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Examining the relationship between word learning, nonword repetition, and immediate serial recall in adults

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Two experiments examined whether the association between word-learning, nonword repetition, and immediate serial recall observed in children also exists in normal adults. The experiments also introduce a novel paradigm for studying word-learning. Experiment 1 studied the performance of 52 adults in nonword repetition, immediate serial recall, and word-learning tasks, examining the correlation between these measures. The results indicate that the developmental relationships between all three abilities also exist in adults. Experiment 2 investigated the robustness of these results using different stimuli and a variant of the word-learning task, and it also examined performance in a visuospatial span task, to test an alternative account of the results of Experiment 1; the results from 58 adults provide further evidence that the developmental association between word-learning, nonword repetition, and immediate serial recall extends into adulthood. The theoretical implications of these findings are discussed in terms of alternative models of the relationship between these abilities.

A variety of evidence that has accumulated in recent years suggests that human vocabulary acquisition processes and aspects of human verbal short-term memory may be related. 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, Service, Hitch, Adams, & Martin, 1999; Gathercole, Willis, Emslie, & Baddeley, 1992). 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, 1990; Gathercole, Hitch, Service, & Martin, 1997;

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Michas & Henry, 1994). 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). 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, at least in children, and in neuropsychologically impaired populations (Baddeley, Gathercole, & Papagno, 1998; Gathercole & Baddeley, 1993). 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 et al., 1998; Brown & Hulme, 1996; Gathercole et al., 1999).

There are, of course, many questions that remain unanswered. One such question is whether the patterns of relationship between immediate serial recall, nonword repetition, and word-learning observed in children also obtain in normal adults. Answers to this question would provide constraints on the nature of the processing that underlies these abilities. If these abilities are unrelated in normal adults, or if their relationship is dissimilar to that observed developmentally, this would suggest that the relative and/or absolute configuration of the underlying mechanisms changes over the course of development. If, on the other hand, relationships similar to those observed developmentally can be observed in normal adults, the most parsimonious interpretation would be that the elements of the underlying processing system maintain their absolute and relative configuration.

There are several reasons why we might expect the developmental pattern of relationships between immediate serial recall, nonword repetition, and word-learning not to be observed in normal adults. For one thing, the variation in each of these abilities can be expected to be smaller in normal adults than in children, and this could lead to a lack of observable relationship. Another possibility is that, even if significant relationships are present in adults, their pattern might be quite different from that in children. For instance, there is evidence to suggest that performance in both nonword repetition and immediate serial recall is affected by long-term phonological knowledge (e.g., Gathercole, Willis, Emslie, & Baddeley, 1991b; Hulme, Maughan, & Brown, 1991). It might plausibly be expected, therefore, that the very different long-term phonological knowledge that adults have as compared with children would lead to different patterns of relationship between immediate serial recall and nonword repetition. Additionally, it has been suggested that the learning of new words draws not only on verbal short-term memory, but also on the two kinds of long-term memory termed procedural and declarative memory (Gupta & Cohen, 2002; Gupta & Dell, 1999); to the extent that children and adults have differing profiles of procedural and declarative knowledge, this could lead to a differing relationship between word-learning and nonword repetition and immediate serial recall in the two populations. Still another possible reason why adult patterns of relationship might differ from those observed in children is because of differences between the two populations in the use of strategies in immediate serial recall.

In addition to these empirical considerations, there is also theoretical motivation for examining the issue of adult correlations between these abilities. Gupta (1995, 1996b; Gupta & MacWhinney, 1997) proposed a computational model that attempted to account for relationships between immediate serial recall, nonword repetition, and word-learning. The essence of this model is depicted in Figure 1a. This work incorporates a simple model of lexical and

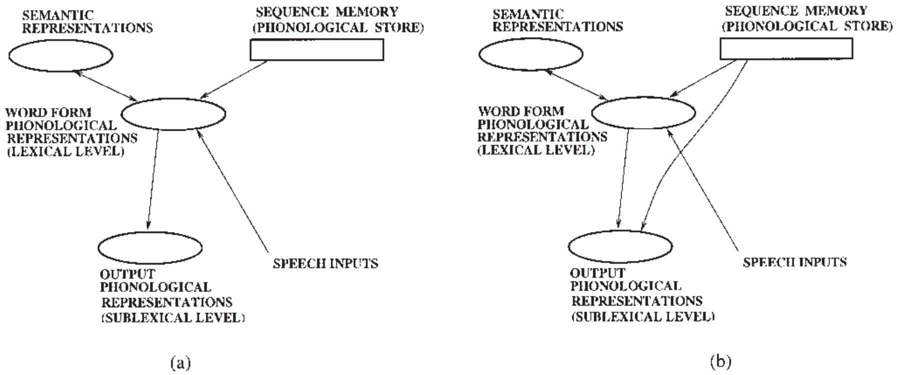

Figure 1. Conceptual structure of the computational model proposed by Gupta. (a) The model as originally proposed (Gupta, 1995, 1996b; Gupta & MacWhinney, 1997). (b) Current formulation of the model.

sublexical processing, and a sequence memory that encodes the serial order of word forms as they are presented to the lexical system, via temporary learning in the short-term connection weights from the sequence memory to the lexical level. That is, the sequence memory takes "snapshots" of the activation of linguistic representations as they occur in sequence at the lexical level of representation as a result of presentation of speech inputs. As long as the connection weights have not decayed too much, the sequence memory can cause that sequence of activations to be replayed and thus recalled; in the model, this recall exhibits typical serial position effects. Each lexical level representation incorporates a further encoding of the serial order of its constituent sequence of sublexical level units. 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 (which appears to be the view outlined in Baddeley et al., 1998), but rather a serial ordering device that sets up associations to a sequence of activations in the lexical system. This formulation of the sequence memory is quite consistent with that of several other recent models of immediate serial recall (e.g., Brown, Preece, & Hulme, 2000; Burgess & Hitch, 1992, 1999; Hartley & Houghton, 1996; Page & Norris, 1998; Vousden, Brown, & Harley, 2000), and indeed incorporates mechanisms from some of the earlier models (in particular, Burgess & Hitch, 1992; Hartley & Houghton, 1996). However, the aims of the Gupta model were largely complementary to the aims of these other models, being concerned more with explaining relationships between immediate serial memory and aspects of linguistic processing, and concerned less with accounting for the many phenomena of immediate serial recall per se. It offered an account of word-learning, nonword repetition, and immediate serial recall, incorporating the notion that verbal short-term memory mechanisms work closely with linguistic representations at the lexical level.

