hand, any obtained serial position effects were unrelated to short-term memory mechanisms, there would be no particular reason to expect a correlation between syllable repetition accuracy and list recall performance. In particular, neither the morphological nor the masking accounts would predict a correlation of syllable repetition accuracy with list recall performance; indeed, these hypotheses would offer no account of such a result. The common sequencing mechanisms account, on the other hand, would offer a simple account of such a finding, as discussed in the introduction. Experiment 4 therefore tested these alternative hypotheses by examining (a) syllable serial position effects in repetition of nonwords, and (b) the correlation of syllable repetition accuracy for these nonwords with digit span in the same participants. To test that any correlation between repetition accuracy and digit span would reflect shared variance that is specifically related to verbal processing and verbal short-term memory, a test of visuospatial short-term memory and an assessment of nonverbal intelligence were also administered to each participant, so as to be able to partial out variance associated with nonverbal intelligence and nonverbal short-term memory ability.

Method

Participants

A total of 60 undergraduate students at the University of Iowa participated in this experiment for course credit. All were native speakers of English who reported having normal hearing and normal or corrected-to-normal vision. Each participant engaged in a nonword repetition task, an immediate serial recall task, a visuospatial short-term memory task, and an assessment of nonverbal intelligence. Each participant also engaged in a number of other experimental tasks that were not relevant to the present investigation.

Materials, design, and procedure

Nonword repetition

Syllable serial position functions were derived from participants' repetition of 30 seven-syllable nonwords in a nonword repetition task. The procedure and scoring was exactly like that adopted for repetition of seven-syllable nonwords in Experiment 1. Ten sets of materials were created by random selection from the same corpus of nonwords used in Experiment 1. The 10 sets were counterbalanced across participants.

Immediate serial recall

The auditory digit stimuli were the same as in Experiment 3. Random sequences of these stimulus tokens were generated, varying in length from 5 digits to 11 digits. Each digit sequence was presented auditorily by computer at the rate of one digit per second. One trial consisted of presentation of one sequence of a particular length. There were eight trials at each list length. Presentation of the lists began with sequences of five digits. If a participant recalled in correct serial order five or more of the eight sequences (trials) at a particular list length, the next higher list length was introduced. If the participant failed to meet this criterion at a particular list length, the serial recall task was terminated at the end of the eight trials for that list length. The longest list length for which a participant correctly recalled five or more sequences was taken as the measure of that participant's digit span.

Visuospatial short-term memory

The particular test of visuospatial memory chosen for present purposes was the letter rotation task, also known as the spatial span task, that has been described and employed in several studies (Friedman & Miyake, 2000; Gupta, 2003; Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001; Shah & Miyake, 1996). The materials and procedure were identical to those used by Miyake et al. (2001) and by Gupta (2003).

A single trial consisted of a short sequence of presentations of a capital letter in different orientations on a computer display. On each trial, the letter was drawn from the set {F, J, L, P, R}, and the same letter was used on all presentations within a particular trial. On each stimulus presentation within a trial, the letter was displayed in either normal or mirror-imaged form, in one of seven possible orientations (rotated either 45°, 90°, 135°, 180°, 225°, 270°, or 315° from the upright). The participant's task was to say aloud, as quickly and as accurately as possible immediately following each stimulus presentation, whether the stimulus was normal or mirror-imaged. The participant was also required to remember, for recall at the end of the trial, where the top of each letter was located with respect to a normal upright orientation.

