ACADEMIC PRESS

Available online at www.sciencedirect.com

SCIENCE DIRECT®

Journal of Memory and Language 48 (2003) 527–541

Journal of Memory and Language

www.elsevier.com/locate/jml

Verbal working memory is involved in associative word learning unless visual codes are available

Wouter Duyck,* Arnaud Szmalec, Eva Kemps,[1] and André Vandierendonck

Department of Experimental Psychology, Ghent University, Henri Dunantlaan 2, B-9000 Ghent, Belgium

Received 24 December 2001; revision received 28 October 2002

Abstract

Baddeley, Gathercole, and Papagno (1998) proposed a model of associative word learning in which the phonological loop, as defined in Baddeley's working memory model, is primarily a language learning device, rather than a mechanism for the memorization of familiar words. Using a dual-task paradigm, Papagno, Valentine, and Baddeley (1991) found that articulatory suppression, loading verbal working memory, had an effect on the memorizing of word–nonword pairs, but not on the memorizing of word–concrete word pairs. The present work explored the potential for visual codes in unfamiliar word learning. In a first experiment, we replicated the results of Papagno et al. for both nonwords and highly imageable nouns. In addition, we found that articulatory suppression disrupted the memorizing of word–abstract word pairs, suggesting that phonological involvement may be triggered by the absence of visual representations for the abstract words. Experiment 2 showed that an artificially induced association between a nonword and a non-nameable visual image was sufficient to compensate for diminished verbal working memory resources due to articulatory suppression. In a third experiment, we demonstrated that our results generalize to other types of abstract words (i.e., function words), auditory stimulus presentation, and to word learning in children.

Keywords: Associative word learning; Imageability; Verbal working memory; Phonological loop

The present paper addresses the importance of visual codes for the acquisition of new words by means of associative learning in adults and children. As learning new vocabulary is crucial to intellectual development (Sternberg, 1987), the identification of the cognitive processes involved in acquiring new words is of major importance. This can lead to important theoretical and practical insights concerning language acquisition both in healthy adults and children, and in patients with language impairments.

Psycholinguistic research on language acquisition has focused on the association between concepts and words (e.g., Markman, 1994) or on how the syntax of a language is adopted (e.g., Gleitman, 1993). Another line of research has dealt with working memory (WM) involvement during the first stages of word acquisition (for an extensive review, see Baddeley et al., 1998). This work is characterized by an emphasis on the acquisition of the phonological representation of new words. The WM model developed by Baddeley and Hitch (Baddeley & Hitch, 1974; Baddeley, 1986) has been shown to constitute an appropriate theoretical framework to investigate the role of phonological codes in word acquisition. The model comprises three components: a central executive (CE) and two subsidiary slave systems, the phonological loop (PL) and the visuo-spatial sketch pad (VSSP). The CE serves as an attentional control mechanism, and is responsible for coordinating the operations of the two slave systems. The PL is

---

* Corresponding author. Fax: +32-9-264-64-96.
E-mail address: wouter.duyck@rug.ac.be (W. Duyck).

[1] Present address: The School of Psychology, Flinders University, Adelaide, Australia.

doi:10.1016/S0749-596X(02)00533-8

responsible for the short-term storage and processing of verbal material, such as spoken words. It can also provide verbal encodings of visually presented material such as written words and nameable pictures. Rapid decay of the phonological representations in the store can be offset by a strategic rehearsal process. The phonological store is operational from the age of three (Gathercole & Adams, 1993), while the rehearsal process is fully developed only after the age of seven (Gathercole & Hitch, 1993; see also Henry & Millar, 1991, 1993; Kemps, De Rammelaere, & Desmet, 2000). The VSSP is involved in the temporary retention and manipulation of visuo-spatial material, such as spatial patterns and locations.

This WM model has been successfully incorporated within neuropsychological and developmental areas of research (Baddeley, 1997). Moreover, there is substantial support for the neural substrates of the PL (e.g., Baddeley, Papagno, & Vallar, 1988; Grasby et al., 1993; Paulesu, Frith, & Frackowiak, 1993). Also, the WM model provides an attractive theoretical framework when using dual-task methodology: the involvement of a particular WM system in a given task can be investigated by comparing performance under single-task and dual-task conditions. If primary task performance is affected by simultaneous execution of a dual-task that loads only one of the components, it can be assumed that the WM component involved is necessary for the execution of the primary task. It should also be noted that a revised WM model was recently proposed to include a third slave system, the episodic buffer (Baddeley, 2000). This component is believed to function as a temporary interface between the slave systems and long term memory.

A substantial body of evidence has been accumulated for a model of language acquisition which proposes that the verbal component of Baddeley's WM model (the PL) is primarily involved in the storage of unfamiliar sound patterns of words until more stable (long-term) representations can be established. Hence, it is no longer viewed as a mechanism for the memorization of familiar words. Therefore, the PL has been designated as "primarily a language learning device" (Baddeley et al., 1998). The next sections summarize several relevant studies for this hypothesis, categorized by participants (children vs. adults), design (correlational vs. experimental), and language (native vs. foreign) (for a more extensive overview, see Baddeley et al., 1998).

Developmental research has demonstrated the importance of a verbal WM system such as the PL for word acquisition in children. Positive correlations have been observed between measures of verbal WM capacity and native vocabulary knowledge in children of various ages, particularly when nonword repetition scores were used to measure verbal WM capacity instead of the more widely used digit span[2] (Bowey, 2001; Gathercole & Adams, 1993, 1994; Gathercole, Hitch, Service, & Martin, 1997; Gathercole et al., 1999; Gathercole, Willis, Emslie, & Baddeley, 1992; Michas & Henry, 1994). Service (1992) for example showed that nonword repetition scores were a significant predictor of the performance of Finnish children learning English two years later. Cheung (1996) and Masoura and Gathercole (1999) replicated this finding with, respectively, Chinese and Greek children learning English. As for experimental studies, Gathercole and Baddeley (1990) showed that children with low nonword repetition scores performed more poorly on a native word learning task than children with higher verbal WM capacity. Native word learning was experimentally conceptualized as learning the association between unfamiliar names (e.g., *Pimas*) and toy animals. There was no difference between groups with respect to learning the association between the same toys and familiar names (e.g., *Thomas*). Similar findings were reported by Gathercole et al. (1997) and Michas and Henry (1994), who also showed that experimental word learning performance is positively correlated with phonological memory skills. These findings suggest that the link between verbal WM capacity and native vocabulary acquisition remains after controlling for language exposure.

With regard to research on word learning by adults, Papagno and Vallar (1992) showed that phonological similarity and item length had an effect on the associative memorizing of word–nonword pairs, but not on the memorization of word–word pairs. Both these effects of phonological similarity and word length are attributed to the operation of verbal WM: phonologically similar and longer items require more verbal WM resources than phonologically dissimilar and shorter items. Hence, Papagno and Vallar's findings suggest involvement of verbal WM in associative new word learning. Later, Papagno and Vallar (1995) found that polyglots have greater digit spans and higher nonword repetition scores than control participants. Polyglots were also better at memorizing word–nonword pairs, but not at memorizing word–word pairs, even though they did not perform better on tests assessing general intelligence or visuo-spatial abilities.