Recent findings have led to revision of this model. In particular, the finding that syllable serial position has primacy and recency effects in repetition of individual polysyllabic nonwords (Gupta, in press) has led to reformulation of the model to have the conceptual structure shown in Figure 1b. For present purposes, the key aspect of the reformulation is the addition of direct (short-term) connections from the sequence memory to the sublexical level of representation, which introduces a direct role for the sequence memory in temporarily maintaining and repeating the sequence of sublexical units that comprise an individual nonword. This offers a simple account of the finding of primacy and recency effects in repetition of individual polysyllabic nonwords: They arise for the same reason as that in serial recall of lists of lexical items, because of the involvement of the sequence memory at both levels. The original model also allowed for serial position effects in repetition of individual nonwords, but attributed them to sequencing mechanisms different from the sequence memory.

The two formulations of the model are distinguished by differing predictions with regard to correlations between immediate serial recall, nonword repetition, and word-learning. The earlier formulation offered an account of the developmentally observed correlations between these measures, but predicted that these correlations would not persist in adulthood. In that model, the correlations between these abilities arose from the development of the linguistic system; as this system is no longer developing in adulthood, there is a predicted loss of correlations. The revised formulation predicts that such correlations will obtain not only developmentally, but also in adulthood. This is because of the direct involvement of the sequence memory in sequencing at both the lexical and sublexical levels, which gives it a role, for instance, in both immediate serial recall and nonword repetition, both developmentally, and in an adult state. Examining correlations between immediate serial recall, nonword repetition, and word-learning in adults would thus serve to discriminate between the two models.

The empirical and theoretical considerations outlined above together motivated the present examination of what pattern of relationship actually does obtain between immediate serial recall, nonword repetition, and word-learning in normal adults. In relevant previous studies with normal adults, participants have typically learned lists of paired associates, with each pair consisting of one foreign-language word and its native-language translation equivalent (Atkins & Baddeley, 1998; Papagno, Valentine, & Baddeley, 1991; Papagno & Vallar, 1992). These studies found that such learning is affected by concurrent articulation (Papagno et al., 1991) and also by phonological similarity and word-length (Papagno & Vallar, 1992). As these factors are known to affect immediate serial recall in similar ways, the results suggest that the learning of new phonological forms may, in adults as in children, be related to the verbal short-term memory mechanisms underlying immediate serial recall, at least for second language learning. Papagno and Vallar (1995) examined adult participants' learning of sets of eight word–nonword pairs, and obtained correlations between participants' performance in this task and that on tests of immediate serial recall and nonword repetition. However, half the participants in the Papagno and Vallar (1995) study were deliberately chosen to be polyglots. Thus, 25% of the participants spoke four languages fluently, and a further 25% spoke three languages fluently; the obtained correlations may therefore not have been typical of "normal" adults. Consistent with this possibility, Service and Craik (1993) found as part of a broader investigation that in a sample of young adults with a mean age of 25 years, repetition of nonwords was not significantly correlated with performance in a word-learning task that employed the same general list-learning structure as that described above. However, as the authors acknowledged, the lack of a significant correlation may have been an artifact of the relatively small number of stimuli used in the nonword repetition task and of the relatively small amount of variation in nonword repetition performance. Indeed, in the same study, the same measures were significantly correlated in a sample of older adults, in whose nonword repetition scores there was greater variation. Thus overall the results of these studies are somewhat inconsistent and inconclusive.

Atkins and Baddeley (1998) noted that such list-learning studies are in some respects rather artificial as simulations of word-learning, and they therefore devised a new paradigm for investigating second-language learning. In this paradigm, foreign-language items (words or sentences) were paired in a list with their native-language translations. In the initial part of the experiment, the presentation and testing of each pair in the list were repeated multiple times in succession until the participant provided the correct translation, before moving onto presentation and testing of the next pair. In a later phase of the procedure, the inclusion of pairs in the study lists was based on whether or not the participant provided a correct translation. Atkins and Baddeley (1998) found that verbal memory span (based on a variety of immediate serial recall tasks) was significantly correlated with the speed of second-language vocabulary learning in adults in this task.

Although such studies provide important evidence, they appear more relevant to second-language learning than to the learning of new words in a native language, for a number of reasons. First, they require the mapping of a novel word form onto an already-labelled semantic representation (i.e., one that is already associated with a word form in the native language) and/or onto the native-language word form label, as is typical in second-language learning, rather than onto an unlabelled semantic representation, as is more characteristic of learning a new word in a native language. Second, they employed lists of multiple pairs of word forms, which also does not closely approximate the situation under which new words are first learned in a native language. Proactive and retroactive interference between list items are well known to occur in list-learning situations (Crowder, 1976; Keppel & Underwood, 1962; Postman, 1976; Underwood, 1957; Wickens, Born, & Allen, 1963), and this appears to extend to word learning that is embedded in a list-learning paradigm: Presentation of lists of as few as three nonword–picture pairs leads to such interference (e.g., Gupta, 1995, Experiment 1); learning lists of words in a third language interferes with previously learned lists of words in a second language (Isurin & McDonald, 2001); and the fast mapping that is normally possible in learning new words does not appear to be present in list-learning situations (e.g., Carey, 1978; Holdgrafer & Sorensen, 1984; Papagno et al., 1991). Third, several of these studies (Atkins & Baddeley, 1998; Papagno et al., 1991; Papagno & Vallar, 1992) employed textual presentation of word forms, which does not closely approximate the situation under which new words are first learned in a native language. The results of the two studies that used auditory presentation (Papagno & Vallar, 1995; Service & Craik, 1993) were inconsistent, with the former obtaining correlations, and the latter failing to obtain correlations.

For these various reasons, it seemed important to obtain clearer evidence regarding correlations between word-learning, nonword repetition, and immediate serial recall in normal adults. Furthermore, in investigating these relationships, it seemed important to devise a simulated word-learning task in which the pairings would consist of an auditorily presented novel sound pattern and a previously unlabelled semantic referent, presented in something other than a list-learning paradigm. Such a procedure would appear to more closely approximate the conditions under which new words are learned in a first language. One of the goals of the present work was to devise such a task and to use this task as the basis for examining the relationship between word-learning, nonword repetition, and immediate serial recall in adults. The present article describes two experiments that were conducted in order to systematically examine these relationships. Experiment 1 introduced a novel word-learning paradigm in order to examine the relationship between all three of the abilities. Experiment 2 investigated the robustness of the results of Experiment 1, using different stimuli and a variant of the word-learning task, and also examined performance in a visuospatial span task, to test an alternative account of the results of Experiment 1.

