# Working Memory in the Acquisition of Vocabulary and Syntax: Putting Language in Good Order

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This paper argues that working memory is heavily involved in language acquisition as (a) a major part of language learning is the learning of sequences, (b) working memory allows short-term maintenance of sequence information, and (c) short-term rehearsal of sequences promotes the consolidation of long-term memories of language sequences. It first reviews evidence supporting this position. Next it presents an experiment that demonstrates that subjects encouraged to rehearse foreign language (FL) utterances are better than both silent controls and subjects who are prevented from rehearsal by articulatory suppression at (a) learning to comprehend and translate FL words and phrases, (b) explicit metalinguistic knowledge of the detailed content of grammatical regularities, (c) acquisition of the FL forms of words and phrases, (d) accuracy in FL pronunciation, and (e) some aspects of productive (but not receptive) grammatical fluency and accuracy. Finally, it describes possible mechanisms underlying these effects.

The attainment of fluency, both in native and foreign languages, involves the acquisition of memorized sequences of language. Learning vocabulary involves sequencing the phonological properties of the language: the categorical units, syllable structure, and phonotactic sequences. Learning discourse involves sequencing the lexical units of the language: clauses and collocations (Sinclair, 1991).

Ability to retain novel sequences has long been regarded as a core component of human intellectual skill, and short-term memory (STM) for sequences of words or digits has therefore featured in sub-tests of the Stanford-Binet and Wechsler IQ tests. But humans could not have evolved STM in preparation for the need to remember telephone numbers. Thus in the 1970s cognitive psychology focused on the question of "what is STM for?"—what is its role as a working memory in everyday cognition (Baddeley, 1986; Baddeley & Hitch, 1974; Gathercole & Baddeley, 1993)? If one major function of working

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memory concerns the retention of sequences of language, and if language acquisition heavily involves sequence learning, then it seems likely that language acquisition is one of the things that working memory is for. This proposition is supported by demonstrations that individuals' language development, both in terms of lexis and syntax, is limited by their STM.

## Working Memory and Vocabulary

Psychometric assessment of STM in young children is routinely performed in test batteries such as the Illinois Test of Psycholinguistic Abilities (ITPA; McCarthy & Kirk, 1961) and the Wechsler Pre-school and Primary Scale of Intelligence (WPPSI; Wechsler, 1967). The ITPA measures STM span for digit sequences, whereas the WPPSI assesses the longest sentence that can be correctly repeated. These two measures of STM correlate highly with children's vocabulary knowledge as measured by ability to give definitions for a word (WPPSIvocab, $r \geqslant 0.6$) and as assessed by ability to correctly blend individual sounds into a known word (ITPAsound blending, $r \geqslant 0.5$) (Reynell, 1983, p. 34). Such high correlations, considerably larger than those predicted by a general intelligence factor, suggest that ability to retain short-term sequences of verbal material is associated with long-term vocabulary acquisition. The correlations with ITPA digit span are particularly impressive because here the span and vocabulary measures do not share content.

Gathercole and Baddeley (1989) provide more focused evidence of this association: four-year old children's phonological STM span (their ability to repeat novel non-words in order) predicted the size of their native language vocabulary one year later, even when prior vocabulary levels were statistically controlled. This suggests that ability to represent the novel sound sequence of a new word in phonological STM has a role in its longer term consolidation both for later articulation and as an entity with which meaning can be associated.

There are now a number of studies using different methodologies that converge on this conclusion. Gathercole and Baddeley (1990) report a training study where children poor on non-word repetition were found to be slower than children who were good on non-word repetition at learning new vocabulary (phonologically unfamiliar names such as *Pimas* for toys). They were not slower to learn a new mapping for familiar vocabulary (familiar names, e.g. *Thomas* for the toys). Baddeley, Papagno, and Vallar (1988) describe an adult neuropsychological patient, PV, who had a highly specific acquired deficit of immediate phonological memory. PV was completely unable to make associations between spoken word and non-word pairs, despite showing normal phonological processing of non-word material. She had no difficulty, however, in learning new associations between pairs of words. Thus temporary phonological memory seems particularly involved in the long-term learning of *unfamiliar* phonological material.

Just as phonological STM predicts acquisition of vocabulary in native language, so it does in second and foreign languages. Service (1992) demonstrated that Finnish children's STM for pseudowords that sounded like English predicted their acquisition of English as a foreign language two and a half years later. Phonological STM seems

particularly implicated in productive vocabulary where the student has a greater cognitive burden in terms of sensory and motor learning. Seibert (1927) showed that, for productive learning of French vocabulary, saying words aloud led to faster learning and better retention than did silent rote repetition of vocabulary lists. Ellis and Beaton (1993a) demonstrated that although keyword techniques are efficient means for receptive vocabulary learning, for productive learning they are less effective than repetition (at least for learners naïve to the pronunciation patterns of the foreign language). Papagno, Valentine, and Baddeley (1991) showed that when learning to produce novel vocabulary with written responses, articulatory suppression (which disrupts the articulatory loop component of short-term memory) interfered with the learning of Russian vocabulary but not native-language paired associates in Italian adults.

Each language has its own set of phonemes and its charateristic sequential phoneme probabilities, which constitute phonotactic regularity. Gathercole, Willis, Emslie, and Baddeley (1991) demonstrated that the "wordlikeness" of non-words (e.g. "defermication" is high in English wordlikeness compared to "loddenapish") predicted their ease of short-term repetition. Phonotactic regularity predicts long-term acquisition as well: foreign language (FL) words that are more difficult for a learner to pronounce are acquired more slowly than are those that are easier to pronounce (Rodgers, 1969), and this holds even when word length, frequency, part-of-speech, and imageability are controlled (Ellis & Beaton, 1993a, 1993b). Thus the familiarity of a novel word's phonological structure determines both its short-term repetition accuracy and its long-term learnability.

In sum, there is a considerable body of evidence that phonological factors are involved in (particularly productive) vocabulary acquisition: (a) Phonological STM span predicts both native and second language vocabulary acquisition; (b) interfering with phonological STM by means of articulatory suppression disrupts vocabulary learning when semantic associations between the native and foreign word are not readily available; (c) short-term repetition of novel FL words in working memory promotes their long-term learning; and (d) FL word regularity in terms of native language phonotactics determines learnability.