Direct experimental evidence for verbal WM involvement in language learning by adults comes from a

---

[2] This is probably due to the fact that nonwords, unlike digits, do not have any semantic or lexical representation, which can affect memory span scores (Bourassa & Besner, 1994; Hulme, Maughan, & Brown, 1991; Poirier & Saintaubin, 1995; Wetherick, 1975). However, even nonword repetition scores may not be a pure measure of phonological storage capacity, as they are also influenced by language-specific probability of used phonotactic segments (Gathercole, Frankish, Pickering, & Peaker, 1999).

study by Papagno et al. (1991). Following classical dual-task logic, they reasoned that it should be possible to show verbal WM involvement in associative word learning by demonstrating an interference effect of a simultaneously performed task which loads the PL. In contrast, such a task should not interfere with performance on an associative word memorization task if both words are known, because this association can be learned using other codes (i.e., semantic, visual, ...) than phonological ones. Using Italian participants, Papagno et al. found that articulatory suppression (repeated uttering of the sound "bla"), a secondary task known to load the PL, interfered with the learning of Italian–Russian pairs (e.g., *libro-cniga*), but not of Italian word pairs (e.g., *lupo-carta*). This was found for both auditory and visual stimulus presentation. A replication with English participants learning English–Finnish (e.g., *cowboy-pila*) and English–English (e.g., *roof-hunter*) word pairs yielded similar results. However, the researchers failed to replicate the effect for English–Russian word pairs (Experiments 3 and 4). They claimed that this might be due to the fact that the participants succeeded in learning the Russian words under articulatory suppression by making use of lexical or semantic associations. For example, the word pair *throat-garlo* may have been learned by lexically associating *garlo* with the English word *gargle*, which in turn can be associated semantically with *throat.*

Recent neuropsychological studies support the assumption that some (e.g., semantic) variables originating from long-term memory may influence performance in verbal WM tasks. Hanten and Martin (2001) showed that BS, a patient with a developmental phonological short-term memory deficit, was able to perform well in a wide range of learning and memory tasks if he could make use of lexical or semantic information. However, his performance dropped significantly if this was not possible, such as for learning lists of words of low frequency and low imageability. Similarly, Martin and Saffran (1999) found that the ability of aphasic patients with lexical and short-term memory deficits to learn supraspan word lists (i.e., lists of which the length exceeds the patients' working memory capacity) was influenced by word imageability, word frequency, and the linguistic relationship between the words of a list. This is similar to the imageability effect on word repetition performance which is typically observed in patients suffering from deep dysphasia, a rare language impairment associated with a phonological short-term memory deficit (Majerus, Lekeu, Van Der Linden, & Salmon, 2001). Also, Bird, Franklin, and Howard (2002) showed that the discrepancies between nouns and function words in comprehension and production performance of aphasic patients disappeared when imageability was controlled.

In summary, there is a substantial body of evidence in support of the involvement of a verbal WM system such as the PL in learning new native or foreign vocabulary until more stable long-term representations are formed (Baddeley et al., 1998). However, people use existing (e.g., semantic, lexical, ...) long-term language knowledge to mediate verbal learning whenever possible (Papagno et al., 1991, Experiments 3 & 4; Hanten & Martin, 2001; Martin & Saffran, 1999).

Most of the studies mentioned above are of a correlational nature and therefore provide only indirect evidence for the involvement of the PL in vocabulary learning. The possibility that a third causal factor accounts for the common variance in the two associated constructs cannot be ruled out. For example, it is possible that an enriched linguistic environment (e.g., better education, exposure to books, ...) results in a larger vocabulary and a greater working memory capacity. Hence, the observed relation between word learning and working memory capacity may not be a causal one. Of course, this criticism does not apply to the handful of experimental word learning studies (Gathercole & Baddeley, 1990; Gathercole et al., 1997; Michas & Henry, 1994).

The study of Papagno et al. (1991) provided more direct evidence for verbal WM involvement in foreign word acquisition. However, their results are subject to a methodological constraint. Just as in the two studies of Papagno and Vallar (1992, 1995), word imageability was not taken into account when selecting stimuli: almost all target words were highly imageable.[3] Therefore, not only did word–word pairs differ from word–nonword pairs with regard to the novelty of the second word in the pair, but also with regard to the availability of a strong link between the second word and a visual representation. By definition, this was not the case for the nonwords. This confound might explain the absence of an articulatory suppression effect on the learning of the word–word pairs: participants might have used a visual memorization strategy (e.g., imagining a picture of a wolf with a card in its mouth for the *lupo-carta* pair) to learn the word–word associations, whereas only a verbal strategy was available for the word–nonword pairs, due to the absence of a visual representation for the nonwords. An associative imageable word pair memorization paradigm, in which two words are encoded by means of an image combining the visual representations of both words, is typically used in studies that elicit visual memorization as a method to investigate VSSP

---

[3] For all but one of their word stimuli (i.e., *attic*), an imageability rating could be found in the MRC psycholinguistic database (Coltheart, 1981; Fearnley, 1997; Wilson, 1988): mean imageability values were 585 (Experiments 1 and 2; $SD = 37$), 572 (Experiments 3 and 4; $SD = 58$), and 589 (Experiment 6; $SD = 42$), measured on a imageability scale ranging from 100 to 700. Mean imageability was only moderate for the stimuli of Experiment 7 (i.e., 364, $SD = 44$).

functioning (e.g., Andrade, Kemps, Werniers, May, & Szmalec, 2002; Logie, 1986; Quinn & McConnell, 1996). This line of reasoning is in agreement with the neuropsychological studies of Bird et al. (2002), Hanten and Martin (2001), Majerus et al. (2001), and Martin and Saffran (1999) mentioned earlier, who reported effects of imageability on verbal WM performance of patients with various phonological short-term memory deficits. Similar beneficial effects of word imageability on verbal short-term memory performance of people without such a deficit have been reported by Paivio and Smythe (1971) and Walker and Hulme (1999).

In conclusion, it is possible that the findings of Papagno and colleagues can be attributed to the fact that the participants used a different memorization strategy (i.e., imagery) for the word–word pairs. If this is true, then verbal working memory is not involved in word learning because the words are new, but because they do not yet have a strong association with any visual representation.

This confounding factor, however, does not entirely minimize the importance of verbal working memory in novel word learning. The effect of articulatory suppression on the learning of nonwords suggests that verbal working memory is indeed involved in word learning, but it is possible that the locus of its involvement is limited to the learning of novel phonological representations; the learning of the word associations themselves can rely on other (e.g., visual) WM resources. This hypothesis will be investigated in the following experiments, and further discussed in more detail in the *General Discussion* section. Hence, we believe that, although the learning of phonological codes is important in vocabulary acquisition, it should not be restricted to this aspect, because semantic and visual representations are probably equally important.

Experiment 1

To investigate the involvement of visual codes in the learning of word pairs, the present study used an associative word learning experiment with word pairs of which the second word was low in imageability. If, in accordance with Papagno et al. (1991), verbal WM is involved only in the associative memorization of word–new word pairs, articulatory suppression should not affect performance on these pairs. However, it is our view that such an effect would occur due to the fact that abstract (low imageable) words are not strongly associated with any visual representation. It should also be noted that Papagno et al. always compared performance under articulatory suppression with performance under concurrent matrix tapping (a secondary task loading the VSSP). We believe it is more useful to compare performance under articulatory suppression with a single task condition, in order to get a purer indication of the effect of diminished verbal WM resources. No such control condition was included in the study of Papagno et al.

Method

Participants

Forty-eight first-year students enrolled at the Faculty of Psychology and Educational Sciences, Ghent University, participated for course requirements and credit. Their native language was Dutch.

Design

The experiment was a 3 (target word: concrete, abstract, nonword) × 2 (suppression: control, articulatory suppression) × 5 (trial: one to five) design. Target word was included as a between-subjects factor, while suppression and trial were manipulated within subjects. The number of correctly recalled target words (from zero to eight) was the dependent variable.

Materials

All words were chosen from Van Loon-Vervoorn (1985), who obtained imageability ratings for 4600 Dutch nouns on a seven point scale. Two lists of word pairs were constructed for each of the three types of target words: one list for the control condition and another for the articulatory suppression condition. Lists were counterbalanced over the two conditions. Each list consisted of eight word pairs (see Appendix A). Each word pair consisted of a cue and a target word. The cue words were common Dutch nouns and were used to initiate the recall of the target words. The target words were concrete words, abstract words or nonwords which had to be remembered after presentation of the accompanying cue word. In all three target word conditions, the same cue words were used to ensure that differences between conditions were solely due to the target words. Both cue and target words consisted of two syllables. All cue words were highly imageable ($M = 6.65$, $SD = 0.20$). Cue words and target words could not be easily associated, either semantically (e.g., *roof-house*) or lexically (e.g., *roof-room*), so as to prevent problems as those encountered by Papagno et al. (1991, Experiments 3 & 4, see earlier).

All targets had moderate word frequency according to the CELEX counts (Baayen, Piepenbrock, & Van Rijn, 1993). Mean target word frequency was matched as closely as possible, to ensure that the concrete (high imageable) words were not more frequent than the abstract (low imageable) target words ($t < 1$). The mean log frequency per million of the cue words was 1.35 ($SD = 0.70$).