EXPERIMENT 1

Experiment 1 aimed to obtain measures of nonword repetition, verbal memory span, and word-learning, to examine whether this set of abilities is correlated in adults, as it has been shown to be in children. To this end, a standard digit span test was administered to each participant, a test of nonword repetition was devised and administered to each participant, and a test of word-learning was also devised and administered to each participant.

Method

Participants

A total of 52 undergraduate students at the University of Illinois aged between 18 and 26 years participated in this experiment for course credit. Each student participated in all three experimental tests: nonword repetition, word-learning, and immediate serial recall.

Immediate serial recall

Materials and procedure. One token of each of the digits one through nine spoken by a female native speaker of American English was recorded as 16-bit digitized sound at a sampling rate of 22.05 kHz on a Macintosh computer using the SoundEdit software program produced by Macromedia, Inc. (SoundEdit 16 users guide, 1997). Random sequences of these tokens were generated, varying in length from five digits to eleven digits.

Each digit sequence was presented auditorily on a PowerMacintosh 7200/60 computer using the PsyScope experiment control system (Cohen, MacWhinney, Flatt, & Provost, 1993), 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.

Nonword repetition

Materials, design, and procedure. A total of 90 nonwords were presented to each participant in the nonword repetition task, consisting of an equal number of two-syllable, four-syllable, and seven-syllable nonwords. The set of two-syllable nonwords was constructed to have onsets roughly spanning the letters of the English alphabet, as were the sets of four-syllable and seven-syllable stimuli. Examples of the stimuli are shown in Appendix A. One token of each of the nonwords spoken by a female native speaker of American English was recorded as 16-bit digitized sound at a sampling rate of 22.05 kHz on a Macintosh computer using the SoundEdit software program. For presentation in the task, these 90 stimuli were divided into five blocks of 18 nonwords each, with each block containing 6 nonwords of each syllable length, randomly selected from the set of 30 nonwords of that syllable length.

The stimuli were presented to each participant auditorily using the same computer hardware and software as for the digit span task, with no pause between the five blocks of 18 stimuli. Presentation order of stimuli within each block was randomized. Participants were instructed to repeat the nonword they had just heard, as soon as a fixation cross appeared on the computer display, 100 ms after offset of the nonword. The experimenter rated the participant's response as correct or incorrect using a binary criterion of right or wrong.

Word-learning

As noted previously, the goal was to devise a word-learning paradigm that would tap into the fundamental processes involved in learning a new word in a native language. The aim was to avoid textual presentation of word–form pairs and instead to use pairings consisting of an auditorily presented novel word form and a visual image depicting its referent. It was also preferred that the referent be a novel object, so that the word form would have to be linked to previously unnamed semantics rather than to already-named semantics. A further aim was to avoid presenting the nonword–picture pairs in lists, as such a training regime leads to proactive and retroactive interference. However, requiring adult participants to learn only one nonword–picture pairing would make the task trivially easy and would not provide a sensitive measure. The necessary word-learning procedure therefore had to steer between these two extremes.

In an attempt to satisfy all these requirements, a paradigm was devised that presented participants with nonword–picture pairs in which the nonwords were presented auditorily and represented the names of the pictured objects, which were taken from a set of pictures intended to depict imaginary animals (Schwartz & Smith, 1997). Presentation of each nonword–picture pair was followed by cued recall, in which the picture served as the cue, and participants were asked to name the picture (i.e., recall the nonword with which the picture had been paired during presentation). To prevent participants from simply recalling the name from verbal short-term memory, the cued recall test did not immediately follow presentation of the nonword–picture pair.

Design. Each block of the experiment consisted of five trials. The first four trials involved auditory presentation of a nonword. Two of these trials were target trials while the other two were foil trials. On target trials, the nonword (the target) was accompanied by the picture of an imaginary animal (the cue). On foil trials, the nonword was not accompanied by a picture. For both target and foil trials, the participant's task was to repeat the nonword. For target trials, the participant's task was additionally to learn the "name" of the "animal". The two target trials in a block were identical (that is, they each presented the same nonword and animal) and were always successive trials: They were either the first and second, or second and third trials of each block. Foil trials were either the first and fourth, or third and fourth trials of each block. The foil nonwords were different on each foil trial.

On the fifth trial in a block, the participant was cued with the animal picture that had appeared in the target trials of that block and was asked to recall the nonword target that had accompanied it. Note that this cued recall trial was always separated from the target trials by at least one foil trial. This basic block structure was repeated 36 times, always with different nonword foils within a block and across blocks, but with only six target–cue pairs, so that the participant received six blocks of training and testing on each of six target–cue pairings.

The overall structure of the experiment is depicted in Table 1 for the case where the target–cue pair appeared on Trials 2 and 3. There were two experimental blocks in which the first target–cue pair was presented and tested, followed by two blocks in which a second target–cue pair was presented and tested. These four blocks were followed by a cued-recall block in which the participant was asked to name both the targets they had been learning. Order of presentation of the two picture cues was randomized.

TABLE 1
Structure of word-learning task in Experiment 1

	Stimulus	*Participant response*
1.	Nonword foil	Repeat nonword
2.	Nonword target 1 + Animal 1 picture	Repeat nonword
3.	Nonword target 1 + Animal 1 picture	Repeat nonword
4.	Nonword foil	Repeat nonword
5.	Cue: Animal 1 picture	Name animal
6.	[Repeat Steps 1–5 with Animal 1, Target 1]	
7.	[Repeat Steps 1–6 with Animal 2, Target 2]	
8.	Cue: Animal 1 picture	Name animal
9.	Cue: Animal 2 picture	Name animal
10.	[Repeat Steps 1–9 two more times]	
11.	[Repeat Steps 1–10 with Animal and Target 3, 4]	
12.	[Repeat Steps 1–10 with Animal and Target 5, 6]	

This whole procedure was repeated two more times with the same two target–cue pairs, making a total of six blocks of presentation for each of these target–cue pairs. The two target–cue pairs were then replaced by two others, and the whole procedure was repeated again, making a total of six blocks of presentation for each of the two new target–cue pairs. Finally, the whole procedure was repeated with the fifth and sixth target–cue pairs. Thus all six target–cue pairs were presented six times each.