## Working Memory and Syntax

Considerably less work has addressed the role of phonological STM in the acquisition of syntax, even though there is increasing support for the notion that the same psychological mechanisms underpin vocabulary and syntax acquisition (Marchman & Bates, 1994). However, the same sorts of evidence that have been described for vocabulary are to be found for an association between verbal STM span and grammatical ability.

1. There are psychometric data. The ITPA grammatical closure test asks children to complete oral statements like "Here is a child. Here are three ____" while showing them an appropriate picture to reduce the STM load of the test itself. The psychometric STM span measures described above correlate highly with this measure ($r \geq 0.52$), as they do with general verbal comprehension and expression abilities as measured on the Reynell (1983) test ($0.62 \geq r \geq 0.54$). Children who are better at short-term retention of verbal sequences are also grammatically more proficient.

Phonological working memory has also been shown to correlate with grammatical ability. Speidel (1993) describes poor language development (word-order problems and syntactic errors) in a child with a phonological STM disability. Blake, Austin, Cannon, Lisus, and Vaughan (1994) demonstrate that STM for words predicted mean length of utterance in 2- to 3-year olds better than did either chronological age or mental age. Adams and Gathercole (1995) analysed speech corpora of 3-year old children and showed that good phonological memory ability was associated with longer, more grammatically complex productions that contained a richer array of words.

2. The obverse is also true: Syntactic development is prejudiced in individuals with deficient working memory. Dyslexia is a development disorder associated with reduced working memory storage for verbal materials—indeed, reduced STM span is one of the classic defining criteria of the condition (Ellis & Large, 1987; Ellis & Miles, 1981). Scarborough (1991) longitudinally assessed at ages from 30 to 60 months the syntactic abilities of pre-schoolers who later became disabled readers, and demonstrated that the dyslexic individuals were poorer on all measures of syntax (grammatical complexity on the Index of Productive Syntax, mean length of utterance, and sentence comprehension on the Northwestern Syntax Screening Test). In dyslexic children, therefore, reduced short-term memory span, phonological processing deficits, and restricted acquisition of syntax go hand-in-hand, and it seems likely that problems in identifying and learning the sequences of categorical units of language is the common feature in all of these difficulties.

Dyslexic individuals also have considerable difficulty in learning foreign languages. Sparks, Ganschow, Javorsky, Pohlman, and Patton (1992) demonstrate that language delayed college students who are deficient on native syntax and phonology and who have verbal short-term memory deficits in their native language also score poorly on all subtests of the Modern Language Aptitude Test (Carroll & Sapon, 1955).

3. Finally, there is evidence from a training study. Daneman and Case (1981) provided direct evidence for individuals' STM capacity determining their efficacy in learning an artificial language. Children between 2 and 6 years old were simultaneously exposed to novel actions involving one, two, or three semantic features and to novel labels for these actions. The labels had a stem form (e.g. *pum*), and semantic features were marked syntactically with either a suffix (e.g. *pum–abo*), a prefix, or both a suffix and a prefix (e.g. *a–pum–tay*). Posttests were given in which the children had to supply either the appropriate action for a label or the appropriate label for an action. The results showed the following: (a) Syntactic complexity affected the difficulty of producing the labels but not their recognition. Suffixes were easier to process than prefixes and prefixes were in turn easier than suffixes and prefixes. That syntactic complexity affects production but not recognition is the morphological counterpart of the finding of Ellis and Beaton (1993a, 1993b) that the phonotactic complexity of novel words affects their production more than their recognition; (b) STM capacity was a strong predictor of acquisition of the language.

Daneman and Case argued that, in the early stages of learning, before the morpheme sequences have been lexicalized, learners had to retrieve the verb stem (*pum*) and the appropriate markers (e.g. *a–* and *–tay*), order them appropriately in STM, and produce the result. Because *a* and *tay* had to be placed on opposite sides of the verb stem, they were encoded and stored in STM as separate chunks. By contrast, because the two syllables of *abo* are contiguous, they could be treated as one chunk. Consequently,

generating *puma bo* in the linguistic production task was easier than producing *apumtay*, because it imposed less working memory load. Learners with greater working memory capacity were better able to sequence more complex morphological constructions in the short term, and, as a consequence of practice at this, they were more likely to consolidate automatized chunked sequence representations of frequent patterns in long-term memory (LTM).

In sum, these studies suggest an involvement of phonological WM in syntax acquisition: (a) Phonological STM span predicts native grammatical ability; (b) individuals with STM deficits show restricted acquisition of syntax both in native and foreign languages; (c) the more chunks in a syntactic marker, the more difficult it is to acquire; (d) children's STM capacity determines their success in learning the syntax of an artificial language.

## The Present Experiment:
## Repetition and Language Learning

This review has demonstrated a role of phonological working memory in vocabulary acquisition, and it has further extended the argument to suggest that phonological working memory functions in the acquisition of syntax. But although there are experiments that show that phonological rehearsal of novel words facilitates long-term vocabulary learning, this same case remains to be demonstrated for the role of phonological rehearsal of multi-word utterances in (a) the acquisition of phrases and collocations and (b) abstraction of syntactic regularities.

In addition to its theoretical interest, this question has practical import: should learners be encouraged to repeat new FL or second-language utterances or not? Indeed, contrary to the implications of the psychological research reviewed above, some applied linguists advocate that speech be prohibited and a "silent period" maintained during the early stages of language acquisition (Asher, 1969; Krashen & Terrell, 1983).

In order to study this, the present experiment very simply investigated the role of articulatory rehearsal of FL utterances in language acquisition. It compared FL Welsh acquisition between individuals who were encouraged to repeat novel-language utterances and those who were prevented by articulatory suppression so to do. A third group of learners constituted a control group: These individuals remained silent during language exposure but were otherwise allowed to do as they chose—although they did not overtly rehearse the utterances, they may well have naturally done so subvocally. A wide variety of aspects of language acquisition were assessed: For receptive language, there was the ability to translate isolated words and multi-word utterances into native English; for production, there was (a) the ability to remember the FL words and phrases given the English, (b) the ability to pronounce these correctly, (c) the ability to use a complicated grammatical structure, the soft mutation in Welsh—to determine when it is appropriate and to remember the particular phonological changes for particular noun-initial phonemes. We also assessed two other aspects of the assimilation of grammatical structure: (a) implicit knowledge of grammaticality as indexed by accuracy and latency of recognition of correctness in speeded well-formedness tests; (b) explicit knowledge of the underlying rule-structure of the soft mutation in Welsh.