Word–concrete word pairs (high imageable target word). All target words were highly imageable (List One: $M = 6.77$, $SD = 0.17$; List Two: $M = 6.68$, $SD =$

0.06) nouns. The mean log frequency per million of the target words was 0.94 ($SD = 0.67$).

Word–abstract word pairs (low imageable target word). Cue words in this condition were the same as in the condition mentioned previously. All abstract target words were nouns with a very low imageability rating (List One: $M = 1.80$, $SD = 0.20$; List Two: $M = 1.84$, $SD = 0.20$). The mean log frequency per million of the target words was 1.00 ($SD = 0.54$).

Word–nonword pairs. Cue words in this condition were the same as in the other conditions. The nonwords were disyllabic strings of random vowels and consonants, chosen in such a way that they contained morphemes which are likely to occur in Dutch, but did not resemble existing Dutch words.

Procedure

Participants were randomly assigned to one of the three target word conditions (concrete, abstract or nonword), in which the two lists of eight word pairs were presented: one in the control condition and one in the articulatory suppression condition (in a counterbalanced order). Each participant was seated in front of a 15″ screen, connected to an IBM compatible PC. The computer driven experiment started after extensive oral instructions. The procedure was as similar as possible to that of Papagno et al. (1991). Each trial consisted of a learning and a test phase. During the learning phase, the eight word pairs were presented centered on the screen in a random order. The cue word was presented above the target word. The pairs remained on the screen for 2 s, with a 2 s inter-trial-interval (ITI). Participants were asked to memorize the words, so that they would be able to recall the second word, after presentation of the first word. No indication was given concerning possible memorization strategies. During the test phase, all cue words were presented sequentially in a random order. Participants were required to type the appropriate word completely within a 7 s interval. Then, the following cue word was presented. Each trial consisted of this learning and test phase. Each participant completed five of these trials in both the control and articulatory suppression conditions. In the latter, participants were asked to continuously utter the word ‘de’ (Dutch for ‘the’) during the learning phase. Suppression started 4 s before presentation of the first word pair and terminated 4 s after the last pair had been presented. Articulatory suppression was performed only during the encoding of the words, not during the test phase. The experiment lasted approximately 35 min.

Results

The number of correctly recalled words was subjected to a 3 (target word: concrete, abstract, nonword) × 2 (suppression: control, articulatory suppression) × 5 (trial: one to five) ANOVA. Tests of analyses by participants and by items will be referred to as F_1 and F_2, respectively. A response was rated as ‘correct’ when it sounded like the correct word when it was pronounced according to Dutch grapheme-to-phoneme conversion rules. All means are displayed in Fig. 1.

The main effect of target word was significant, $F_1(2,\ 45) = 67.94$, $MSE = 11.99$, $p < .001$, $F_2\ (2,\ 45) = 299.92$, $MSE = 2.93$, $p < .001$. Post-hoc comparisons using Tukey’s HSD test showed that performance was significantly lower for word–nonword pairs than for word–concrete word and word–abstract word pairs (all p’s $< .001$ for analyses by participants and by items). There was no significant difference between word–concrete word and word–abstract word pairs, $p_1 > .58$ and $p_2 > .16$. The effect of suppression was also significant, $F_1(1,\ 45) = 45.24$, $MSE = 3.04$, $p < .001$ and $F_2(1,\ 45) = 92.67$, $MSE = 1.86$, $p < .001$, just as the main effect of trial, $F_1(4,\ 180) = 175.33$, $MSE = 1.74$, $p < .001$ and $F_2(4,\ 180) = 348.71$, $MSE = 0.84$, $p < .001$. Tukey’s HSD test showed significant differences ($p < .001$) between all trials except for trials four and five, which differed only in the analysis by items ($p_1 > .11$ and $p_2 < .02$). Hence, it seems that memorization performance began to level off somewhat after four trials.

As expected, the interaction between target words and suppression reached significance, $F_1(2,\ 45) = 5.72$, $MSE = 3.04$, $p < .01$, $F_2(2,\ 45) = 12.09$, $MSE = 1.86$, $p < .001$. More important, a planned comparison of the interaction involving only concrete and abstract words was also significant: the articulatory suppression effect was much stronger for word–abstract word pairs, $F_1(1,\ 45) = 7.60$, $MSE = 3.04$, $p < .01$, $F_2(1,\ 45) = 12.11$, $MSE = 1.86$, $p < .01$. Accordingly, planned comparisons showed a significant articulatory suppression effect for both abstract and nonwords, respectively. $F_1(1,\ 45) = 25.32$, $MSE = 3.04$, $p < .001$, $F_2(1,\ 45) = 43.56$, $MSE = 1.86$, $p < .001$ and $F_1(1,\ 45) = 30.08$, $MSE = 3.04$, $p < .001$, $F_2(1,\ 45) = 70.47$, $MSE = 1.86$, $p < .001$. There was no articulatory suppression effect for concrete words, $F_1(1,\ 45) = 1.28$, $MSE = 3.04$, $p > .26$ and $F_2(1,\ 45) = 1.28$, $MSE = 3.04$, $p > .10$.

Discussion

We succeeded in replicating the main findings of Papagno et al. (1991). Articulatory suppression disrupted associative word–nonword learning, suggesting verbal WM involvement in the acquisition of new words. Such an effect was not present when the task involved two highly imageable familiar words. However, articulatory suppression did also affect performance when the target was familiar, but had a low imageability rating. Hence, the conclusions of Papagno et al. regarding associative learning of familiar words should be restricted to highly imageable words. This supports the hypothesis

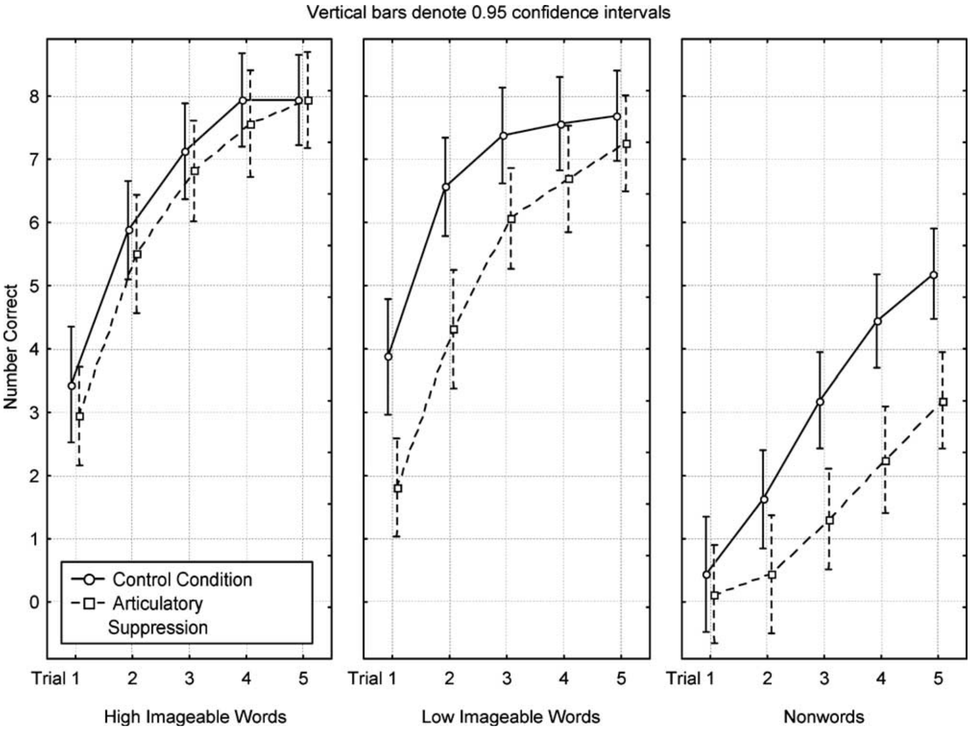


Fig. 1. Mean number of correctly recalled target words by target word, suppression, and trial (Experiment 1).

that the absence of a visual code is the determining factor for verbal WM involvement in associative word learning, rather than the novelty of a word. It follows that the association between two words (not the respective phonological representations) may be learned by means of other than verbal (e.g., visual) WM resources.