The dependent measure was performance on the cued recall trials at the end of each block. There were six such trials for each target, and thus a total of 36 such trials across the six targets for each participant.

Materials. Six pictures were selected from the imaginary animals in the "TOTimals" set (Schwartz & Smith, 1997) to serve as the cues in the six nonword–picture pairings that each participant would be required to learn. Each of the six nonword–picture pairs was to appear six times, each time in a block that contained the picture stimulus, the target nonword name paired with it, as well as two nonword foils. Thus 13 nonword stimuli were required for each of the six TOTimals. A total of 78 four-syllable nonwords were created for this purpose, divided into six sets of 13 each. Each of the six chosen TOTimals was randomly assigned to one of these sets of nonwords. One of the 13 nonwords from the set was chosen to be the target (i.e., the name of the TOTimal), and the other 12 nonwords then became the foil stimuli for blocks in which that TOTimal would appear. The choice of which nonword was to be the target was counterbalanced across participants.

Each of the 78 nonword stimuli was recorded as digitized sound using the same methods as those for the digit span and nonword repetition tasks; the stimuli are shown in Appendix B, divided into six sets of 13 each, as described above. The six pictures chosen from the set of TOTimals were digitally scanned from the original line drawings so that they could also be presented by computer.

Procedure. All nonword and picture stimuli were presented to each participant using the same computer hardware and software as those for the other tasks. Nonwords were presented auditorily, and the picture stimuli were displayed on the computer monitor. The instructions given to the participants were as follows:

> You will hear sets of three unfamiliar words. Each word will be spoken by the computer. After each word is spoken, a cross will appear on the screen. When the cross appears, you should repeat the word you just heard. In each set of three unfamiliar words, ONE word will represent the name

of an imaginary animal. When you hear this one word, you will also see a picture of the animal. You should try to learn the name of this animal. After the set of three words has been presented, and you have repeated each one, the picture of the animal you saw will appear on the screen. As soon as you see this picture, you should say the name of the animal, which you learned.

This describes the procedure within one experimental block, corresponding to Steps 1-5 in Table 1. The structure of the remainder of the procedure was as described under "Design" and as summarized in Table 1.

Results and discussion

Scores on the tests of digit span, nonword repetition, and word-learning are shown in Table 2. The measure for overall nonword repetition is based on repetition of 90 nonwords whereas the measures for two-syllable, four-syllable, and seven-syllable nonwords are based on repetition of the 30 nonwords of each length. Correlations between digit span, overall nonword repetition performance, and word-learning scores are shown in Table 3. As shown in the Table, all pairwise correlations were significant. As also shown, there was a significant partial correlation between digit span and nonword repetition score (when word-learning score was partialled out), as well as between digit span and word-learning score (when nonword repetition score was factored out). The partial correlation between word learning and nonword repetition (with digit span factored out) was not significant.

The present results extend the pattern of relationships that has been observed developmentally to the adult case. The findings also suggest that the lack of a relationship between nonword repetition and word-learning in young adults reported by Service and Craik (1993) was probably due to a lack of power in that study, which used only 24 stimuli (of three and four

TABLE 2
Mean performance on measures examined in Experiment 1

Measure		*M*	*SD*
Digit span		7.08	1.14
Word leaning % correct		78.26	9.93
Non repetition % correct	all nonwords	63.10	8.56
	2-syllable	97.31	3.17
	4-syllable	74.23	12.35
	7-syllable	38.78	18.08

TABLE 3
Experiment 1: Correlations between span, nonword repetition, and word-learning

	Pairwise correlations		*Partial correlations*	
Measures	*Coefficient*	*Bonferroni probability*	*Coefficient*	*Probability*
Digit span and NWR	.409	.008	.314	.023
Digit span and WL	.388	.013	.284	.041
WL and NWR	.357	.028	.236	.092

syllables in length) in the nonword repetition task, as compared with 90 stimuli in the present study, which included two-, four-, and seven-syllable nonwords.

The partial correlations obtained in the present experiment were also of interest. The correlation between digit span and overall nonword repetition remained significant even when word-learning was partialled out. Similarly, the correlation between digit span and word-learning remained significant even nonword repetition was partialled out. This finding is important because it indicates that the dependent measure in the word-learning task did not simply measure immediate repetition of animal names. However, the correlation between nonword repetition and word-learning was not significant when digit span was partialled. Together these various results indicate that in adults, digit span is associated with both nonword repetition and word-learning, but that there is no significant association between nonword repetition and word-learning other than via their mutual association with digit span.

How do these results compare with the developmental data? Developmental results are summarized and compared with the present results in Table 4, which shows that the pattern of adult correlations is quite similar to the developmental patterns, particularly those for the older children: All of the adult correlations are at an intermediate level between those reported for 8-year-olds and those for 13-year-olds. The fact that the present correlations are in line with the developmental correlations but substantially lower than those obtained by Papagno and Vallar (1995) is consistent with the possibility that the inclusion of polyglots in that study had an impact on the results. Turning to specific correlations, it can be seen that the simple correlation between digit span and nonword repetition obtained in the present study is similar to that reported for 8-year-old children. Partial correlations between these two measures were not available for the developmental data. The simple correlation obtained between digit span and word-learning in the present experiment is comparable to that of the 8-year-olds, and when nonword repetition is factored out, the partial correlation is similar to the partial correlation in 8-year-olds. Finally, the simple correlation obtained in the present study between nonword repetition and word-learning in adults is also consistent with that reported for the older children, although in this case closer to that for the 13-year-olds. However, the partial correlation (when digit span was factored out) was not significant in adults.

TABLE 4
Correlations between nonword repetition, word-learning, and serial recall: Comparison of results of Experiment 1 with developmental data from Gathercole et al.

		Gathercole et al.[a]					*Experiment 1*
Correlation between		*4 yrs*	*5 yrs*	*8 yrs*	*13 yrs*	*Correlation between*	*Adults*
Span and CNRep	simple	.524**	.667**	.445*	.320**	Span and NWR	.409**
	partial						.314*
Span and Vocab	simple	.284*	.376**	.355**	.450**	Span and WL	.388*
	partial	.107	.122	.266*	.390**		.284*
Vocab and CNREp	simple	.413**	.419**	.284*	.390**	WL and NWR	.357*
	partial	.397**	.387**	.151	.370**		.236

[a]Gathercole et al. (1992, for ages 4 through 8), and Gathercole et al. (1999, for age 13).
$*p < .05$; $**p < .01$.