## Method

### Subjects

Eighty-seven non-Welsh-speaking subjects (57 females and 30 males) were recruited from the Departmental subject panel or the University undergraduate population. Their age range was 18–40 years (mean = 21). They were paid £2.50 for participating in the experiment. They were randomly assigned to one of the three conditions.

### Materials and Procedure

The experiment consisted of one learning phase and a variety of testing phases. It lasted approximately two hours.

In the *learning phase*, subjects were instructed to learn English translations of Welsh utterances produced by a Macintosh computer programmed using Hypercard. These utterances, digitized recordings of a fluent Welsh speaker, included 10 single words (5 pairs of nouns beginning with the letters *t, c, d, p,* and *m*), 10 uses of these words in a phrasal construct incorporating "*ble mae____*" ["where is____"], and 10 usages of these words in the phrasal construct "*ei____o*" ["his____"]. As can be seen in Appendix 1, the construct "*ei____o*" makes use of a grammatical rule, the Welsh soft mutation, which causes certain initial phonemes of nouns to change sound (see Ellis, 1993). Different classes of consonant undergo different phonological changes. For example, the voiceless plosives / p, t, k / are replaced by the voiced plosives / b, d, g /; the voiced plosives / b, d / are replaced by the homorganic fricatives / v, δ /; and the nasal / m / is replaced by the homorganic fricative / v /. Soft mutation is caused by a wide variety of grammatical contexts. Some of these are very specific, such as (i) after the personal pronoun meaning "his"—thus "son" translates as "*mab*" but "his son" is "*ei fab o*"; (ii) after the preposition "*o*" meaning "from"—thus the local town is "Bangor", but one would come "*o Fangor*". Others are very general, for example when a feminine singular noun follows the definite article "*y*"—thus "*gwraig*" ["housewife"] becomes "*y wraig*". Thus the soft mutation of Welsh is a complicated rule system, and learners need to know of (a) its existence, (b) the set of phonemes that mutate and their mutated equivalents, and (c) the contexts that call for this mutation. Like many aspects of grammar, it looks remarkably complicated when explicitly described, yet native language speakers use the structure flawlessly and unconsciously.

On each trial of the *learning phase*, the computer played a pre-recorded utterance and the subject had to respond by typing in the English translation. If the response was unknown or incorrect, the correct English translation was displayed on the VDU and the subject was allowed to take as long as was necessary to study the correct translation before repeating that trial—they pressed the return key when ready, the utterance was reiterated, and they then typed in the freshly studied translation. The 30 utterances were presented in random order, and four passes through these materials composed the learning phase. The computer monitored the accuracy of the subjects' translations.

The three conditions in the experiment differed only during this learning phase. Subjects in the *silent* condition maintained silence. Subjects in the *repetition* condition were instructed always to repeat aloud the Welsh utterances whenever they heard the computer say them. In contrast, subjects in the *articulatory suppression* (AS) condition were prevented from ever articulating the language strings during the learning phase. This was achieved by their having to count a whispered one to five in a continuous cycle whilst listening to the Welsh stimuli and typing in the correct translations. The experimenter sat in throughout the session to monitor and ensure subjects' compliance with this requirement.

The experiment additionally involved another between-subjects factor, which was crossed with the silent/repetition/AS conditions and which contrasted explicit with implicit instruction. Half of the subjects, the explicit group, first received a short phase of instruction in Welsh soft-mutation.

This simply involved out-of-context learning, to a criterion of one complete set of 5 correct trials, the unmutated equivalents of the five mutated initial letters out of context (e.g. g = c, f = m, etc.). As there were no consistent interactions between this factor and the silent/repetition/AS factor and as effects of explicit/implicit instruction are not the focus of the present paper, it will not be discussed further here. Further details are available from the authors on request.

The experiment assessed various aspects of language learning that had resulted from the language experienced during the learning phase.

The *well-formedness test* was designed to elicit fast judgements of grammatical correctness. The subjects were asked to respond by typing *Y* if a string was grammatical and *N* if the string was not. They were first given practice trials in English to familiarize themselves with the technique (e.g. "he run down the road" — N). Once they were happy with this procedure, they moved on to judge 40 Welsh stimuli. Randomly ordered aural trials where each of the exemplar words appeared correctly mutating in the mutating construct ("*ei geg o*"), correctly not mutating in the non-mutating construct ("*ble mae ceg*"), incorrectly mutating in the non-mutating construct ("*ble mae geg*") and incorrectly not mutating in the mutating construct ("*ei ceg o*") were played to the subjects. They were asked to make a judgement concerning grammaticality as quickly as possible, and no feedback was given. The computer monitored accuracy and response latency.

The *rule test phase* assessed explicit metalinguistic awareness of the rule structure underlying mutations. The phrasal construct and the initial sound of a Welsh noun were played to the subjects, and they had to type in the unmutated sound of the noun (e.g. "*ei d . . . o*" = t). No feedback was given, and the subjects were tested just once on the five initial sounds of the nouns alone and when embedded in both constructs.

The *speech production test* assessed ability to produce orally strings of the complete set (Appendix 1) of previously heard Welsh utterances. All groups heard the English translation of the stimuli and were required to say the correct Welsh translation. It was the first time that any subject had to translate from native to foreign language, and the first opportunity for the silent and suppression groups to speak Welsh. This phase was recorded, and subjects' speech was later scored for accuracy of syntax, morphology, knowledge of rule structure, and pronunciation. The recordings were saved until all subjects had completed the experiment, and then the speech productions were analysed in a random order by the experimenter. Various measures were taken from the subjects' utterances. The proportion of trials on which a subject actually attempted a Welsh utterance was counted—a fair proportion of trials produced "no attempts". Acquisition of vocabulary (the 10 main words spoken alone and in the two different phrasal constructs) was next assessed in two ways: First there was a lexical analysis: if the spoken response was approximate enough to the appropriate Welsh word that it could be recognized as it or a close deviation from it, it was scored as correct on this measure. Then there was a strict pronunciation measure, which demanded that the word be pronounced completely correctly before a score was given. The production of the two phrasal constructs ("*ble mae____*", "*ei____o*") was assessed in a similar fashion: (a) for a close approximation, (b) for completely accurate pronunciation. Measures of grammatical performance involved separately counting the number of times subjects correctly mutated the initial sounds of nouns used with the "*ei____o*" construct and correctly did not mutate the initial sounds of words used in the "*ble mae____*" construct. Finally, there was a measure of overall correctness of whole phrases, which demanded that the utterance be completely correct, both in terms of appropriate lexical and syntactic form and of correct pronunciation.