Experiment 2

If the availability of a visual code is indeed the crucial factor counteracting the negative effects of articulatory suppression on the learning of word–concrete word pairs, imagery (in a visual working memory component such as the VSSP) may play a role in this kind of word learning. To test this hypothesis more directly, a second experiment was designed. We decided not to use visuo-spatial suppression as a secondary task to study the role of visual working memory in the learning of word–concrete word pairs for two reasons. First, any visuo-spatial suppression effect is likely to be circumvented through verbal memorization strategies. Such a strategy cannot be hindered by induction of articulatory suppression because it is undesirable to use two secondary tasks at the same time. Second, most active VSSP tasks are spatial rather than visual in nature (e.g., spatial tapping, Farmer, Berman, & Fletcher, 1986), while the passive secondary tasks are mainly visual (e.g., dynamic visual noise, Quinn & McConnell, 1996). No active, predominantly visual secondary task was found to be appropriate for this study. The method that we decided to use circumvents these problems. It seeks to remove the articulatory suppression effect on the learning of word–nonword pairs by means of inducing an association between the nonword and a nonnameable visual code. A thoroughly learned associated visual nonword representation may allow visuospatial WM resources to compensate for diminished verbal WM capacity imposed by the secondary verbal task. If this is the case, then the articulatory suppression effect can be expected to disappear. Then, it follows that imageability can be put forward more confidently as the crucial factor for verbal WM involvement in associative word learning.

Method

Participants

Sixteen first-year students enrolled at the Faculty of Psychology and Educational Sciences, University of Ghent, participated for course requirements and credit. They were all native Dutch speakers. None of them participated in Experiment 1.

Design

The experiment was a 2 (induction: control, visual code) × 2 (suppression: control, articulatory suppression) × 5 (trial: one to five) design. The factor induction was manipulated between subjects, while suppression and trial were within-subjects factors.

Materials

The cue words and the nonwords were those used in Experiment 1. Sixteen nonnameable, monochrome line drawings were constructed and randomly assigned to the nonwords. Computer images drawn by hand were used to avoid clear geometrical figures (lines, triangles, …) which can easily be named. They are displayed in Appendix B.

Procedure

All participants were randomly assigned to one of the induction conditions. They received the two lists of word–nonword pairs: one to be memorized in the control condition and one under articulatory suppression (counterbalanced with order).

Each participant was seated in front of a 15″ screen, connected to an IBM compatible PC. Instructions were presented on the screen. The experiment consisted of an association phase, a learning phase and a test phase. During the association phase, participants in the visual induction condition had to learn the association between the nonwords and their corresponding visual codes. The line drawings were presented in a white square (169 cm^2) on a black background. The corresponding nonword was presented above the white square in which the line drawing was presented. Participants in the control condition only saw these nonwords with a white, empty square underneath. These stimuli (nonwords with or without visual codes) were all presented 20 times for a period of 4 s with a 1 s ITI. In the learning phase, word–nonword pairs were presented and memorized following the procedure of Experiment 1, both with and without articulatory suppression. In the test phase, memorization of the word pairs was tested as described in the *Procedure* section of Experiment 1. The experiment lasted approximately 60 min.

Results

The number of correctly recalled words was subjected to a 2 (induction: control, visual code) × 2 (suppression: control, articulatory suppression) × 5 (trial: one to five) ANOVA. Tests of analyses by participants and by items will be referred to as F_1 and F_2, respectively. A response was rated as 'correct' if it sounded like the correct word when it was pronounced according to Dutch grapheme-to-phoneme conversion rules. All means are displayed in Fig. 2.

We observed significant main effects of suppression and trial, $F_1(1,\ 14) = 14.36$, $MSE = 5.96$, $p < .01$,

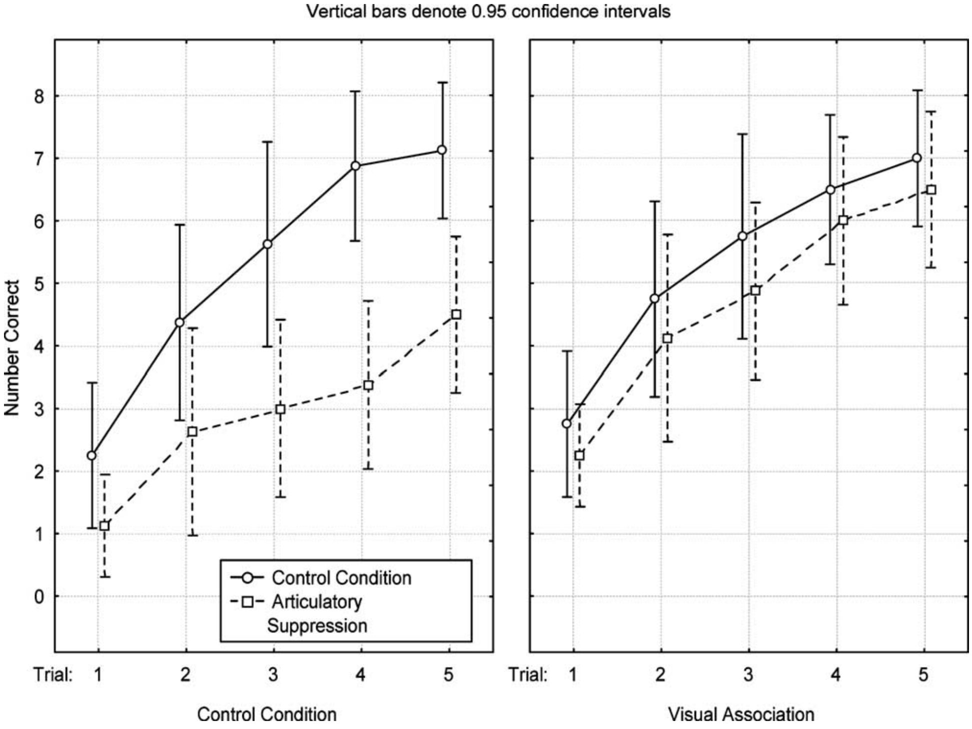


Fig. 2. Mean number of correctly recalled target words by induction, suppression, and trial (Experiment 2).

$F_2(1,\ 15) = 27.53, MSE = 1.50, p < .001$ and $F_1(4,\ 56) = 66.90,\quad MSE = 1.28,\quad p < .001;\quad F_2(4,\ 60) = 126.17,\ MSE = 0.37,\ p < .001$, respectively. Tukey's HSD test showed significant differences ($p < .05$) between all trials except between trials four and five in the analysis by participants ($p_1 > .23$ and $p_2 < .05$). Hence, it seems that memorization performance began to level off a bit after four trials. The effect of induction was only significant in the analysis by items, $F_1(1,\ 14) = 2.13,\ MSE = 17.36,\ p > .16$ and $F_2(1,\ 15) = 14.97,\ MSE = 1.30,\ p < .01$.

As expected, there was a significant suppression by induction interaction, $F_1(1,\ 12) = 4.77,\ MSE = 6.72,\ p < .05$ and $F_2(1,\ 15) = 10.60,\ MSE = 1.49,\ p < .01$. Planned comparisons revealed that the articulatory suppression effect was not significant on any trial in the induction condition (all p_1's $> .28$; all p_2's $> .18$), nor across trials, $F_1(1,\ 14) = 1.21, MSE = 5.96, p > .29$ and $F_2(1,\ 15) = 3.03,\ MSE = 1.00,\ p > .10$. However, in the control condition, we observed a significant suppression effect on every trial (all p_1's $< .02$; all p_2's $< .01$), except for the first (probably due to a floor effect), $p_1 < .06$ and $p_2 < .05$. The effect of suppression was also significant across trials, $F_1(1,\ 14) = 18.15,\ MSE = 5.96,\ p < .001,\ F_2(1,\ 15) = 27.17,\ MSE = 1.99,\ p < .001$.

Discussion

Experiment 2 confirms the hypothesis that the effect of articulatory suppression on associative word learning can be circumvented by artificially establishing an association between a nonword and a visual representation of a nonnameable line drawing. Articulatory suppression did not affect the learning of word–nonword pairs when participants had previously seen those nonwords 20 times together with their corresponding visual images. In the control condition without visual association, however, a verbal suppression effect was observed on every trial (except for a probable floor effect in the analysis by participants on the first trial). Hence, associative word learning only relies on verbal WM if a visual representation is not available. These results also suggest that the association between the nonwords and the line drawings was not learned via a verbal label (e.g., *zigzag*) assigned to the drawings, since this would probably have triggered an articulatory suppression effect.