Overall, the results thus far suggest that the relationships between digit span, nonword repetition, and word-learning in adults are similar to those observed in children, and especially in older children. It is important to keep in mind, however, that it is not the magnitudes of correlations in themselves that should be of primary interest, but rather the overall pattern of correlations between the measures. This is because there are several differences in the way that the various measures were determined in children as compared with adults in the present study. First, the developmental studies cited report vocabulary measures, whereas the present results incorporate a measure of word-learning performance. (It should be noted, however, that Gathercole et al., 1997, examined relationships between digit span, nonword repetition, and performance in a simulated word-learning task with 5-year-olds and found patterns of correlation similar to the developmental results summarized above.) Second, the measures of nonword repetition were different, being based on the CNRep for the children aged 4, 5, and 8 years (Gathercole, Willis, & Baddeley, 1991a; Gathercole et al., 1992; Gathercole, Willis, Baddeley, & Emslie, 1994), on repetition of pairs of nonwords for the 13-year-olds (Gathercole et al., 1999), and on an entirely different corpus of nonwords in the present study. Third, the partial correlations reported in the developmental studies represented the partialling out of variance attributable to nonverbal intelligence, whereas each pairwise partial correlation reported in the present study represents the partialling out of variance attributable to the third of the three measures examined. These various differences suggest that, even though the present study yielded adult correlations that are similar in magnitude to those in older children, the more significant finding is that the pattern of simple and partial correlations between the three measures is similar to that obtained developmentally.

But how robust is this pattern of correlations in adults? The developmental patterns of correlation have now been replicated a number of times (Gathercole et al., 1999; Gathercole et al., 1991a; Gathercole et al., 1992; Gathercole et al., 1994; Gathercole et al., 1997). However, correlations in adults for all three of these measures have only previously been reported in the Papagno and Vallar (1995) study, in which polyglots comprised half the sample; and in at least one previous study, nonword repetition and word-learning were found to be uncorrelated in young adults (Service & Craik, 1993). It therefore seemed appropriate to replicate the present results, in order to verify their robustness in adults. A further consideration is that in the developmental results, nonverbal intelligence was partialled out, so that those correlations cannot be attributed simply to mediation by general factors. However in the present study, although the pairwise partial correlations were significant even when the third of the three measures was factored out, there was no control for the possibility of mediation by a third variable such as general (nonverbal) ability. Experiment 2 aimed to address these issues.

EXPERIMENT 2

If the correlations obtained in Experiment 1 are in fact representative of the patterns of relationship between nonword repetition, immediate serial recall, and word-learning in adults, then they should be robust in the face of variation in procedure and stimuli. Additionally, if the correlations reflect shared variance that is specifically related to verbal processing and verbal short-term memory rather than general ability, then they should remain significant even after partialling out the covariance with a measure of nonverbal intelligence. Experiment 2 was designed to test these predictions. It aimed to replicate and extend the investigations of

Experiment 1, using variants of the procedures and stimuli adopted in Experiment 1 and adding a test of nonverbal short-term memory.

Method

Participants

A total of 58 undergraduate students at the University of Iowa aged between 18 and 26 years participated in this experiment for course credit. Each student participated in four experimental tests: nonword repetition, word-learning, immediate serial recall, and a visuospatial span task.

Immediate serial recall

Materials and procedure. The materials and procedure for immediate serial recall were exactly as those in Experiment 1.

Nonword repetition

Materials, design, and procedure. A total of 90 nonwords were used as stimuli for the nonword repetition task. Of these, 30 were two syllables long, 30 were four syllables long, and 30 were seven syllables in length. The two-syllable and seven-syllable stimuli were identical to those used in Experiment 1. The four-syllable stimuli differed from those used in the nonword repetition test in Experiment 1; they were drawn from the 78 nonwords used in the word-learning test in Experiment 1 and were identical to those stimuli. Examples of these four-syllable nonwords are listed in Appendix A. As in Experiment 1, the 90 stimuli presented to each participant were divided into five blocks of 18 nonwords each, with each block containing 6 nonwords of each syllable length, randomly selected from the set of 30 nonwords of that syllable length. The procedure followed for presentation of the 90 nonword stimuli to participants was identical to that in Experiment 1, the only difference being that the computer used was a PowerMacintosh G3 computer.

Word-learning

As in Experiment 1, the test of word-learning presented participants with nonword–picture pairs in which the nonwords were presented auditorily and represented the names of the pictured objects. The participants' task was to learn the names of the pictured objects so that they could subsequently produce the names when cued with the pictures. However, the specific stimuli and the details of the procedure differed from those in Experiment 1. In particular, the stimuli used as cues were drawings of "aliens from other planets" that have been constructed specifically for use in this word-learning paradigm. The advantage of these stimuli over the imaginary animals used in Experiment 1 is that they have little resemblance to known objects, and hence are less likely to evoke pre-existing names. The nonwords used as targets were drawn from a database of 360 four-syllable nonwords that were constructed with controlled phonotactic properties and a controlled distribution of onsets. In addition, the experimental procedure differed from that in Experiment 1, as detailed below.

Design, materials, and procedure. Each block of the experiment consisted of five trials in an *exposure phase*, followed by two trials in a *test phase*. The five trials during an exposure phase consisted of two target trials interspersed with three foil trials. On a target trial, participants were presented with a visual array of pictures of aliens. One of these (the cue) was highlighted by being framed in a box, and simultaneously a nonword representing the name of that alien (the target) was presented auditorily. The participant's task was to learn this name–referent pairing; the participant was also required to repeat the name.

The specific name–referent pairings presented on the two target trials in one exposure phase block were different. On the three foil trials within an exposure phase block there was auditory presentation of a foil nonword, which the participant was required to repeat, but not required to learn; the foil nonword was not accompanied by any visual image. In the test phase that immediately followed an exposure phase, the participant was tested on the two target pairs to which they had been exposed in the preceding exposure phase. The participant was presented with the same array of alien pictures that had appeared on the target trials of the exposure phase. One of the two aliens that had appeared as a referent in a target trial was highlighted (the cue), and the participant was asked to recall the nonword target that had accompanied it (i.e., recall its name). Then, the other alien that had appeared as a referent in a target trial was highlighted, and the participant was asked to recall its name.