Participants were given a maximum of 3 s to verbally respond "Normal" or "Mirror" immediately following each stimulus presentation in the trial. Immediately following the participant's oral response or a lapse of 3 s, the experimenter pressed a key to display the next stimulus in the trial (the same letter, but in a different orientation). At the end of each trial, the participant turned to an answer sheet containing a spatial grid and marked numbers to indicate the orientations of the letter presentations in the preceding sequence as well as their serial order. For instance, if the trial had consisted of four presentations of a letter at the orientations 45°, 135°, 90°, and 315°, then a correct response would be to write "1" in the 45° segment of the grid, "2" in the 135° segment of the grid, "3" in the 90° segment of the grid, and "4" in the 315° segment of the grid. However, it was not required that the numbers be entered onto the grid in the order 1, 2, 3, 4, nor was the identity of the letter required to be recalled. The task thus required the reconstruction of orientation information in its correct serial order, but did not require output in the correct serial order, and did not require identity information. There were three practice trials with sequences of two letter presentations each, following which the length of sequences in each trial increased progressively from two letter presentations to five letter presentations, with five trials at each length, for a total of 20 trials. The dependent measure was the number of letter orientations correctly recalled in the correct serial position. The maximum possible score across all 20 trials was 70 letter orientations correct in the correct serial position. The score on this measure was taken as the visuospatial memory measure.

Nonverbal intelligence

Nonverbal intelligence was measured with the Cattell Culture Fair Intelligence Test (Form A, Scale 3; Cattell & Cattell, 1973), which is designed to assess intelligence equivalently across cultural groups using novel, nonverbal stimuli. The 50 test items take a total maximum of 12.5 min to complete and are divided into four subtests. In the Series subtest (13 items) subjects are asked to select the response that best continues a series. The Classifications subtest (14 items) requires participants to identify which two figures are different from three other figures. The third subtest, Matrices (13 items), requires individuals to select the response that best completes a matrix design. Finally, Conditions (10 items) requires individuals to select the response that duplicates the topographic layout of a provided picture.

The test was administered individually by a trained experimenter and the task instructions for each subtest were read aloud verbatim from the instruction manual. Each subtest was begun after completion of the spoken instructions and timed with a stopwatch. Participants indicated their responses by filling in an answer grid with a pencil and were instructed to stop and put their pencil down as soon as time for that subtest expired. Answers were later scored by the experimenter using a stencil grid placed over the filled answer grid.

Results and discussion

One participant's data were excluded from analysis because of noncompliance with instructions in the nonword repetition task. For the nonword repetition task, a 2×7 (stress type $\times$ serial position) repeated measures ANOVA indicated a significant main effect of syllable serial position $F(6, 348) = 68.2$, $MSE = 220.2$, $p < .0005$, a significant main effect of stress location $F(1, 58) = 7.0$, $MSE = 225.0$, $p < .05$ and a significant interaction between serial position and stress location $F(6, 348) = 30.3$, $MSE = 144.8$, $p < .0005$. Fig. 5 plots repetition accuracy collapsed across stress type. Both primacy $F(1, 58) = 83.6$, $p < .0005$, $MSE = 103.7$ and recency $F(1, 58) = 46.9$, $p < .0005$, $MSE = 146.9$ were significant.

The purpose of incorporating measures of nonverbal ability in Experiment 4 was primarily as a means of verifying that any correlation between nonword repetition and digit span was not simply based on general ability, following the approach that has been employed in a number of previous studies. For instance, in investigating correlations between nonword repetition, vocabulary, and digit span in 5-year-old children, Gathercole et al. (1997) partialled out general nonverbal ability. The measure of general nonverbal ability used was a composite score derived from the Raven's Colored Progressive Matrices (Raven, 1986), and the Block Design subtest of the Wechsler Intelligence Scales for Children-Revised (Wecshler, 1974), which were both also administered to each participant. Both these measures are visuospatial in nature. The tests of nonverbal intelligence and visuospatial STM were included in the present experiment following the same logic. The nonverbal intelligence measure was intended as a direct gauge of general ability. The letter rotation task, also known as

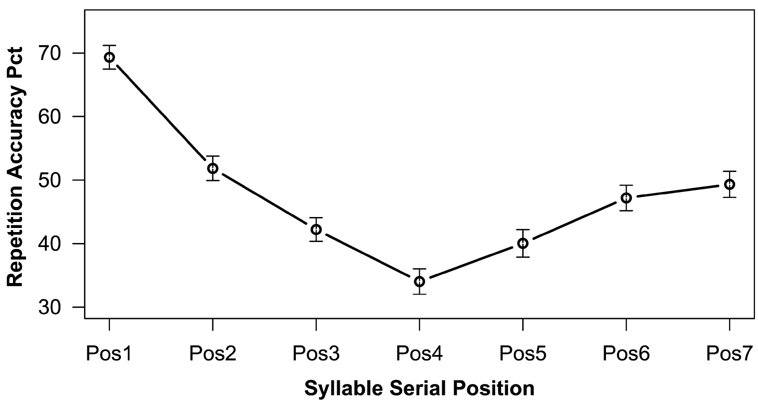

Fig. 5. Experiment 4: Serial position curve in repetition of 7-syllable nonwords (with standard error bars).