It follows that the imageability, rather than the novelty of a word determines verbal WM involvement in learning associations between words. Therefore, it is plausible that the lack of verbal WM resources (due to articulatory suppression) can be compensated by using visual short-term memory strategies (such as imagery) when learning the association between pairs of words that have links with some visual representation. In agreement with Baddeley et al. (1998) and Papagno et al. (1991), the present experiments confirm that verbal WM is important when learning new native and foreign vocabulary. However, they also clarify that this phenomenon can be attributed to the absence of visual representations for new words, and that verbal WM may be necessary for learning phonological representations, but not for learning the word associations themselves.

Experiment 3

In this last experiment, we seek to investigate whether our findings regarding the importance of visual codes for the acquisition of words generalize to other (a) age groups, (b) types of words, and (c) presentation modalities.

First, it is important to show that the effect of imageability on associative word learning is not only present in adults, because children learn more vocabulary than adults do. For example, it is estimated that pupils acquire around seven words per day (almost 3000 words per year) during the elementary through high school years (Nagy & Anderson, 1984; Nagy & Herman, 1987). Furthermore, because most studies on verbal working memory involvement in word learning by children are of a correlational nature (see earlier), it is useful to test the experimental word learning paradigm used in Experiment 1 in a younger age group. Because most Belgian (Dutch speaking) school children begin to learn English, French, and sometimes German, ancient Greek and Latin in the first year of high school, we decided to investigate the effect of imageability on word learning in a group of first year high school students (± 12 years old). Furthermore, a dual-task methodology such as the one used in Experiment 1, would be too demanding for younger children.

Second, because at least some 12 year olds may not know some of the abstract words used in Experiment 1 (e.g., *inteelt* [inbreeding]), we sought to generalize our previous findings to other types of low imageable words. We chose function words (e.g., *because*, *when*, *therefore*, ...) because these are learned at an early age and are by definition among the least imageable of all words. The fact that function words are also very frequent and thus easier to remember, strengthens a potential effect of articulatory suppression on the associative learning of word–function word pairs.

Finally, we decided to use auditory stimulus presentation in the present experiment to exclude the possibility that visual codes are only important in associative word learning when the words are presented visually.

Method

Participants

Forty-two pupils enrolled in the first year of the Klein Seminarie high school of Roeselare, Belgium, volunteered for this experiment. Their ages ranged from

11 years, 11 months to 13 years ($M = 12.04$; $SD = 0.38$). They were all native Dutch speakers.

Design

The experiment was a 3 (target word: concrete, abstract, nonword) × 2 (suppression: control, articulatory suppression) × 5 (trial: one to five) design. Target word was included as a between-subjects factor while suppression and trial were manipulated within subjects. The number of correctly recalled target words (from zero to six) was the dependent variable.

Materials

Analogous to Experiment 1, two lists of six word pairs were constructed for each of the three target word conditions, by removing two items from the original stimuli of Experiment 1 (see Appendix A). This was done because a pilot study had indicated that learning eight word pairs was too difficult for children of this age. Again, the two lists were counterbalanced over the two suppression conditions.

The remaining cue words had a mean imageability of 6.66 on a seven point scale ($SD = 0.21$) according to the ratings reported by Van Loon-Vervoorn (1985). Their CELEX (Baayen et al., 1993) mean log frequency per million was 1.46 ($SD = 0.71$). The remaining concrete target words were all highly imageable ($M = 6.70$, $SD = 0.14$). As mentioned earlier, we chose function words as the abstract target words for this experiment, because (a) it was likely that some of the abstract words of Experiment 1 were not well known by some children, (b) function words are among the least imageable words, and (c) we sought to generalize our findings to other word types. Because no imageability ratings are available for Dutch function words, we considered the ratings for the English translation of those function words according to the MRC Psycholinguistic Database (Coltheart, 1981; Wilson, 1988; Fearnley, 1997). This assumption of cross-linguistic imageability similarity of translation equivalents is supported by the high ($r = .95$) correlation between the Dutch and the English MRC imageability ratings of the cue and target words of Experiment 1. The mean imageability of the function words for which a rating could be found was only 244.22 ($SD = 25.20$) on a scale from 100 to 700. The concrete target words were more imageable ($p < .001$), but less frequent ($p < .001$) than the abstract target words. The fact that function words are highly frequent words does not alleviate, but even strengthens a potential effect of articulatory suppression on the associative learning of word–function word pairs.

Word–concrete word pairs (high imageable target word). All target words were highly imageable (List One: $M = 6.75$, $SD = 0.19$; List Two: $M = 6.65$, $SD = 0.04$). Their mean log frequency per million was 0.93 ($SD = 0.51$).

Word–abstract word pairs (low imageable target word). The function words had very low imageability ratings (List One: $M = 251.20$, $SD = 33.06$; List Two: $M = 235.50$, $SD = 7.33$). Their mean log frequency per million was 2.26 ($SD = 0.55$).

Word–nonword pairs. Just as in Experiment 1, the nonwords were disyllabic strings of random vowels and consonants, chosen in such a way that they contained morphemes which are likely to occur in Dutch, but did not resemble existing Dutch words.

Procedure

The procedure was identical to that of Experiment 1, but differed with regard to the presentation modality: words were not presented visually, but auditorily by means of headphones, using the timing parameters of Experiment 1. The subjects wrote down their responses in a notebook.

Results

The number of correctly recalled words was subjected to a 3 (target word: concrete, abstract or nonword) × 2 (suppression: control and articulatory suppression) × 5 (trial: one to five) ANOVA. Tests of analyses by participants and by items will be referred to as F_1 and F_2, respectively. A response was rated as correct as soon as it sounded like the correct target word, according to Dutch grapheme-to-phoneme conversion rules. One participant was excluded from all analyses because he could not remember a single word, in any of the conditions. All means are displayed in Fig. 3.

We observed a main effect of target word, $F_2(2,\ 38) = 50.36$, $MSE = 7.52$, $p < .001$, $F_2(2,\ 33) = 152.96$, $MSE = 3.13$, $p < .001$. Post-hoc comparisons using Tukey's HSD test indicated that performance was poorer for the abstract words than for the concrete words, and for the nonwords compared to the abstract words (all p's $< .001$ for analyses by participants and by items). The main effects of suppression, $F_1(1,\ 38) = 37.23$, $MSE = 2.63$, $p < .001$, $F_2(1,\ 33) = 23.94$, $MSE = 4.73$, $p < .001$, and trial, $F_1(4,\ 152) = 117.57$, $MSE = 0.90$, $p < .001$, $F_2(4,\ 132) = 232.78$, $MSE = 0.53$, $p < .001$ were also significant. Tukey's HSD test showed significant differences ($p < .001$) between the first three trials, but not between trials three and four, and four and five, respectively, $p_1 > .19$, $p_2 < .05$ and $p_1 > .70$, $p_2 > .38$. Hence, it seems that memorization performance began to level off somewhat after three trials.

As expected, the interaction between target word and suppression was significant: $F_1(2,\ 38) = 11.46$, $MSE = 2.63$, $p < .001$, $F_2(2,\ 33) = 7.59$, $MSE = 4.73$, $p < .01$. More important, a planned comparison of the interaction involving only the concrete word and the abstract word conditions showed that the articulatory suppression effect was much weaker for the former than for the