The overall structure of the experiment is depicted in Table 5. In the first block of the experiment, two target pairs and three nonword foils were presented during the exposure phase; the two target pairs were then tested during the test phase, all as just described. Seven further exposure–test blocks followed, using the same two target pairs, for a total of eight blocks of training and testing using these two target pairs. During these eight blocks, the visual array on target trials and in test trials was always the same, composed of the two aliens that were being named and the same two foil aliens. However, during the eight blocks, nonword foils were always different, that is, a nonword foil was never presented more than once. Following the eight blocks of training and testing on the first two target pairs, two new target pairs were trained and tested, in eight further experimental blocks. This was followed by eight experimental blocks of training and testing on a fifth and sixth target pair. Thus each of the cue–target pairs was presented and tested eight times during these 24 blocks of the experiment. Finally, participants were presented with an array showing all six aliens whose names they had been learning; each alien was highlighted in turn, and the participant's task was to name the alien.

The dependent measure was performance on the cued recall trials in each test phase (there were eight such trials for each target), as well as in the overall cued recall trial at the end of the entire experiment (there was one such trial for each target). Thus there were 9 trials for each target, and thus a total of 54 trials across the six targets for each participant.

The pictures used as cues and foils were drawn at random from a database of drawings of "aliens from other planets", drawn specifically to serve as interpretable but novel stimuli for which no previous names exist; Appendix C shows examples of stimuli from this database. To create nonwords for use in this

TABLE 5
Structure of word-learning task in Experiment 2

Stimulus		*Participant response*
Exposure phase		
1.	Nonworld foil	Repeat nonword
2.	Nonword target 1 + visual array of pictures with Target Object 1	Repeat nonword
3.	Nonword foil	Repeat nonword
4.	Nonword target 2 + visual array of pictures with Target Object 2	Repeat nonword
5.	Nonword foil	Repeat nonword
Test phase		
6.	Target pair 1 test	Name Target Object 1
7.	Target pair 2 test	Name Target Object 2
8.	[Repeat Steps 1–7 seven times]	
9	[Repeat Steps 1–8 with Target Pairs 3, 4]	
10.	[Repeat Steps 1–8 with Target Pairs 5, 6]	
11.	[Test Target Pairs 1 through 6]	

experiment, a computer algorithm was used to randomly generate 360 four-syllable nonwords that conformed to certain phonotactic constraints. The nonwords are too numerous to list individually; however, the contraints according to which they were generated are shown in Appendix D. One token of each of these 90 nonwords was recorded as digitized sound using the same method as that for all other stimuli.

All nonword and picture stimuli were presented to each participant using the same hardware and software as for the digit span and nonword repetition tasks. Nonwords were presented auditorily, and the picture stimuli were displayed on the computer monitor. The procedure was as that in the word-learning task of Experiment 1, with appropriate modifications to accommodate the different structure of training and testing.

Visuospatial short-term memory

The purpose of incorporating a measure of nonverbal ability was primarily as a means of verifying that correlations between the three measures of interest were not simply based on general ability. 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 that they used was a composite score derived from the Raven's Coloured Progressive Matrices (Raven, 1986), and the Block Design subtest of the Wechsler Intelligence Scales for Children—Revised (Wechsler, 1974), which were both also administered to each participant. Both these measures are visuospatial in nature.

Following this approach, a test of visuospatial span was incorporated in Experiment 2. 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; Miyake, Friedman, Rettinger, Shah, & Hegarty, 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, nonword repetition, and word-learning reflect shared variance that is specifically related to verbal processing and verbal short-term memory rather than general ability, then they should not be substantially affected by partialling out covariance with the spatial span task.

*Materials and procedur*e. All stimuli were presented to each participant using the same computer hardware and software as those for the other tasks. The specific Psyscope program for the letter rotation task was kindly provided by A. Miyake and was the same as that used by Miyake et al. (2001). The materials and procedure were also identical to those used by Miyake et al.

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 45, 90, 135, 180, 225, 270, or 315 degrees 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 degrees, then a correct response would be to write "1" in the 45-degree segment of the grid, "2" in the 135-degree segment of the grid, "3" in the 90 degree segment of the grid, and "4" in the 315-degree 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.

Results and discussion

Scores on the tests of digit span, nonword repetition, word-learning, and spatial span are shown in Table 6. These scores are based on the results of 56 participants, after excluding two outliers, identified as those observations that exceeded a threshold jacknifed distance from the centroid of the nonword repetition, digit span, and word-learning scores (JMP users guide, 1989, p. 477). The measure for overall nonword repetition is based on repetition of 90 nonwords, whereas the measures for two-syllable, four-syllable, and seven-syllable nonwords are based on repetition of the 30 nonwords of each length. The percentage correct measure for word-learning is based on the 54 trials on which each participant was asked to recall the names of aliens. The measure of spatial span is the number of letter orientations correctly recalled in serial order in the letter rotation task.

Correlations between digit span, overall nonword repetition performance, and word-learning scores are shown in Table 7. As in Experiment 1, all pairwise correlations were significant. The pattern of partial correlations was also as that in Experiment 1. There was a significant partial correlation between digit span and nonword repetition score (when word-learning score was partialled out), as well as between digit span and word-learning score (when nonword repetition score was factored out). The partial correlation between word-learning and nonword repetition (with digit span factored out) was not significant.

TABLE 6
Mean performance on measures examined in Experiment 2

Measure		*M*	*SD*
Digit span		6.55	1.08
Word-learning % correct		46.23	19.86
Nonword repetition % correct	all nonwords	75.28	9.14
	2-syllable	97.90	3.63
	4-syllable	90.97	8.08
	7-syllable	36.97	19.92
Spatial span		31.13	10.43

TABLE 7
Experiment 2: Correlations between digit span, nonword repetition, and word-learning

	Pairwise correlations		*Partial correlations*	
Measures	*Coefficient*	*Bonferroni probability*	*Coefficient*	*Probability*
Digit span and NWR	.363	.018	.267	.047
Digit span and WL	.373	.014	.281	.036
WL and NWR	.353	.023	.252	.062

TABLE 8
Experiment 2: Correlations between digit span, nonword repetition, and word-learning with spatial span score partialled out

	Partial correlation	
Measures	*Coefficient*	*Probability*
DigSpan and NWR	.259	.054
DigSpan and WL	.345	.009
WL and NWR	.323	.015

As shown in Table 8, the correlation between word-learning score and digit span remained significant when spatial span was partialled out, as did the correlation between word-learning score and nonword repetition score. The correlation between nonword repetition score and digit span was marginally significant when spatial span was partialled out. Consistent with these results, spatial span was significantly correlated with both digit span ($r = .390$; $p < .005$) and with nonword repetition score ($r = 0.358$; $p < .01$), but not with word-learning ($r = 0.152$; $p > .25$).