The computerized presentation of materials entailed a move away from truly naturalistic learning but allowed the advantage of a complete record of the time taken, errors made, and number of trials needed for each subject, these, in turn, allowing a thorough analysis of the group differences.

## Results

For the sake of clear focus and brevity, we describe only the effects of condition on accuracy. The condition means and 95% confidence intervals for each condition in each phase of the experiment are shown in Figure 1.

*Learning Phase.*   There was a significant effect of condition on the number of accurate translations generated in the learning phase $F(2, 83) = 13.31$, $MS_e = 475.91$, $p < 0.0001$. Post hoc Bonferroni comparisons of the means demonstrated that AS was significantly inferior to repetition ($p < 0.0001$) and to silent ($p < 0.005$), but that repetition was only marginally superior to silent ($p = 0.05$).

Phrases involving the mutating construct "*ei____o*" were learned less accurately (15.9%, *SD* 11.6) than either the non-mutating phrase "*ble mae____*" (38.5%, *SD* 17.3) or the words alone (42.1%, *SD* 17.7), $F(2, 166) = 279.75$, $MS_e = 63.42$, $p < 0.0001$. Although there was some Construct $\times$ Condition interaction, $F(4, 166) = 3.54$, $MS_e = 63.42$, $p < 0.01$, Bonferroni tests confirmed significant advantages of repetition over AS for all three constructs (words alone, "*ble mae____*", and "*ei____o*").

*Well-formedness Test.*   Performance on this test as a whole was significantly greater than the 50% chance level, $t(86) = 12.49$, $p < 0.0001$, as it was for each group taken individually (all $ps < 0.0001$). However, there was no significant effect of condition on the grammaticality judgements, $F(2, 81) = 1.58$, $MS_e = 120.16$, *n.s.*

*Rule Test.*   The different conditions of exposure had a significant effect on subjects' resultant explicit knowledge of the rules of mutation, $F(2, 83) = 3.77$, $MS_e = 1127.29$, $p < 0.05$. Bonferroni testing demonstrated that this effect lay mainly in the inferior performance of the AS group compared to repetition ($p = 0.01$) and silent ($p = 0.06$).

*Speech Production.*   The learners' attempts at producing Welsh were scored in a number of ways. The first measure was the number of trials on which subjects actually attempted a Welsh utterance. There was a significant effect of condition on this, $F(2, 81) = 11.95$, $MS_e = 554.77$, $p < 0.0001$. Bonferroni tests demonstrated an advantage of repetition over both silent ($p < 0.005$) and AS ($p < 0.0001$), but no significant difference between these latter two groups.

There were two separate measures of vocabulary acquisition. First, responses that approximated enough to the appropriate Welsh word that they could be categorized as such or as deviations from it were scored as correct. There was a significant effect of condition on this, $F(2, 81) = 18.26$, $MS_e = 388.11$, $p < 0.0001$. Bonferroni tests demonstrated worse performance of AS compared with both silence ($p < 0.05$) and repetition ($p < 0.0001$), and a significant advantage of repetition over silence ($p < 0.0005$). Adoption of the stricter criterion that the vocabulary had to be pronounced completely correctly confirmed the particular advantage of repetition, $F(2, 81) = 20.13$, $MS_e = 160.91$, $p < 0.0001$, repetition > silent ($p < 0.0001$), repetition > AS ($p < 0.0001$), silent $\approx$ AS (*n.s.*).

The production of the phrasal constructs ("*ble mae____*", "*ei____o*") was scored in similar fashion. There was a significant effect of condition on production of approximately correct phrases, $F(2, 81) = 18.30$, $MS_e = 905.01$, $p < 0.0001$, with repetition > silent ($p <$
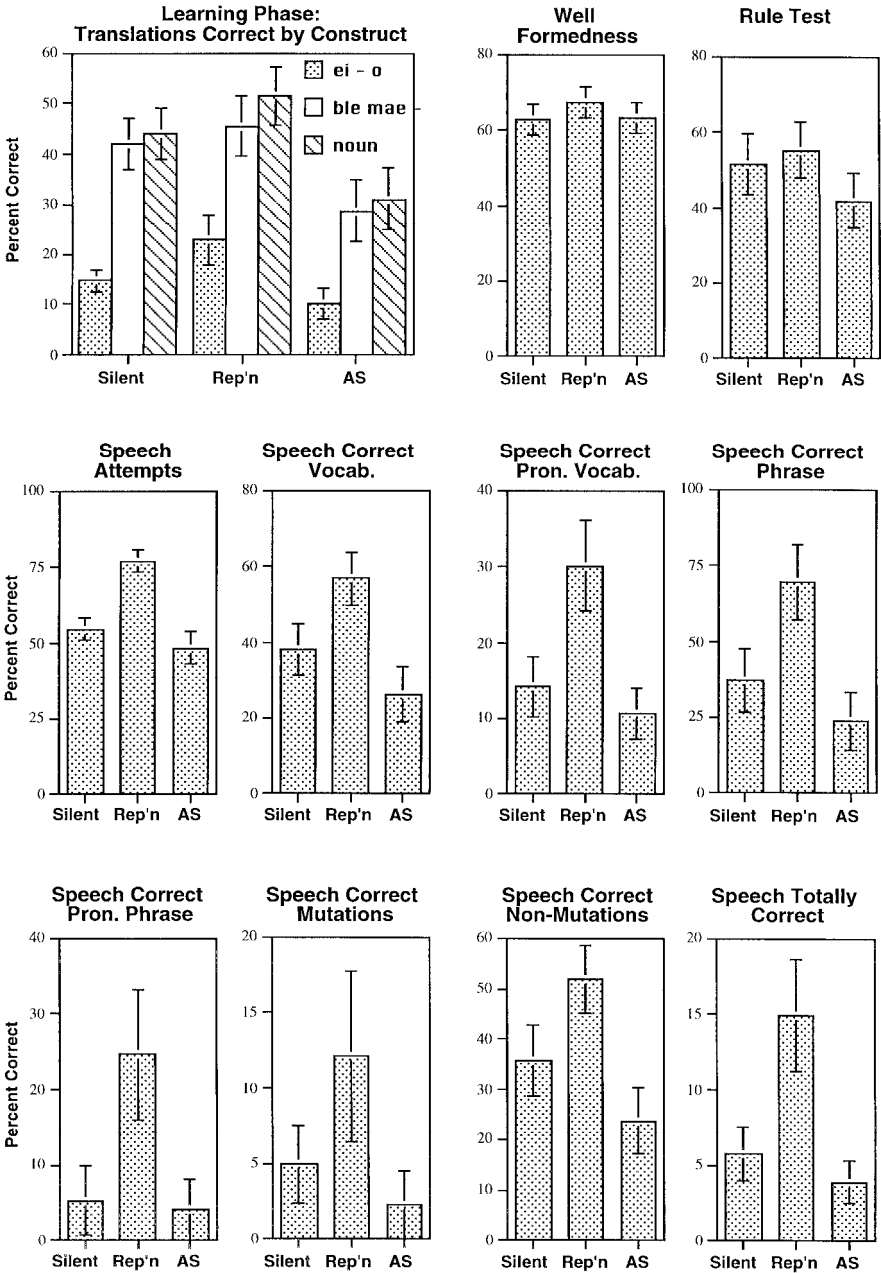
FIG. 1. Mean percentage of accuracy as a function of condition in each phase and outcome measure of the experiment. Abbreviations for the conditions are as follows: Silent = silent group, Rep'n = repetition group, AS = articulatory suppression group. Error bars represent 95% confidence intervals.