the spatial span task, has been described and employed in several studies (Friedman & Miyake, 2000; Miyake et al., 2001; Shah & Miyake, 1996). Miyake et al. (2001) examined the relationship between this task and two tasks that they selected as accepted measures of executive functioning and/or general ability: the Tower of Hanoi, and random number generation. Latent variable analysis revealed that the spatial span task was strongly correlated with these measures of general ability. For these reasons, the spatial span task was adopted in the present experiment as a reasonable nonverbal measure that loads on general ability. If correlations between immediate serial recall and nonword repetition reflect shared variance that is specifically related to verbal short-term memory rather than general ability, then they should not be substantially affected by partialling out covariance with the spatial span task and the nonverbal intelligence measure.

Table 3 shows correlations between the proportion of syllables correct in nonword repetition, digit span, nonverbal intelligence, and visuospatial STM. The upper half of the correlations matrix shows simple pairwise correlations between the measures. Of primary interest for present purposes, the proportion of syllables correct in nonword repetition was strongly and significantly correlated with digit span. In addition, digit span was significantly correlated with spatial span, consistent with previous findings (Atkins & Baddeley, 1998; Gathercole et al., 1999; Gupta, 2003), and visuospatial STM was significantly correlated with nonverbal intelligence. The lower half of the correlations matrix in Table 1 shows pairwise correlations after partialling out the other measures. The proportion of syllables repeated correctly in the nonword repetition task remained as strongly and as significantly correlated with digit span even when nonverbal intelligence and visuospatial STM were partialled out.

These results are easily explicable in terms of the common sequencing mechanisms account of serial position effects within nonwords, but would not be expected in terms of the morphological or the masking hypotheses. The present results thus support the common sequencing mechanisms account over the other two accounts. Experiment 5 further tested these alternative accounts by examining the effect of nonword duration on repetition accuracy.

Table 3
Experiment 4 correlations between proportion of syllables correctly repeated (SylsPct), digit span (DigSpan), nonverbal intelligence as measured by the Cattell Culture Fair Intelligence Test (IQ), and visuospatial span (Spatial)

	SylsPct	DigSpan	IQ	Spatial
SylsPct	•	0.556***	−0.008	0.006
DigSpan	0.583***	•	0.166	0.302*
IQ	−0.067	0.100	•	0.324*
Spatial	−0.178	0.317*	0.274*	•

The upper half of the matrix shows simple correlations, the lower half partial correlations.

* $p < .05$.

*** $p < .0001$.

Experiment 5

According to the working memory model, trace decay plays a central role in explaining list memory effects (e.g., Baddeley, 1986). If the within-nonword serial position effects observed in Experiments 1, 2, and 4 reflect sequencing mechanisms that are shared with list recall, we should find effects of trace decay in repetition of polysyllabic nonwords as well. In particular, nonwords consisting of a given number of syllables should be more poorly repeated if they are presented with a longer than a shorter total duration, by being spoken slowly rather than quickly at presentation, because there will have been greater time for the trace to decay.[4]

The masking and morphological accounts, however, do not make such a prediction. If the within-nonword serial position effects in the previous experiments were due to masking, such masking should not be increased by a longer presentation duration for nonwords: backward masking should be reduced because more processing time is available for each syllable before it is masked by a succeeding syllable, while forward masking should be reduced or no different. The masking account would therefore predict improved repetition accuracy, or no difference in repetition accuracy, for long over short duration nonwords; reduced repetition accuracy for longer duration nonwords would be inconsistent with this account. The morphological account would offer no explanation for either reduced or enhanced repetition accuracy for longer duration nonwords.