The patterns of correlation between word-learning, nonword repetition, and digit span in Experiment 2 thus replicate those obtained in Experiment 1. The two sets of results are compared with each other and with the developmental results in Table 9. As can be seen, both the magnitude and the pattern of correlations in Experiment 2 are very similar to those in Experiment 1. Importantly, the correlations between word-learning and digit span and between word-learning and nonword repetition do not appear to be mediated simply by general ability. If that were the case we should have obtained significant reductions in these correlations when spatial scan scores were partialled out. Instead, these correlations did not change appreciably when spatial span was partialled out, and they remained significant. The correlation between nonword repetition score and digit span remained marginally significant when spatial span was partialled out.

The significant correlation between spatial span and digit span is consistent with earlier findings: Atkins and Baddeley (1998) obtained a significant correlation between a spatial pattern recall measure and digit span using visual presentation in adults, and Gathercole et al. (1999) obtained a significant correlation between a spatial memory measure and digit span using auditory presentation in 5-year-olds. Additionally, the present correlation between

TABLE 9
Correlations between nonword repetition, word-learning, and serial recall: Comparison of Experiment 1 and Experiment 2 results with developmental data from Gathercole et al.

Correlation between		*Gathercole et al.*[a] *4 yrs*	*5 yrs*	*8 yrs*	*13 yrs*	*Correlation between*	*Experiment 1 Adults*	*Experiment 2 Adults*
DigSpan and CNRep	simple	.524**	.667**	.445*	.320**	DigSpan and	.409**	.363*
	partial					NWR	.314*	.267*
DigSpan and Vocab	simple	.284*	.376**	.355**	.450**	DigSpan and	.388*	.373*
	partial	.107	.122	.266*	.390**	WL	.284*	.281*
Vocab and CNRep	simple	.413**	.419**	.284*	.390**	WL and	.357*	.353*
	partial	.397**	.387**	.151	.370**	NWR	.236	.252

[a]Gathercole et al. (1992, for ages 4 through 8), and Gathercole et al. (1999, for age 13).
$*p < .05$; $**p < .01$.

spatial span and nonword repetition is consistent with Gathercole et al.'s (1999) finding of a significant correlation between a spatial memory measure and nonword repetition in 5-year-olds.

Overall, the results of Experiment 2 provide an important replication of the patterns of correlation observed in Experiment 1, thereby attesting to the robustness of the underlying relationships in adults; they also extend the previous results by showing that it is unlikely that the correlations between the three measures are simply due to general ability.

GENERAL DISCUSSION

The two studies described here were both investigations into the relationship between word-learning, nonword repetition, and immediate serial recall in adults. Experiment 1 provided evidence that the correlations between nonword repetition, immediate serial recall, and word-learning observed in children also exist in adults. The relationships obtained were very consistent with those reported in children in terms of simple correlations, partial correlations, and overall pattern. Experiment 2 replicated and extended these results.

Experiments 1 and 2 differed in a number of respects. The four-syllable nonwords used in the nonword repetition tasks, the cues and targets used in the word-learning tasks, and the specifics of the training and testing procedure used in the word-learning tasks were all quite different across the two experiments. Despite this, the pattern of correlations obtained in the two experiments was very similar; moreover, in both experiments, this pattern of correlations was quite similar to that obtained in children. Furthermore, in Experiment 2, the correlation between word-learning and nonword repetition and between word-learning and digit span was essentially unchanged when spatial span score was partialled out, and the correlation between nonword repetition and digit span also remained marginally significant.

These findings point to three conclusions: first, that there are indeed robust relationships underlying word-learning, nonword repetition, and immediate serial recall in adults; second, that the pattern of these relationships is very similar to the pattern observed in children; and third, that the relationship between word-learning, nonword repetition, and digit span in adults is unlikely to be based simply on general ability. Additionally, the present findings serve to clarify previous results. For instance, Service and Craik (1993), failed to obtain a significant correlation between nonword repetition and word-learning in young adults. The present pattern of highly significant and replicable correlations between these measures suggests that Service and Craik's (1993) results simply reflected a lack of power, as discussed previously. Papagno and Vallar (1995) obtained substantially higher correlations between these measures in an investigation in which half the sample consisted of persons who spoke three or more languages fluently. The correlations obtained in the present Experiments 1 and 2 are much closer to the developmental ones, suggesting that the inclusion of polyglots in the Papagno and Vallar (1995) study may have had an impact on their results. Thus the present experiments provide new evidence indicating that the rich patterns of relationship between immediate serial recall, nonword repetition, and word-learning that have been observed in children and in special populations also exist in normal adults. These patterns of relationship thus appear to reflect fundamental aspects of the human cognitive architecture; they extend through development into adulthood.

In addition, the present findings provide information relevant to the theoretical considerations raised in the Introduction. Of the two formulations of the model discussed there, only the revised formulation predicts adult correlations between immediate serial recall, nonword repetition, and word-learning. Thus, the present results support the revised version of the Gupta model over the original (Gupta, 1995, 1996b; Gupta & MacWhinney, 1997) model. The revised version incorporates a direct link from the sequence memory to the sublexical level of representation (Figure 1b) and therefore provides a simple account of the observed adult correlations, whereas the original model did not offer a straightforward account of these correlations. Before outlining the revised model's account, some further discussion of the model is necessary. In the model, the sequence memory (which is somewhat akin to the phonological store) does not participate directly in the eventual learning of a nonword or novel word form, but rather merely facilitates the accuracy of its immediate repetition, such facilitation occurring via temporary learning in the short-term connection weights from the sequence memory to the sublexical level. This facilitation in turn provides a basis for the more accurate eventual learning of the novel word form; however, this learning occurs not in the weights from the sequence memory, but in the long-term connection weights from the word form (lexical) level to the sublexical level; this link thus represents long-term learning/knowledge. Note that the sequence memory also has short-term connection weights to the word form level, and these are what provide for immediate serial recall of a list of word forms. The revised model thus accounts for the relationships observed in the present studies as follows. The correlation between immediate serial recall and nonword repetition arises because the sequence memory is directly involved in temporarily maintaining the serial order of a list of word forms (in immediate serial recall of lists) as well as in temporarily maintaining the serial order of the sequence of sublexical units that constitute a novel word form (in nonword repetition). The correlation between nonword repetition and word-learning arises because greater accuracy in nonword repetition provides for greater accuracy in eventually learning the nonword. The correlation between immediate serial recall and word-learning arises because of the dependence of word-learning on nonword repetition (which is supported by the sequence memory), and because both immediate serial recall and word-learning are dependent on the strength of the bidirectional connections between word form phonological representations and semantic representations, as in the original model (Gupta, 1995, 1996a, 1996b). The revised model thus offers what appears a promising account of some important aspects of the relationship between immediate serial recall, nonword repetition, and word-learning. Of course, there are many complexities and contentious issues in the debate over such relationships, and over the nature and structure of linguistic representations, and it remains to be seen how full an account can be provided by such a model as it develops.