0.0001), repetition > AS ($p < 0.0001$), silent $\approx$ AS (*n.s.*). There was a similar effect on the accurate pronunciation of phrases, $F(2, 81) = 13.52$, $MS_e = 279.97$, $p < 0.0001$, with repetition > silent ($p < 0.0001$), repetition > AS ($p < 0.0001$), silent $\approx$ AS (*n.s.*).

The measure of grammatical performance in terms of the subjects' correctly soft mutating the initial sounds of nouns used with the "*ei____o*" construct also demonstrated a significant effect of condition, $F(2, 81) = 6.62$, $MS_e = 111.95$, $p < 0.005$, with repetition > silent ($p < 0.05$), repetition > AS ($p < 0.001$), silent $\approx$ AS (*n.s.*). The obverse ability of correctly not-mutating the initial sounds of nouns used with the "*ble mae____*" construct yielded similar effects, $F(2, 81) = 16.65$, $MS_e = 352.61$, $p < 0.0001$, with repetition > silent ($p < 0.005$), repetition > AS ($p < 0.0001$), silent > AS ($p < 0.05$).

All of these aspects of production contribute to an overall measure of correctness where the criterion is that the Welsh utterance should be an appropriate translation that is well formed in lexis and syntax and accurately pronounced. Again there is a significant effect of condition, $F(2, 81) = 21.10$, $MS_e = 48.52$, $p < 0.001$, with repetition > silent ($p < 0.0001$), repetition > AS ($p < 0.0001$), silent $\approx$ AS (*n.s.*).

## Discussion

It is clear that rehearsal in phonological STM provides a wide range of language-learning advantages. If we compare individuals who were forced to rehearse (repetition) with those prevented from so doing (AS), then the results of this experiment demonstrate that phonological rehearsal of FL utterances results in superior performance in (a) receptive skills in terms of learning to comprehend and translate FL words and phrases, (b) explicit metalinguistic knowledge of the detailed content of grammatical regularities, in this case the phonological changes of the Welsh soft mutation, (c) acquisition of the FL forms of words and phrases, (d) accuracy in FL pronunciation, and (e) grammatical fluency and accuracy, in this case in terms of correctly mutating or not-mutating as appropriate in a given grammatical construct. The only test where this comparison was non-significant concerned receptive grammaticality judgements. One criticism that might be levied against these conclusions is that AS might not be serving as a rehearsal-specific interference, but, rather, that it may cause general interference as a result of its additional attentional processing demands, and thus the design requires a non-articulatory interference treatment (such as finger-tapping as used by Papagno et al., 1991) as a control. However, this criticism does not apply here because the effects (a), (c), (d), and (e) described above are all replicated as significant in the advantage of the repetition group over the silent group, who were not subjected to any interference treatments at all.

These findings do not tell us whether the advantage of rehearsal lies at input or output. The repetition effect may arise from the subjects' articulating the FL utterances (output), from their hearing their own repetitions (and thus getting twice the input of the AS group), or from a combination of the two. Further experimentation is needed to choose between these alternatives.

So what is the involvement of phonological STM in language learning? Our argument will echo Melton's preference "for a theoretical strategy that accepts STM and LTM as mediated by a single type of storage mechanism. In such a continuum, frequency of repetition appears to be the important independent variable, 'chunking' seems to be

the important intervening variable, and the slope of the retention curve is the important dependent variable" (Melton, 1963, p. 19). Melton based these conclusions on the interactions of STM and LTM in the learning of letter or digit sequences. We begin by considering vocabulary acquisition and then extend the argument to syntax.

## Working Memory–LTM Interactions in the Acquisition of Vocabulary Surface Form

For the case of vocabulary acquisition, Gathercole et al. (1991, pp. 364–365) take a position similar to Melton's: "Nonword repetition ability and vocabulary knowledge develop in a highly interactive manner. Intrinsic phonological memory skills may influence the learning of new words by constraining the retention of unfamiliar phonological sequences, but in addition, extent of vocabulary will affect the ease of generating appropriate phonological frames to support the phonological representations." This is as true for foreign as for native language. The novice FL learner comes to the task with a capacity for repeating native words. The degree to which the relevant skills and knowledge are transferable to immediate FL word repetition depends on the degree to which the phonotactic patterns in the FL approximate to those of the native language (Ellis & Beaton, 1993b). Thus long-term knowledge affects phonological STM. The present experiment and that of Ellis and Beaton (1993a) shows that the reverse is also true—repetition of FL forms promotes long-term retention. We assume that as learners practise hearing and producing FL words, so they automatically and implicitly acquire knowledge of the statistical frequencies and sequential probabilities of the phonotactics of the FL. In turn, as they begin to abstract knowledge of FL regularities, they become more proficient at short-term repetition of novel FL words. And so FL vocabulary learning lifts itself up by its bootstraps.