Experiment 5 tested these differing predictions by examining participants' repetition of four-syllable nonwords when they were presented at either a normal speaking rate or at a slow speaking rate.

Method

Participants

A total of 14 undergraduate students at the University of Iowa participated in this experiment for course credit. All were native speakers of English who reported

[4] It should be noted that, although informal questioning of participants suggests that rehearsal does not occur during nonword presentation, any rehearsal that did occur would not be a confounding variable—rather, it would work against the prediction of the trace decay hypothesis, because of greater opportunity for rehearsal at the longer spoken duration.

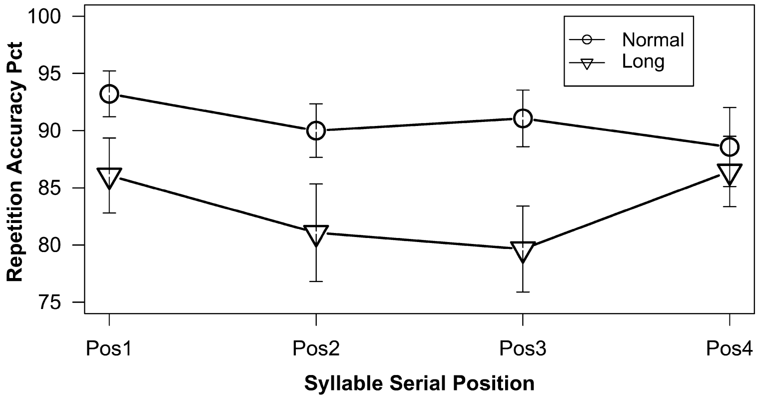

Fig. 6. Experiment 5: Serial position curves for normal and long duration nonwords (with standard error bars).

having normal hearing and normal or corrected-to-normal vision.

Material, design, and procedure

A total of 40 four-syllable nonwords were selected at random from the corpus of nonwords used in Experiment 1, 3, and 4. The digital tokens of these nonword types had been recorded at a normal speaking rate (mean duration = 1557 ms, $SD = 77.7$). New tokens were created by the same speaker employing the same procedures as for the original recordings, except that the stimuli were spoken at an intentionally slow rate (mean duration = 3949 ms, $SD = 59.8$). The 40 stimulus types were randomly divided into two groups of 20 each. Two sets of materials were then created by combining the normal duration tokens of one group of 20 stimulus types with the long duration tokens of the other group of 20 stimulus types, and vice versa. These two sets of material were counterbalanced across participants. The order of stimulus presentations was randomized for each participant. As in previous experiments, the participant's task was to repeat each auditorily presented nonword. The participant's repetition response was scored online as overall correct or incorrect by the experimenter. Responses were also audiotaped for later scoring of accuracy by syllable serial position. All other aspects of the procedure were exactly as for four-syllable nonwords in Experiment 1.

Results and discussion

The percentage of nonwords repeated correctly at the normal duration ($Mean = 83.2$, $SD = 12.9$) was greater than at the long duration ($Mean = 63.9$, $SD = 19.6$). The difference was significant $F(1, 13) = 21.5$, $MSE = 120.9$, $p < .001$. Fig. 6 displays serial position functions for the long and normal duration nonwords. The function for long duration nonwords was lower than for normal duration nonwords, consistent with the lower overall repetition accuracy for these nonwords. The serial position function was also more bowed for the slow duration nonwords than for the normal duration nonwords. Although primacy and recency effects were not significant for either the long or normal duration nonwords, which was likely due to the smaller sample size in the present experiment as compared with Experiment 1, a 2×2 (nonword duration $\times$ serial position) repeated measures ANOVA comparing accuracy at the last two serial positions for the two nonword durations revealed an almost-significant interaction, indicating a stronger tendency toward recency for the long than normal duration nonwords $F(1, 13) = 4.4$, $p = .06$, $MSE = 69.1$.