In conclusion, the present work provides new evidence about the relationship between immediate serial recall, nonword repetition, and word-learning in adults. It also highlights the need for more detailed specification of underlying mechanisms. Further empirical and computational work is needed to further our understanding of these important patterns of relationship, and efforts in this direction are currently under way.

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APPENDIX A
Examples of nonword repetition task stimuli, Experiments 1 and 2

2-Syllable	4-Syllable, Experiment 1	4-Syllable, Experiment 2	7-Syllable
AFTYSS	ANTRISKOLDATE	AMBERILLOCK	ASKENIDOBISKULATE
DRASHING	DIGRANTULIN	DIFFERAYMUS	DRAYBISHOCKSINALLOBIT
FLACKTRON	FINSTRAPTOKING	FROVILANKUS	FOMMIGRAVELONTIPAN
GLINCHER	GUNDOCTIPREEL	GINSTABULAR	GISTORACKIDOPULIN
HEELON	HISSKRYDOGENE	HESTOMEEKILL	HUNDINOTERALITY
ISTRUM	IMPLACSODOCK	INKRISTAVEN	INFRASKOVIJIDEENIT
JOMBINN	JIGVENTOXILE	JELLANTIFER	JEDABULOSKERAMIC
KENTRAID	CRASTIPAILTRY	KAFTOGROPY	KADDENISTRONOMACY
STUPWIG	SACKNOBENTILE	SPIKANTHODILL	SACRONIMBENALOPY
VINGLE	VENDRACKTIDISH	VAMPONTIGREE	UMPLICKERANNITIZER
ZABBLE	ZIGEETRIFLAKE	ZITRICAYMUS	ZOOBENIFFERALTOPINE

APPENDIX B
Word-learning stimuli, Experiment 1

AMBERILLOCK	WIDDESTIFER	PRISTONKOPY
CHEELYFOGGEST	YABBELOVIN	RUSVEEDINOST
DIFFERAYMUS	ZITRICAYMUS	SHIBBATORY
ENSIDORITE	ASTRIVIBOCK	UFTILLAMUS
FISCOLUMBATE	BENIARIP	VAMPONTIGREE
GINSTABULAR	DEMARGASEP	WUCKARIMBUS
HESTOMEEKILL	ESTINOFEEM	YITTERFEEGIN
INKRISTAVEN	FOSTICHIMUS	ZORGONORY
JUNTIFORMAL	GOOVADRISIM	ARDENTIFFLE
KRAMMESTIDENT	HANTEGRONY	BROGEENIVENT
LYPORAMIC	IMAKSORATE	CONSTRAPITEEK
MAGNISTIPATE	KLISTOSKERILL	EPHINORIC
NUMENAYDIS	LAVOMBULINE	FROVILANKUS
PERUMBIFUL	HEFTONAMIC	DAFFOSTEJIN
QUINORAMPUS	IMPLORITTER	EKLAMPORIS
RIFUNGONATE	KAFTOGROPY	GOBRISKOVEEN
SPIKANTHODILL	LOOFINAMBIM	HOSHETAJIK
TEFFEROPIC	MAGNOSILDING	JELLANTIFER
UNDISTIKOSH	NESTIVAKEN	MOFUSTIBLE
VADROOBACY	OCCLISTIMATE	PLICKENORDUS
WIPEEMERON	PEDANKULIN	QUESTOPEEMICH
YELTISTICOM	QUAGGISINDOM	SINTIMANKER
ZUNDIMICAL	ROOPATRIFIST	TROSVINACTIN
ANGONOMY	TREMPAJIDAL	UPTINAGRISH
BOVIDEREEN	UMBOXEDY	VOLUKINSTER
CLUPPERATING	VITTERASHIP	ZONOLAMBIC

APPENDIX C
Examples of word-learning cues, Experiment 2

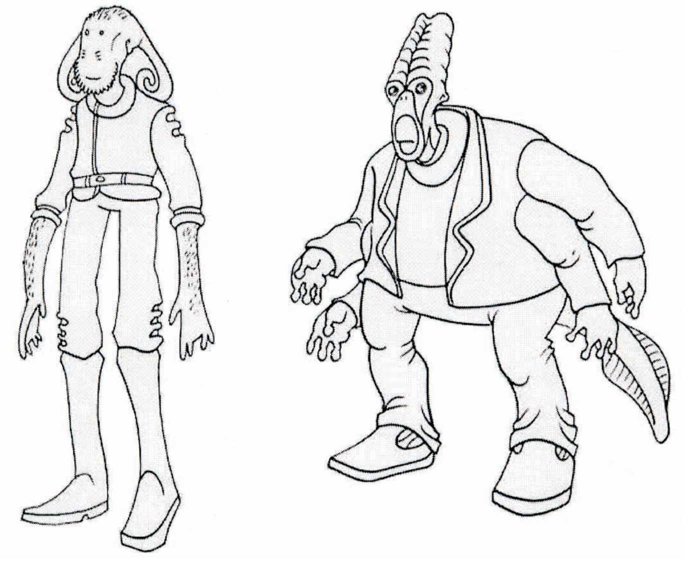

Figure A2. Examples of "aliens" used as referents in the word-learning task of Experiment 2.

APPENDIX D
Structure of word-learning targets, Experiment 2

Constraints on nonword construction:
Nonword → syll1 + syll2 + syll3 + syll4
syll1 → Consonant + Vowel
syll2 → Consonant + Vowel
syll3 → Consonant + Vowel
syll4 → Consonant + Vowel + Coda

Consonant → b, ch, d, g, j, k, p, t
Vowel a, e, i, o, u
Coda
b, be
c, ce
d, de
f, fe
g, ge
l, le
m, me
n, ne, nt
p, pe
r, re, rt
s, st
t, te, th
ve
x
ze