Although learners need not be aware of the *processes* of such pattern extraction, they will later be aware of the *product* of these processes, because the next time they experience that pattern it is the patterned chunk of which they will be aware, not the individual components (e.g. while children are learning about analogue clocks, they closely attend to the features and relative positions of hands and numerals; when experienced adults consult their watch, they are aware of *the time* and have no immediate access to such lower-level perceptual information; Morton, 1967). Such influences of LTM on working memory underlie the development of automaticity (LaBerge & Samuels, 1974; McLaughlin, 1978; Schmidt, 1992). Example of these interactions in the domain of language include the effects of long-term lexical knowledge on STM for words (Brown & Hulme, 1992), long-term phonological knowledge on STM for nonwords and foreign-language words (Ellis & Beaton, 1993b; Gathercole & Baddeley, 1993; Treiman & Danis, 1988), long-term grammatical knowledge on STM for phrases (Epstein, 1967), and long-term semantic knowledge on STM for word strings (Cook, 1979).

## Working Memory in the Acquisition of Vocabulary Reference

However, these processes concern merely the acquisition of chunks of language, and language ability involves much more than its surface form—its function is reference. The above-described learning mechanisms result in sequences of language that are *potential* labels, but we must consider also the development of reference.

In addition to implicit learning within input modalities, attentional focus in working memory can result in the formation of cross-modal associations. Nodes that are simultaneously or contiguously attended in working memory tend to become associated in the long term. The implicit pattern-detection processes that occur *within* these modalities of representation entail that any such *cross-modal* associations typically occur between the highest chunked level of activated node. Thus, to extend Morton's (1967) example, the adult looking at the clock when post falls through the letter-box each morning learns an association of *mail-time* with 08.30, not one between envelopes and the big hand of the clock.

Similar processes occur within the language system. Consider as illustration two children of different ages hearing the complaint, "I have a headache", while they observe salient visual input. The older child, who knows the words *hɛd* and *eik*, attends to the sequence of these *two* chunks along with the visual pattern. The younger child, who has heard neither such words nor such syllables before, has to attend to a much longer sequence of chunks: //h // ɛ // d // ei // k //, and there is concomitantly a greater chance of error in sequencing (for example, Crystal, 1987, describes a child who pronounced *blanket* as [bwati], [bati], [baki], and [batit] within a few hours of each other). No strong cross-modal association between the attended unit in the visual module and a common representation in the language module can result. The more the units of language come as packaged wholes, the greater the possibility of attentional focus and resultant association.

A similar explanation can be applied to the FL learning involved in the present experiment. The more often the FL utterances are repeated in phonological working memory, the more regularities and chunks of spoken FL are abstracted, and the more accurately and readily these can be called to working memory, either for accurate pronunciation as articulatory output or as labels for association with the native-language translations.

## Working Memory in the Acquisition of Longer Utterances

Just what are the meaningful units of language acquisition (Peters, 1983)? Sinclair (1991, p. 110), as a result of his experience directing the Cobuild project, the largest lexicographic analysis of the English language to date, proposed *the principle of idiom*: "a language user has available to him or her a large number of semi-preconstructed phrases that constitute single choices, even though they might appear to be analysable into segments." Collocations and stock phrases are viewed with just the same importance in FL research, where they are known as holophrases (Corder, 1973), prefabricated routines and patterns (Hakuta, 1974), formulaic speech (Wong-Fillmore, 1976), memorized sentences and lexicalized stems (Pawley & Syder, 1983), or formulas (R. Ellis, 1994). An important index of nativelike competence is that the learner uses idioms fluently. So language learning involves learning sequences of words (frequent collocations, phrases, and idioms), as well as sequences within words. For present purposes, such collocations can simply be viewed as big words, and the role of working memory in learning such structures is the same as that for words. Just as repetition aided the consolidation of Welsh vocabulary in the present experiment, so it did the long-term acquisition of Welsh phrases.

### Working Memory in the Acquisition of Grammar

But word sequences have characteristic structures all their own, and the abstraction of these regularities is the acquisition of grammar. There are good reasons to consider that sequence information is central to the acquisition of word grammatical class. Slobin (1973) proposed that "paying attention to the order of words and morphemes" is one of the most general of children's "operating principles" when dealing with their native language, and word order is similarly one of the four cues to part of speech in the Bates and MacWhinney (1981) Competition Model of FL processing. More recently, Tomasello (1992) has proposed that young children's early verbs and relational terms are *individual* islands of organization in an otherwise unorganized grammatical system: In the early stages, the child learns about arguments and syntactic markings on a *verb-by-verb* basis, and ordering patterns and morphological markers learned for one verb do not immediately generalize to other verbs. Positional analysis of each verb island requires long-term representations of that verb's collocations, and thus these accounts of grammar acquisition posit vast amounts of long-term knowledge of word sequences. Only later are syntagmatic categories formed by abstracting regularities from this large dataset in conjunction with morphological marker cues (at least in case-marking languages). Computational accounts of the learning of word class from positional analysis of natural language can be found in Kiss (1973), Sampson (1987), Charniak (1993), and Finch and Chater (1994).

The present experiment has shown that short-term repetition of FL utterances allows the consolidation of long-term representations of words and word sequences. Subjects could produce these forms better as a result, and they appeared to be more nativelike in that they could accurately produce grammatical utterances as lexicalized phrases. The stock of lexicalized phrases that they so acquired also allowed them to develop superior explicit, metacognitive knowledge about the underlying rule structure.

Theories of implicit acquisition of grammar from automatic analysis of word order in a stock of exemplars in LTM would also hold that these word sequences should allow the repetition subjects a better implicit knowledge of the Welsh soft-mutation. Yet they seemed to have no significant advantage in making fast, accurate judgements of grammaticality. Why might this be? Perhaps the grammaticality tasks are very difficult because they ask subjects to distinguish between the correct form and the most likely error, and also because the learners' focus has been on understanding and translation rather than on form (R. Ellis, 1994; Long, 1991). Furthermore, even though rehearsal extended the repetition subjects' stock of phrases, this was a very short experiment compared with the experience of millions of utterances that underpins fluent attainment of natural-language grammar. The work of Bowerman (1976), Marchman and Bates (1994), and Tomasello (1992) demonstrates that a "critical mass" of individual "islands of organization" for each word needs to be acquired before patterns of organization can be abstracted from them.