Thus, accuracy was lower for the long than normal duration nonwords, and recency was more marked for the long duration nonwords, both of which would be predicted by a trace decay account.[5] These results are inconsistent with the masking account, and inexplicable on the morphological account. They are, however, predicted by and easily explained by the common sequencing mechanisms account. It should be noted that the greater overall accuracy for normal duration nonwords could be interpreted as reflecting a greater perceptual clarity for normal duration rather than long duration verbal stimuli. However, such an interpretation would not explain the increased recency. It would therefore seem that trace decay offers the better account, and that these results provide further support for the common sequencing mechanisms hypothesis.

[5] We thank one of the reviewers of this article for pointing this out regarding recency.

General discussion

The five experiments presented in this article aimed to determine whether within-nonword serial position effects are similar to those in list recall, or arise from other factors. Experiment 1 extended previously reported results to a different set of stimulus materials and across a range of stimulus lengths, thus indicating that primacy and recency effects in repetition of nonwords are quite robust. Experiment 1 also indicated that the location of stress interacts with the effect of serial position, suggesting that underlying serial position effects within nonwords are modulated by the placement of stress. Finally, the results of Experiment 1 indicated that these serial position effects are unlikely to be merely an artifact of morphemic endings or beginnings for the nonwords, given that the stimuli did not incorporate a bias for morphemic syllables to be at the beginnings or ends. Nevertheless, these stimuli did incorporate a CVC structure for their final syllables in contrast with a CV structure for all prefinal syllables, thus confounding the observed recency effects. Experiment 2 controlled for this, examining repetition of nonwords constructed entirely of CV syllables. Significant primacy and recency were still observed in repetition of these nonwords. However, the recency effects in these experiments were less strong than those typically observed with auditory presentation of digit or word lists, raising the question of whether recency within nonwords is really similar to recency within lists. Experiment 3 therefore examined primacy and recency effects within lists of nonwords, finding that recency in such lists is also low compared with that in lists of digits, thus indicating that the within-nonword recency is not dissimilar to within-list recency.

Experiments 4 and 5 further tested alternative accounts of the observed serial position effects. According to one such account, these effects could still reflect subtle asymmetries in the distribution of morphological properties of syllables such that first and last syllables were morphologically more salient (the "morphological" account). Alternatively or additionally, the serial position effects could arise from greater perceptual masking for middle than for end syllables (the "masking" account). Neither of these accounts would predict a relationship between participants' syllable repetition accuracy for nonwords and their digit span. Such a relationship, however, is what was obtained in Experiment 4. While this finding is not explicable in terms of the morphological or masking accounts, this result falls out of the hypothesis that the observed within-nonword serial position effects reflect the engagement of serial ordering mechanisms that are shared with performance in list recall tasks (the "common sequencing mechanisms" account). Experiment 5 tested the contrasting predictions of the common sequencing mechanisms account and the masking account by varying the speech rate used for stimulus presentation. The former account predicts poorer repetition at a slower speech rate, while the latter account predicts better performance. Poorer performance was obtained at the slower speech rate, consistent with the common mechanisms account. Overall, the results of the present experiments provide support for the common sequencing mechanisms hypothesis, especially in conjunction with the considerable evidence in the literature for an association between nonword repetition and list recall.

Importantly, the common sequencing mechanisms account is not merely *consistent* with this large body of evidence, it offers an *explanation* of these findings. As embodied in the model proposed by Gupta (2003), depicted in Fig. 1, the common sequencing mechanisms account posits direct short-term connections between the sequence memory and the lexical as well as sublexical phonological levels. Such shared involvement of serial ordering mechanisms provides an extremely simple account of the correlations between list recall and nonword repetition that are observed developmentally (e.g., Gathercole & Baddeley, 1989; Gathercole et al., 1999, 1992; Gupta et al., 2003) and in adults (the present Experiment 4; Gupta, 2003): these correlations arise because the same serial ordering mechanism is engaged. It offers a very simple account of the serial position effects observed in nonword repetition and in list recall: both arise because of engagement of the same serial ordering mechanism. It also offers a straightforward account of the behavioral profile of neuropsychological patients with "pure STM" deficits. Such patients have impairments of verbal serial memory, but are essentially unimpaired in language comprehension and production (e.g., Shallice, 1988). However, they are impaired in nonword repetition and in learning new word forms (Baddeley et al., 1988; Baddeley, 1993).