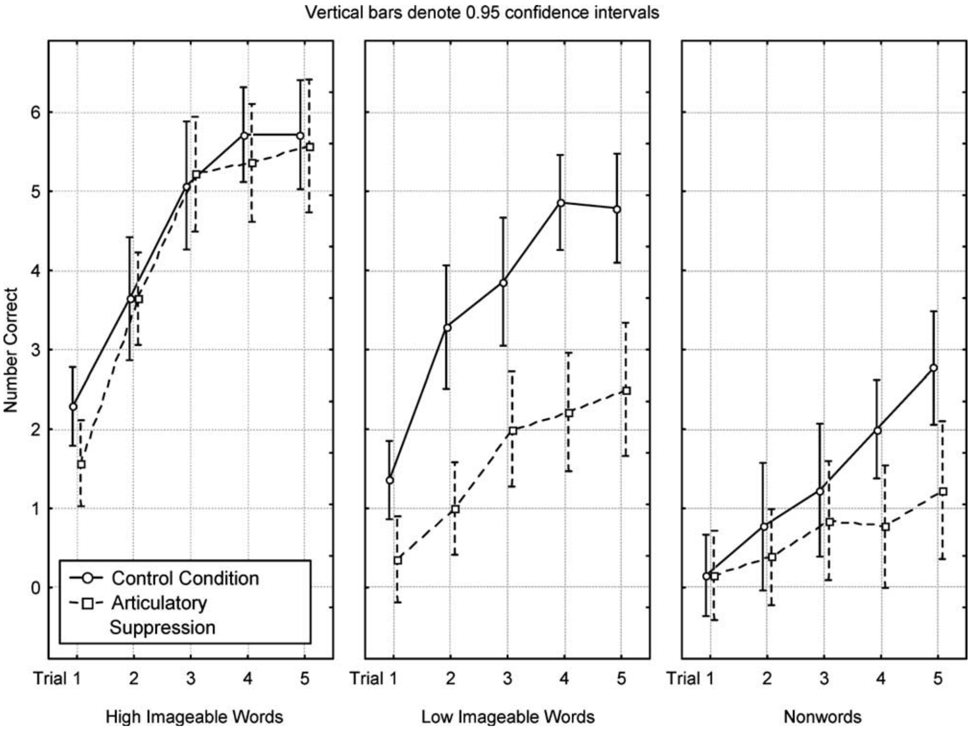


Fig. 3. Mean number of correctly recalled target words by target word, suppression, and trial (Experiment 3).

latter, $F_1(1,\ 38) = 21.52$, $MSE = 2.63$, $p < .001$, $F_2(1,\ 33) = 13.97$, $MSE = 4.73$, $p < .001$. Planned comparisons indicated that the suppression effect was significant for both the abstract words, $F_1(1,\ 38) = 53.90$, $MSE = 2.63$, $p < .001$, $F_2(1,\ 33) = 35.00$, $MSE = 4.73$, $p < .001$, and the nonwords: $F_1(1,\ 38) = 6.18$, $MSE = 2.63$, $p < .05$, $F_2(1,\ 33) = 3.72$, $MSE = 4.73$, $p < .065$. Articulatory suppression did not affect the memorization of concrete words, $F_1 < 1, F_2 < 1$. Finally, the effect of articulatory suppression was stronger for the abstract word condition than for the nonword condition, $F_1(1,\ 38) = 10.92$, $MSE = 2.63$, $p < .01$, $F_2(1,\ 33) = 7.94$, $MSE = 4.73$, $p < .01$, but this is probably due to a floor effect in the nonword condition.

Discussion

All the main findings of Experiment 1 were replicated. As expected, articulatory suppression disrupted the associative learning of both word–nonword and word–function word pairs, but not of word–concrete word pairs. Therefore, the present experiment showed that our findings regarding the importance of visual codes for word learning can be generalized with respect to age (children and adults), word type (function words and nouns), and presentation modality (auditory and visual stimulus presentation). This is further evidence that the absence of a visual code is the determining factor for verbal WM involvement in associative word learning, rather than the novelty of the words.

General discussion

Following extensive evidence for verbal WM involvement in foreign and native vocabulary learning in both children and adults (e.g., Baddeley et al., 1998), we hypothesized that associative learning of (a) word–concrete word pairs would not be impaired by articulatory suppression, whereas memorization of (b) word–abstract word pairs, and (c) word–nonword pairs would. Our data from Experiments 1 and 3 supported this hypothesis. These findings suggest that the conclusion of a number of studies showing that verbal WM is not involved in the associative word learning of familiar words (e.g., Baddeley, 1993; Baddeley et al., 1998; Papagno et al., 1991; Papagno & Vallar, 1992, 1995), only applies to familiar words which are highly imageable. The articulatory suppression effects for the abstract words in this study (nouns and function words) showed that verbal WM resources can be important for the associative learning of familiar words if the absence of visual representations for these words prevents the use of visual WM strategies such as imagery. This issue has been overlooked in previous studies.

Our hypotheses were further tested in Experiment 2, in which we showed that verbal WM involvement in the learning of word–nonword pairs may be minimized by associating a visual image with the nonword. Therefore, word imageability, rather than word novelty, appears to be the key factor that determines the degree of verbal WM involvement in associative word learning. It follows that verbal WM involvement in vocabulary acquisition is merely a consequence of the absence of visual codes for new words.

Baddeley et al. (1998) and Papagno et al. (1991) already mentioned the possibility that verbal WM involvement in associative word learning can be influenced by lexical or semantic factors after they failed to find an articulatory suppression effect on the learning of English–Russian word pairs (Papagno et al., 1991, Experiments 3 & 4, see earlier). Bourassa and Besner (1994) provided evidence that imageability, rather than other semantic or lexical long-term memory variables, is a key factor when investigating influences of long-term knowledge on verbal WM functioning. They found that serial ordered recall was better for content words than for function words. However, differences between the two word classes disappeared when the two stimulus sets were matched for word imageability. Accordingly, Walker and Hulme (1999) found that both backward and forward (written and spoken) serial recall was better for concrete words than for abstract words. These studies are in accordance with the beneficial effects of word imageability on verbal working memory performance observed in neurological patients with verbal short-term memory impairment (Bird et al., 2002; Hanten & Martin, 2001; Majerus et al., 2001; Martin & Saffran, 1999).

While our findings point to a methodological constraint of all previous experimental studies on verbal WM involvement in associative word learning, they do corroborate the importance of verbal WM in vocabulary acquisition. However, it is important to indicate precisely the locus of verbal WM involvement in that process. Freedman and Martin (2001) (see also Martin, 1993; Martin, Shelton, & Yaffee, 1994) showed that there are dissociable phonological and semantic short-term memory components which are linked with corresponding representations in long-term memory. Like Freedman and Martin, we agree with Baddeley et al. (1998) that verbal WM is primarily a language learning device, but only if language learning is defined as the long-term learning of novel phonological forms. Hence, the PL (the phonological short-term memory component in Martin's terminology) is important in language acquisition, but only with respect to forming its corresponding (phonological) long-term representations. Although the learning of phonological codes is important in language learning, the concept of language learning should not be restricted to this aspect, because semantic and visual representations are probably equally important and sometimes acquired earlier than the corresponding phonological representations. A baby for example, has semantic and visual representations of its *mother* long before it acquires the phonological label for that concept. We therefore agree with Freedman and Martin (2001) that the impact of dissociable short-term memory components, such as the PL, on other semantic and visual long-term representations is limited.

This line of reasoning applies to the results of Experiment 2. Our findings do not rule out verbal WM involvement in the learning of nonwords in the visual induction condition. No doubt verbal rehearsal played a role during the association phase when both the phonological code of the nonword and its association with the visual code were learned (solid lines on the right-hand side of Fig. 4). During the learning phase, the participants learned the association between the cue words and the target words by keeping the two respective visual representations together in visual short-term memory (lower dotted lines), because articulatory suppression made it difficult to learn the association by keeping both phonological codes (e.g., [baik]-[pu:sti]) in verbal short-term memory (upper dotted lines). During the test phase, the phonological code of the cue word (e.g., [baik]) successively activated the visual representation of *bike*, the nonnameable visual image associated with *poosti*, and the phonological code of the target word (e.g., [pu:sti]).

In conclusion, it is important to make a distinction between the learning of word associations and the learning of phonological representations of new words. Verbal WM is crucial in language learning, but it is only important for the long-term learning of phonological representations. Our results clearly show that the locus of verbal WM involvement is not necessarily situated in the learning of the word associations themselves. The association can be learned by other means (e.g., a visual WM component such as the VSSP), while the phonological representations cannot.