## Conclusion

We have argued that much of language learning is the acquisition of memorized sequences of language (for vocabulary, the phonological units of language and their phonotactic sequences; for discourse, the lexical units of language and their sequences in clauses

and collocations), and we have demonstrated the involvement of working memory, par-
ticularly the short-term phonological store, in this learning process. Short-term repre-
sentation and rehearsal allows the eventual establishment of long-term sequence
information for language. There are, in turn, reciprocal interactions between long-term
sequence representations and short-term storage whereby long-term sequence informa-
tion allows the chunking of working memory contents that accord with these consolidated
patterns, thus extending the span of short-term storage for chunkable materials. The
more the long-term storage of frequent language sequences, the more easily can they
serve as labels for meaning reference. The more automatic their access, the more fluent is
the resultant language use, concomitantly freeing attentional resources for analysis of the
meaning of the message, either for comprehension or for production planning. Finally, it
is this long-term knowledge base of word sequences that serves as the database for the
acquisition of language grammar. A full account of this constructivist view of language
acquisition is presented in Ellis (in press).

The following questions remain:

1. How are grammatical regularities abstracted from long-term knowledge of word
sequences? This obviously depends on various aspects of the grammatical regularity being
considered, such as its consistency, the type/token ratio of its exemplars, its salience, and
the degree of separation of the relevant dependencies. This question is currently the focus
of a large number of research studies concerning the implicit learning of artificial and
natural languages both by human subjects and by connectionist systems (see, e.g., reviews
in Ellis, 1994).

2. How does the length of the sequence (either as the window that working memory
gives for on-line analysis, or as the length of learned collocation / phrase sequence in
LTM) affect the abstraction of different types of grammatical regularity? Work has just
begun on these issues (e.g. Newport, 1990; Elman, 1993), and it is our research priority.

Such questions put the acquisition of grammar, both implicit and explicit, native,
second, and foreign languages, firmly within the developmental and computational
research arena of working memory. Although acquired short-term memory deficits
have surprisingly little effect on language *use* (Vallar & Shallice, 1990), it is becoming
increasingly clear that individual differences in STM and working memory can have
profound effects on language *acquisition*.

## REFERENCES

Adams, A.-M., & Gathercole, S.E. (1995). Phonological working memory and speech production in
    preschool children. *Journal of Speech and Hearing Research*, *38*, 403–414.
Asher, J.J. (1969). The Total Physical Response approach to second language learning. *The Modern
    Language Journal*, *53*, 3–17.
Baddeley, A.D. (1986). *Working memory*. Oxford: Clarendon.
Baddeley, A.D., & Hitch, G. (1974). Working memory. In G.A. Bower (Ed.), *The psychology of learning
    and motivation*, *Vol. 8*. New York: Academic Press.
Baddeley, A.D., Papagno, C., & Vallar, G. (1988). When long-term learning depends on short-term
    storage. *Journal of Memory and Language*, *27*, 586–595.

Bates, E., & MacWhinney, B. (1981). Second language acquisition from a functionalist perspective. In H. Winitz (Ed.), *Native Language and Foreign Language Acquisition, Annals of the New York Academy of Sciences*, *379*, 190–214.

Blake, J., Austin, W., Cannon, M., Lisus, A., & Vaughan, A. (1994). The relationship between memory span and measures of imitative and spontaneous language complexity in preschool children. *International Journal of Behavioural Development*, *17*, 91–107.

Bowerman, M. (1976). Semantic factors in the acquisition of rules for word use and sentence construction. In D. Morehead & A. Morehead (Eds.), *Normal and deficient child language*. Baltimore, MD: University Park Press.

Brown, G.D.A., & Hulme, C. (1992). Cognitive psychology and second-language processing: the role of short-term memory. In R.J. Harris (Ed.), *Cognitive processing in bilinguals*. Amsterdam: Elsevier.

Carroll, J.B., & Sapon, S.M. (1955). *Modern Language Aptitude Test*. New York: The Psychological Corporation/Harcourt Brace Jovanovich Inc.

Charniak, E. (1993). *Statistical language learning*. Cambridge, MA: MIT Press.

Cook, V. (1979). Aspects of memory in secondary school language learners. *Interlanguage Studies Bulletin—Utrecht*, *4*, 161–172.

Corder, S.P. (1973). *Introducing applied linguistics*. Harmondsworth: Penguin.

Crystal, D. (1987). *The Cambridge encyclopaedia of language*. Cambridge: Cambridge University Press.

Daneman, M., & Case, R. (1981). Syntactic form, semantic complexity, and short-term memory: Influences on children's acquisition of new linguistic structures. *Developmental Psychology*, *17*, 367–378.

Ellis, N.C. (1993). Rules and instances in foreign language learning: Interactions of explicit and implicit knowledge. *European Journal of Cognitive Psychology*, *5*, 289–318.

Ellis, N.C. (Ed.) (1994). *Implicit and explicit learning of languages*. London: Academic Press.

Ellis, N.C. (in press). Sequencing in SLA: Phonological memory, chunking, and points of order. *Studies in Second Language Acquisition*.

Ellis, N.C., & Beaton, A. (1993a). Factors affecting the learning of foreign language vocabulary: Imagery keyword mediators and phonological short-term memory. *Quarterly Journal of Experimental Psychology*, *46A*, 533–558.

Ellis, N.C., & Beaton, A. (1993b). Psycholinguistic determinants of foreign language vocabulary learning. *Language Learning*. *43*, 559–617.

Ellis, N.C., & Large, B. (1987). The development of reading: As you seek so shall you find. *British Journal of Psychology*, *78*, 1–28.

Ellis, N.C, & Miles, T.R. (1981). A lexical encoding deficiency I: Experimental evidence. In G.Th. Pavlidis & T.R. Miles (Eds.), *Dyslexia research and its applications to education*. Chichester: Wiley.