According to the common sequencing mechanisms account as depicted in Fig. 1, this pattern of impairment can be explained as a consequence of impairment of the common serial ordering mechanisms (the "sequence memory"). All of this is of, course, quite consistent with the standard account of working memory (e.g., Baddeley et al., 1998), according to which the phonological store underlies all these phenomena. However, as noted in the introduction, little has generally been said about precisely how the phonological store might be implicated. The present common sequencing mechanisms account can be viewed as proposing a mechanism that is computationally specified, and that is something like the phonological store (although, as also noted in Introduction, with important differences), and as hypothesizing that it is specifically the functionality of maintaining serial order (provided by this mechanism) that underlies these phenomena. It should be noted that there are also other computational architectures that instantiate the general notion that common sequencing mechanisms might apply at multiple levels of structure in various domains of cognition (e.g., Botvinick & Plaut, 2004; Dennis, 2003; Gupta & Cohen, 2002). However, none of these has been directly applied to the present issue of common sequencing mechanisms within novel words and across lists of words. Successful attempts to address this issue in terms of these architectures would be of considerable interest, and would provide alternative computational instantiations of common sequencing mechanisms within and across word forms.

We began this article by noting the links that have developed in recent years between the study of verbal short-term memory and the study of nonword processing and word learning. The common sequencing mechanisms account we have investigated here offers a causal explanation for the relationship between these domains. From this point of view, the interaction of stress with serial position effects (Experiments 1 and 2) is particularly interesting. In terms of the common sequencing mechanisms account, this effect would be interpreted as indicating that nonwords (or novel words) are lists of syllables, with the underlying serial position effects overlaid by the presence of linguistic stress. As noted previously, similar effects have been documented in immediate recall of digit lists as well (Reeves et al., 2000).

Finally, the present findings have some interesting implications for the learning of new words, quite independent of the common sequencing mechanisms hypothesis. For instance, Experiment 1 indicated that serial position effects are weaker in shorter than in longer nonwords. Given that novel words are in effect nonwords to a particular learner on first exposure, this means that serial position effects would be weaker in immediate repetition of shorter than longer novel words. Given that short words are more prevalent than long words in early vocabulary learning situations, this implies that within-word serial position effects in naturalistic word learning would go largely unnoticed, and would only be revealed by investigation of longer novel words, as in the present study. That is, the present results exemplify a phenomenon unlikely to be detected in naturalistic settings. The present finding that primacy was consistently stronger than recency may also have implications for children's learning of new words. A variety of recent evidence has suggested, for instance, that the beginnings of words (including novel words) are particularly salient to infants (Jusczyk, Goodman, & Bauman (1999); Jusczyk & Aslin, 1995; Swingley, Pinto, & Fernald, 1999). The present results suggest primacy as a possible basis for this salience. Systematic investigation of serial position effects in the immediate repetition and learning of novel words in more naturalistic situations would therefore appear to be a fruitful line of inquiry.