This study has some practical implications for vocabulary learning in children, for adults learning a foreign language and for word learning in neuropsychological patients. The results demonstrate facilitation effects due to the availability of visual codes when learning new words. Such an effect may be especially important when semantic or phonological representations have not yet fully developed, as is the case for very young children learning their first words. For example, it may be useful to point to items when teaching a young child a new concrete word. Similarly, foreign language

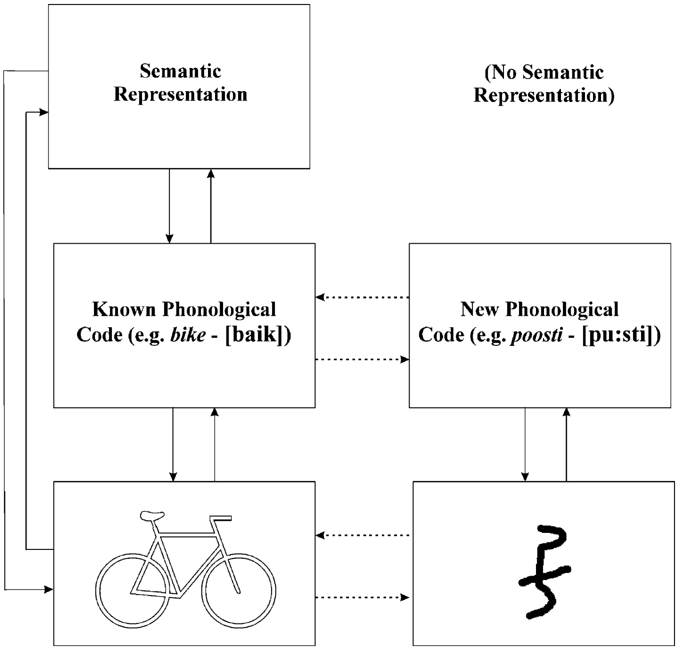


Fig. 4. An extended model of Freedman and Martin's (2001) view on learning word–new word associations including visual codes.

learning in adults may benefit from the use of pictorial material or visual imagery mnemonics. This hypothesis is supported by research on bilingualism, which has shown that links between second language words and semantic information are established quite early during the learning process (Altarriba & Mathis, 1997; Duyck & Brysbaert, 2001), in contrast with assumptions of earlier models of bilingual language organization (e.g., Kroll & Stewart, 1994). As for neuropsychological patients, providing visual information may be sufficient to compensate for verbal short-term memory deficits. Hanten and Martin (2001) showed that BS, a patient suffering from a substantial phonological short-term memory impairment, but who nonetheless obtained a PhD in biology, performed very well in a variety of learning and memory tasks, provided he could use lexical and semantic information. If this was not possible, such as for learning lists of words of low frequency and low imageability, his performance dropped significantly. Similar beneficial effects of imageability on verbal tasks in aphasic and deep dysphasic patients have, respectively, been reported by Bird et al. (2002), Majerus et al. (2001), and Martin and Saffran (1999). Also, in a case study by Baddeley (1993), patient SR was able to learn some English-Finnish word pairs by means of very elaborate semantic associations. Given our results, it is reasonable to assume that patients such as SR or BS could successfully use readily available visual information when they have to perform a difficult word learning task.

In conclusion, the present work has shown that word imageability, a variable that has been overlooked in previous studies (e.g., Baddeley, 1993; Papagno et al., 1991; Papagno & Vallar, 1992; Papagno & Vallar, 1995), determines the degree of verbal WM involvement in paired associate learning of familiar words. Additionally, the current studies demonstrated that the amount of verbal WM resources used to learn associations between familiar and new ('foreign') words is determined by the availability of visual information. Although verbal WM is important in language learning, the locus of its involvement is limited to the learning of phonological representations; the learning of the word associations themselves can rely on other (visual) WM resources.

Acknowledgments

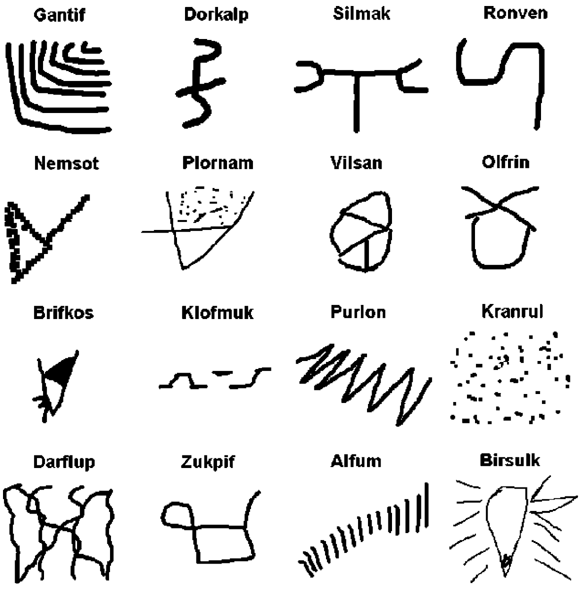
This research was made possible by the Fund for Scientific Research-Flanders, of which the first author is a research assistant, by Grant No. 01105601 of the Special Research Fund at Ghent University to the second author, and by Grant of No. 3G002100 of the Fund for Scientific Research-Flanders to the last author. The authors are indebted to Brian McElree, Lucy Henry, Wouter De Baene, and two anonymous reviewers for critical comments on an earlier draft of this article. We would also like to thank the Klein Seminarie of Roeselare, for their help in finding participants for the child experiment.

Appendix A. Stimuli Experiments 1 and 3 (English translations between brackets)

Word Type	List One	List Two
Word–concrete word pairs (Experiments 1 and 3)	auto [car]-armband [bracelet]	balpen [ballpoint]-geweer [gun]
	badpak [bathing suit]-ladder [ladder]	kamer [room]-aardbei [strawberry]
	bliksem [lightening]-vlinder [butterfly]	konijn [rabbit]-mummie [mummy]
	sleutel [key]-matras [mattress]	nagel [nail]-paleis [palace]
	tafel [table]-oorbel [earring]	oven [oven]-rugzak [rucksack]
	viool [violin]-kasteel [castle]	parfum [perfume]-tractor [tractor]
	kikker [frog]-spijker [nail]*	bontjas [fur coat]-jongen [boy]*
	vinger [finger]-augurk [gherkin]*	koelkast [refrigerator]-lippen [lips]*
Word–abstract word pairs (Experiment 1)	auto [car]-verzoek [request]	balpen [ballpoint]-inteelt [inbreeding]
	badpak [bathing suit]-geding [lawsuit]	bontjas [fur coat]-noodlot [fate]
	bliksem [lightening]-beschik [disposal]	kamer [room]-subject [subject]
	kikker [frog]-toeval [coincidence]	koelkast [refrigerator]-profijt [profit]
	sleutel [key]-tactiek [tactics]	konijn [rabbit]-welzijn [wellbeing]
	tafel [table]-schennis [violation]	nagel [nail]-talent [talent]
	vinger [finger]-stemming [mood]	oven [oven]-schande [shame]
	viool [violin]-voorval [incident]	parfum [perfume]-bijnaam [nickname]
Word–function word pairs (Experiment 3)	auto [car]-sedert [since]	balpen [ballpoint]-vanaf [from]
	badpak [bathing suit]-ofwel [either]	kamer [room]-tenzij [unless]
	bliksem [lightening]-terwijl [while]	konijn [rabbit]-indien [if]
	sleutel [key]-zodat [so (that)]	nagel [nail]-omdat [because]
	tafel [table]-daarom [therefore]	oven [oven]-wegens [due to]
	viool [violin]-misschien [perhaps]	parfum [perfume]-wanneer [when]
Word–nonword pairs (Experiments 1 and 3)	auto [car]-plornam	balpen [ballpoint]-alfum
	badpak [bathing suit]-vilsan	kamer [room]-kranrul
	bliksem [lightening]-olfrin	konijn [rabbit]-brifkos
	sleutel [key]-ronven	nagel [nail]-zukpif
	tafel [table]-dorkalp	oven [oven]-purlon
	viool [violin]-silmak	parfum [perfume]-klofmuk
	kikker [frog]-nemsot*	bontjas [fur coat]-birsulk*
	vinger [finger]-gantif*	koelkast [refrigerator]-darflup*

*These stimuli were not used in Experiment 3.

Appendix B. The sixteen line drawings with their corresponding nonwords used in Experiment 2



References

Altarriba, J., & Mathis, K. M. (1997). Conceptual and lexical development in second language acquisition. *Journal of Memory and Language, 36*, 550–568.

Andrade, J., Kemps, E., Werniers, Y., May, J., & Szmalec, A. (2002). Insensitivity of visual short-term memory to irrelevant visual information. *Quarterly Journal of Experimental Psychology, 55A*, 753–774.

Baayen, R., Piepenbrock, R., & Van Rijn, H. (1993). *The CELEX lexical database. [CD-ROM]*. University of Pennsylvania, Philadelphia: Linguistic Data Consortium.