Ellis, R. (1994). *The study of second language acquisition*. Oxford: Oxford University Press.

Elman, J.L. (1993). Learning and development in neural networks: The importance of starting small. *Cognition*, *48*, 71–99.

Epstein, W. (1967). The influence of syntactical structure on learning. In N.J. Slamecka (Ed.), *Human learning and memory: Selected readings* (pp. 391–395). New York: Oxford University Press.

Finch, S., & Chater, N. (1994). Learning syntactic categories: A statistical approach. In M. Oaksford & G.D.A. Brown (Eds.), *Neurodynamics and psychology*. London: Academic Press.

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

Gathercole, S.E., & Baddeley, A.D. (1990). The role of phonological memory in vocabulary acquisition: A study of young children learning new names. *British Journal of Psychology*, *81*, 439–454.

Gathercole, S.E., & Baddeley, A.D. (1993). *Working memory and language*. Hove: Lawrence Erlbaum Associates, Ltd.

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

Hakuta, K. (1974). Prefabricated patterns and the emergence of structure in second language acquisition. *Language Learning*, *24*, 287–298.

Kiss, G.R. (1973). Grammatical word classes: A learning process and its simulation. In G.H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory*, Vol. 7. New York: Academic Press.

Krashen, S., & Terrell, T. (1983). *The natural approach: Language acquisition in the classroom*. Oxford: Pergamon.

LaBerge, D., & Samuels, S.J. (1974). Towards a theory of automatic information processing in reading. *Cognitive Psychology*, *6*, 292–323.

Long, M.H. (1991). Focus on form: A design feature in language teaching. In K. deBot, R.B. Ginsberg, & C. Kramsch (Eds.), *Foreign language research in cross-cultural perspective* (pp. 39–52). Amsterdam: Benjamins.

Marchman, V.A., & Bates, E. (1994). Continuity in lexical and morphological development: A test of the critical mass hypothesis. *Journal of Child Language*, *21*, 339–366.

McCarthy, J.J., & Kirk, S.A. (1961). *Illinois Test of Psycholinguistic Abilities*. Urbana, IL: Institute for Research on Exceptional Children.

McLaughlin, B. (1978). *Theories of second language acquisition*. London: Edward Arnold.

Melton, A.W. (1963). Implications of short-term memory for a general theory of memory. *Journal of Verbal Learning and Verbal Behaviour*, *2*, 1–21.

Morton, J. (1967). A singular lack of incidental learning. *Nature*, *215*, 203–204.

Newport, E.L. (1990). Maturational constraints on language learning. *Cognitive Science*, *14*, 11–28.

Papagno, C., Valentine, T., & Baddeley, A. (1991). Phonological short-term memory and foreign-language vocabulary learning. *Journal of Memory and Language*, *30*, 331–347.

Pawley, A., & Syder, F.H. (1983). Two puzzles for linguistic theory: Nativelike selection and nativelike fluency. In J.C. Richards & R.W. Schmidt (Eds.), *Language and communication*. London: Longman.

Peters, A.M. (1983). *The units of language acquisition*. Cambridge: Cambridge University Press.

Reynell, J.K. (1983). *Reynell Developmental Language Scales Manual* (revised edition). Windsor: NFER-Nelson.

Rodgers, T.S. (1969). On measuring vocabulary difficulty: An analysis of item variables in learning Russian-English vocabulary pairs. *International Review of Applied Linguistics*, *7*, 327–343.

Sampson, G. (1987). Probabilistic models of analysis. In R. Garside, G. Leech, & G. Sampson (Eds.), *The computational analysis of English*. Harlow, Essex: Longman.

Scarborough, H.S. (1991). Early syntactic development of dyslexic children. *Annals of Dyslexia*, *41*, 207–221.

Schmidt, R. (1992). Psychological mechanisms underlying second language fluency. *Studies in Second Language Acquisition*, *14*, 357–385.

Seibert, L.C. (1927). An experiment in learning French vocabulary. *Journal of Educational Psychology*, *18*, 294–309.

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

Sinclair, J. (1991). *Corpus, concordance, collocation*. Oxford: Oxford University Press.

Slobin, D.I. (1973). Cognitive prerequisites for the development of grammar. In C.A. Ferguson & D.I. Slobin (Eds.), *Studies of child language development* (pp. 175–208). New York: Holt Rinehart Winston.

Sparks, R.L., Ganschow, L., Javorsky, J., Pohlman, J., & Patton, J. (1992). Test comparisons among students identified as high-risk, low-risk, and learning disabled in high-school foreign language courses. *Modern Language Journal*, *76*, 142–159.

Speidel, G.E. (1993). Phonological short-term memory and individual differences in learning to speak: A bilingual case study. *First Language*, *13*, 69–91.

Tomasello, M. (1992). *First verbs: A case study of early grammatical development*. Cambridge: Cambridge University Press.

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

Vallar, G., & Shallice, T. (Eds.) (1990). *Neuropsychological impairments of short-term memory*. Cambridge: Cambridge University Press.

Wechsler, D. (1967). *WPPSI Manual. Wechsler Preschool and Primary Scale of Intelligence.* New York: The Psychological Corporation.

Wong-Fillmore, L. (1976). *The second time around.* Unpublished doctoral dissertation, Stanford University.

# APPENDIX 1

The Welsh Utterances and Their English translations

| | | | | | |
|---|---|---|---|---|---|
| *cefn* | back | *ble mae cefn* | where is a back | *ei gefn o* | his back |
| *ceg* | mouth | *ble mae ceg* | where is a mouth | *ei geg o* | his mouth |
| *dant* | tooth | *ble mae dant* | where is a tooth | *ei ddant o* | his tooth |
| *diod* | drink | *ble mae diod* | where is a drink | *ei ddiod o* | his drink |
| *mab* | son | *ble mae mab* | where is a son | *ei fab o* | his son |
| *meddwl* | mind | *ble mae meddwl* | where is a mind | *ei feddwl o* | his mind |
| *pen* | head | *ble mae pen* | where is a head | *ei ben o* | his head |
| *pres* | money | *ble mae pres* | where is money | *ei bres o* | his money |
| *tafod* | tongue | *ble mae tafod* | where is a tongue | *ei dafod o* | his tongue |
| *trwyn* | nose | *ble mae trwyn* | where is a nose | *ei drwyn o* | his nose |