Appendix A

Examples of nonword stimuli, Experiments 1, 4, and 5

2 syllables, stress1:		*5 syllables, stress3:*	
BASSIM	/ˈbæsɪm/	BOEGEENAYPEETEFF	/boϖgiˈneɪpitɛf/
DOCKOAN	/ˈdɑkoϖn/	DEECEEDONNAYROB	/disiˈdɑneɪrɑb/
GILERE	/ˈgɪlɛɹ/	GOOSIGHDASSOKESS	/gusaɪˈdæsokɛs/
KOOFOOP	/ˈkufup/	KOMAYSOLEEMICE	/komaɪˈsoϖlimaɪs/
PEGGUT	/ˈpɛgʌt/	TAIKUSANOSET	/taɪkuˈseɪnosɛt/
2 syllables, stress2:		*5 syllables, stress4:*	
BIPUP	/baɪˈpʌp/	BIVONIENAILAIR	/baɪvoϖnaɪˈneɪlɛr/
DEEKEAD	/diˈkɛd/	DAYMIKEYTECKEM	/deɪmaɪkiˈtɛkɛm/
GAYPOOM	/geɪˈpum/	GOLOSOWSITTANE	/golosoˈsɪteɪn/
KEEDOKE	/kiˈdoϖk/	KEENAYKOSIRRESS	/kineɪkoˈsɪrɛs/
TOEGUDD	/toϖˈgʌd/	PEATEETEEKAYSIN	/pititiˈkeɪsɪn/
3 syllables, stress1:		*6 syllables, stress4:*	
BASSODOKE	/ˈbæsodoϖk/	BIKIVISEENYBEEK	/biˌkiviˈsinibik/
DAYVAYTASS	/ˈdeɪveɪtæs/	DEEDOOLYNELLOOMUG	/diˌduliˈnɛlumʌg/
GISSAYBIF	/ˈgɪseɪbɪf/	GAIKAYKEEMECKOPEK	/gaɪˌkeɪkiˈmɛkopɛk/
KOTIESOTE	/ˈkoϖtaɪsoϖt/	CAINOKEYGAYRAYSOLE	/keɪˌnoϖkiˈgeɪreɪsoϖl/
TOVVIEDEEM	/ˈtɑvaɪdim/	PEEKOOSAYDAVVOGICK	/piˌkuseɪˈdævogɪk/
3 syllables, stress2:		*6 syllables, stress5:*	
BISIRREL	/baɪˈsɪrɛl/	BEEGAYDIGHTOSEMMADE	/ˌbigeɪdaɪtoˈsɛemeɪd/
DOOSENNANE	/duˈsɛneɪn/	DUTIEFOTODOTOOT	/ˌdutaɪfoϖtoˈdoϖtut/

(*continued on next page*)

Appendix A (*continued*)

GEEFIRRASE	/giˈfɪreɪs/	GAYCITEENILAICERE	/ˌgeɪsaɪtinaɪˈlaɪsiɹ/
KEEGULOL	/kiˈgulɑl/	KEYBEETOOLYSISSATE	/ˌkibituliˈsɪseɪt/
PYLESSIT	/paɪˈlɛsit/	TONEEBOONAYNAMER	/ˌtoɷnibuneɪˈneɪmɚ/
4 syllables, stress2:		*7 syllables, stress5:*	
BEENODOOFOP	/biˈnoɷdufɑp/	BEENEEFOTIESETOVODE	/ˌbinifoɷtaɪˈsɛtovoɷd/
DOEGEDIGHTEEL	/doɷˈgɛdaɪtil/	DOEMOOMEEMYTEEGEEPANE	/ˌdoɷmumimaɪˈtigipeɪn/
GAINAYROKEVE	/geɪˈneɪrokiv/	GAIGAIKAYGAYKENNODOL	/ˌgaɪgaɪkeɪgeɪˈkɛnodɑl/
KOOSOSAYDEEG	/kuˈsoɷseɪdig/	KAYTAYFIEKAYDIFFYSIDE	/ˌkeɪteifaɪkeɪˈdɪfisaɪd/
PEANIRAINANE	/piˈnieɪneɪn/	TOODYKITOTONNYTEM	/ˌtudikitoˈtɑnitɛm/
4 syllables, stress3:		*7 syllables, stress6:*	
BIGHTIEVINNODE	/baɪtaɪˈvɪnoɷd/	BAYDIETEEPEAFEESOOREET	/bɛiˌdaɪtipifiˈsurit/
DAYSOMAYSICE	/deɪsoˈmeɪsaɪs/	DEESOOGEELIKEYFEETUKE	/diˌsugilaɪkiˈfituk/
GOROONEESORE	/goɷruˈnis/	GUNUPEETEETAYREMMANE	/guˌnupititeɪˈrɛmeɪn/
KYSORAYKOFE	/kaɪsoˈreɪkoɷf/	KAIKOKAYGUIDEYTOSSET	/kaɪˌkoɷkeɪgaɪdiˈtɑsɛt/
TIETEENOOSOOSE	/taɪtiˈnusus/	PEAVAILEYEBUDUTONNUVE	/piˌveɪlaɪbuduˈtɑnuv/

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