Baddeley, A. (1986). *Working memory*. Oxford, England: Oxford University Press.

Baddeley, A. (1993). Short-term phonological memory and long-term learning: A single-case study. *European Journal of Cognitive Psychology, 5*, 129–148.

Baddeley, A. (1997). *Human memory: Theory and practice* (2nd ed). Boston: Allyn and Bacon.

Baddeley, A. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences, 4*(11), 417–423.

Baddeley, A., Gathercole, S., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review, 105*, 158–173.

Baddeley, A., & Hitch, G. (1974). Working memory. In G. A. Bower (Ed.), *Recent advances in learning and motivation* (pp. 47–90). New York: Academic Press.

Baddeley, A., Papagno, C., & Vallar, G. (1988). When long-term learning depends on short-term storage. *Journal of Memory and Language, 27*, 586–595.

Bird, H., Franklin, S., & Howard, D. (2002). 'Little words'—not really: Function and content words in normal and aphasic speech. *Journal of Neurolinguistics, 15*(3–5), 209–237.

Bourassa, D., & Besner, D. (1994). Semantics at a glance: Is the right-hemisphere special? *Canadian Journal of Experimental Psychology, 48*, 543–552.

Bowey, J. A. (2001). Nonword repetition and young children's receptive vocabulary: A longitudinal study. *Applied Psycholinguistics, 22*, 441–469.

Cheung, H. (1996). Nonword span as a unique predictor of second-language vocabulary learning. *Developmental Psychology, 32*, 867–873.

Coltheart, M. (1981). The MRC psycholinguistic database. *Quarterly Journal of Experimental Psychology, 33A*, 497–505.

Duyck, W., & Brysbaert, M. (2001). Forward and backward translation in balanced and unbalanced bilinguals requires conceptual mediation: The magnitude effect in number translation. Manuscript submitted for publication.

Farmer, E. W., Berman, J. V. F., & Fletcher, Y. L. (1986). Evidence for a visuospatial scratch-pad in working memory. *Quarterly Journal of Experimental Psychology, 38A*, 675–688.

Fearnley, S. (1997). MRC psycholinguistic database search program. *Behavior Research Methods, Instruments and Computers, 29*(2), 291–295.

Freedman, M. L., & Martin, R. C. (2001). Dissociable components of short-term memory and their relation to long-term learning. *Cognitive Neuropsychology, 18*, 193–226.

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

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

Gathercole, S. E., & Baddeley, A. D. (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., Frankish, C. R., Pickering, S. J., & Peaker, S. (1999). Phonotactic influences on short-term memory (Vol 25, Pg 84, 1999). *Journal of Experimental Psychology—Learning Memory and Cognition, 25*, 562.

Gathercole, S. E., & Hitch, G. J. (1993). Developmental changes in short-term memory: A revised working memory perspective. In A. Collins, S. E. Gathercole, M. A. Conway, & P. E. Morris (Eds.), *Theories of memory* (pp. 189–210). Hove, England: Erlbaum.

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

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

Gleitman, L. (1993). The structural sources of verb meanings. In P. Bloom (Ed.), *Core readings in language acquisitions* (pp. 174–221). Cambridge, England: Harvester Wheatsheaf.

Grasby, P. M., Frith, C. D., Friston, K. J., Bench, C., Frackowiak, R. S. J., & Dolan, R. J. (1993). Functional mapping of brain-areas implicated in auditory—verbal memory function. *Brain, 116*, 1–20.

Hanten, G., & Martin, R. C. (2001). A developmental phonological short-term memory deficit: A case study. *Brain and Cognition, 45*, 164–188.

Henry, L. A., & Millar, S. (1991). Memory span increase with age: A test of 2 hypotheses. *Journal of Experimental Child Psychology, 51*, 459–484.

Henry, L. A., & Millar, S. (1993). Why does memory span improve with age: A review of the evidence for 2 current hypotheses. *European Journal of Cognitive Psychology, 5*, 241–287.

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

Kemps, E., De Rammelaere, S., & Desmet, T. (2000). The development of working memory: Exploring the complementarity of two models. *Journal of Experimental Child Psychology, 77*, 89–109.

Kroll, J. F., & Stewart, E. (1994). Category interference in translation and picture naming: Evidence for asymmetric connections between bilingual memory representations. *Journal of Memory and Language, 33*, 149–174.

Logie, R. H. (1986). Visuo-spatial processing in working memory. *Quarterly Journal of Experimental Psychology, 38A*, 229–247.

Majerus, S., Lekeu, F., Van Der Linden, M., & Salmon, E. (2001). Deep dysphasia: Further evidence on the relationship between phonological short-term memory and language processing impairments. *Cognitive Neuropsychology, 18*, 385–410.

Markman, E. M. (1994). Constraints on word meaning in early language-acquisition. *Lingua, 92*(1–4), 199–227.

Martin, N., & Saffran, E. M. (1999). Effects of word processing and short-term memory deficits on verbal learning: evidence from aphasia. *International Journal of Psychology, 34*, 339–346.

Martin, R. C. (1993). Short-term-memory and sentence processing: Evidence from neuropsychology. *Memory & Cognition, 21*(2), 176–183.

Martin, R. C., Shelton, J. R., & Yaffee, L. S. (1994). Language processing and working-memory: Neuropsychological evidence for separate phonological and semantic capacities. *Journal of Memory and Language, 33*, 83–111.

Masoura, E. V., & Gathercole, S. E. (1999). Phonological short-term memory and foreign language learning. *International Journal of Psychology, 34*, 383–388.

Michas, I. C., & Henry, L. A. (1994). The link between phonological memory and vocabulary acquisition. *British Journal of Developmental Psychology, 12*, 147–163.

Nagy, W. E., & Anderson, R. C. (1984). How many words are there in printed school English. *Reading Research Quarterly, 19*(3), 304–330.

Nagy, W. E., & Herman, P. A. (1987). Breadth and depth of vocabulary knowledge: Implications for acquisition and instruction. In M. G. McKeown & M. E. Curtis (Eds.), *The Nature of Vocabulary Acquisition* (pp. 19–35). Hillsdale, NJ: Erlbaum.

Paivio, A., & Smythe, P. C. (1971). Word imagery, frequency, and meaningdulness in short-term memory. *Psychonomic Science, 22*, 333–335.

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

Papagno, C., & Vallar, G. (1992). Phonological short-term-memory and the learning of novel words: The effect of phonological similarity and item length. *Quarterly Journal of Experimental Psychology, 44A*, 47–67.

Papagno, C., & Vallar, G. (1995). Verbal short-term-memory and vocabulary learning in polyglots. *Quarterly Journal of Experimental Psychology, 48A*, 98–107.

Paulesu, E., Frith, C. D., & Frackowiak, R. S. J. (1993). The neural correlates of the verbal component of working memory. *Nature, 362*(6418), 342–345.

Poirier, M., & Saintaubin, J. (1995). Memory for related and unrelated words: Further evidence on the influence of semantic factors in immediate serial-recall. *Quarterly Journal of Experimental Psychology, 48A*, 384–404.

Quinn, J. G., & McConnell, J. (1996). Irrelevant pictures in visual working memory. *Quarterly Journal of Experimental Psychology, 49A*, 200–215.

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

Sternberg, R. (1987). Most vocabulary is learned from context. In M. G. McKeown & M. E. Curtis (Eds.), *The nature of vocabulary acquisition* (pp. 89–106). Hillsdale, NJ: Erlbaum.

Van Loon-Vervoorn, W. A. (1985). Voorstelbaarheidswaarden Van Nederlandse Woorden: 4600 Substantieven, 1000 Verba, 500 Adjectieven. Lisse: Swets & Zeitlinger.

Walker, I., & Hulme, C. (1999). Concrete words are easier to recall than abstract words: Evidence for a semantic contribution to short-term serial recall. *Journal of Experimental Psychology: Learning Memory and Cognition, 25*, 1256–1271.

Wetherick, N. E. (1975). Role of semantic information in short-term-memory. *Journal of Verbal Learning and Verbal Behavior, 14*(5), 471–480.

Wilson, M. (1988). MRC Psycholinguistic Database—Machine-Usable Dictionary, Version 2.00. *Behavior Research Methods, Instruments and Computers 20(1)*, 6–10.

Further Reading

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