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BRIEF REPORTS

# Teaching Adults New Words: The Role of Practice and Consolidation

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Semantic and orthographic learning of new words was investigated with the help of the picture–word interference (PWI) task. In this version of the Stroop task, picture naming is delayed by the simultaneous presentation of a semantically related as opposed to an unrelated distractor word (a specific PWI effect), as well as by an unrelated word compared with a nonword (a general PWI effect). This interference is taken to reflect automatic orthographic and semantic processing. The authors observed that participants showed both types of PWI effects for newly learned words following a single study session. Interestingly, specific PWI effects were not obtained immediately after testing but did emerge a week later without additional practice. This suggests that a period of consolidation is involved in the establishment of word representations. In addition, identical PWI effects were obtained when the study and test words were presented in either the same or different letter case. This provides evidence that the newly acquired orthographic representations are coded in an abstract format.

*Keywords:* consolidation, word learning, picture–word interference, Stroop, reading

One of the hallmarks of skilled reading is that orthographic and semantic knowledge is retrieved in an automatic fashion. For instance, in the classic Stroop task, participants find it difficult to name the color of print when it spells an inconsistent color name. Similarly, participants are slow to name a picture when a semantically related written distractor word is superimposed on the target, a version of the Stroop task called picture–word interference (PWI). In both cases, the findings suggest that written words are automatically activated to the level of meaning, with semantic competition delaying the naming of the target. (For some qualifications regarding the automaticity of Stroop, see Risko, Stolz, & Besner, 2005.) Surprisingly, however, relatively little research has assessed the learning conditions required to support the skilled processing of words. We briefly consider studies that have assessed orthographic and semantic learning before introducing a new method to study these questions.

## Learning of Orthographic Word Forms

Children's learning of orthographic word forms is often claimed to be rapid. For example, Share (1999) asked second-grade children to read aloud short stories in Hebrew that each contained a novel word repeated either four or six times. Three days later, children were able to select the correct spelling of the target words presented alongside homophone foils. That is, the children appeared to have learned the spelling of the new words. Although these findings are impressive, it is important to note that strategic memory processes, rather than automatic orthographic processes that subserve skilled word identification, may have supported their performance. As far as we are aware, no study carried out with children has considered the time course of learning new orthographic word forms to the point that they are accessed automatically.

A few studies carried out with adults have attempted to address this issue more directly. Salasoo, Shiffrin, and Feustel (1985) conducted a long-term priming study in which participants were presented with words and pseudowords one to three times a day over the course of 10 days. Initially identification in a perceptual identification task was better for words compared with pseudowords (the word superiority effect), but following only six repetitions, identification of the pseudowords matched word performance. Furthermore, when participants were tested a year later, they continued to show equivalent performance on the words and pseudowords. In a related study, masked priming for newly learned words has been reported following a few study trials (Forster, 1985). Both long-term and masked priming are often thought to reflect automatic (and implicit) memory processes (cf. Bowers, 2000), and accordingly, these findings might be taken to support the conclusion that relatively little practice is required before the identification of newly learned words becomes automatic. However, there are other possible interpretations. For instance, there is some evidence that long-term priming for pseudowords is supported by perceptual representations outside the orthographic system that supports word identification (Bowers, 1996), in which case the Salasoo et al. results with pseudowords

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may not speak to word learning. In addition, long-term priming tasks are rarely process-pure (Jacoby, 1992), and accordingly, it is always possible the results were a by-product of explicit memory contamination. It is often argued that masked priming is immune to explicit memory strategies (although see Bodner, Masson, & Richard, 2006), but the effects can extend to unfamiliar words that have never been studied (e.g., Bodner & Masson, 1997). Accordingly, the masked priming results of Forster (1985) may reflect sublexical processes rather than the learning of new word forms.

In contrast with the above studies that might be taken to reflect the rapid learning of new words, McCandliss, Posner, and Givon (1997) provided evidence that skilled orthographic processing requires extensive practice. The authors taught participants pronounceable words over the course of 5 weeks, with over 50 hours of training. Training consisted of various computer tutorials that involved relating written words to a corresponding set of pictures. After 50 hours of practice participants showed evidence of learning new orthographic word forms in a behavioral task that involved categorizing pairs of letter strings presented briefly in sequence as same or different. By the end of training, participants were faster at categorizing the trained new words than unstudied novel words, with performance on the trained new words approaching performance with familiar preexisting words. However, the authors failed to obtain an ERP signature of new orthographic learning. This study thus suggests that learning new orthographic forms in adults requires extensive practice.

More recently, Bowers, Davis, and Hanley (2005) taught participants new word forms by asking them to read and type each item 10 times during a study phase. The new words were orthographically similar to existing words. For example, participants learned the new word *VONKA*, a neighbor of the familiar word *VODKA*. The critical question was whether the new word forms interfered with the identification of the preexisting items. For example, does learning *VONKA* interfere with the identification of *VODKA* (via competition)? Interestingly, *VONKA* had relatively little impact on the identification of the familiar word *VODKA* immediately after study, but after a week's delay (with no additional training) there was a significant inhibitory effect. These findings suggest that new orthographic representations were learned but that the establishment of these new word forms required a period of consolidation, consistent with related findings concerned with learning new spoken words (Gaskell & Dumay, 2003).

In sum, relatively few studies have considered the time course of learning new orthographic forms that support skilled word identification. Previous studies provide quite different estimates about the amount of training required to support automatic orthographic processing, and some findings are open to alternative interpretations.

## Semantic Learning

In semantic word learning studies, participants are typically presented with pairs of unrelated written words during a study phase. The hypothesis is that the repeated associations might result in a new link between the words (and concepts) involved, which should manifest itself as semantic priming. That is, the presentation of one member of the pair (the prime) should facilitate responding to the second member of the pair (the target).

Early work that tried to develop these arbitrary associations was unsuccessful (Neely, 1977). Strategic effects were found at long prime presentation times, but at shorter times, when effects would have been more automatic, there was no priming. However, a series of studies by Dagenbach, Horst, and Carr (1990) suggested that more training and/or elaborative training is required. Consistent with Neely (1977), the authors failed to obtain significant priming between familiar but unrelated word pairs (e.g., *day* and *woman*) or between unfamiliar and familiar word pairs (e.g., *codex* and *book*) following an intensive 15-min practice phase in which the items were repeatedly associated with each other. However, when participants completed the same training of the same items over the course of 5 weeks, as well as completed some more elaborative study tasks, priming emerged. The authors argued that these results provide evidence that semantic integration requires extensive practice. By contrast, Pecher and Raaijmakers (1999) obtained evidence for much more rapid learning. The authors reported automatic priming between unrelated word pairs after participants studied each pair 11 times over the course of 3 days.

As is the case for orthographic learning, then, current research is mixed with regard to the amount of training required to support the development of automatic semantic processing. This research also highlights two additional issues. First, it is important to assess the extent to which the previous learning effects are genuinely semantic. In the above studies, the new associations were learned through a process of repeated episodic association between items, and often the pairs were given little meaning. Accordingly, priming might reflect new associative rather than semantic (e.g., categorical) relations between the words. Indeed, priming is highly sensitive to associative relations (Shelton & Martin, 1992). Second, the above semantic learning studies have not considered the possible role of consolidation, which as noted above, appears to modulate orthographic (and phonological) learning.

## Current Study

The current study was designed to assess whether a single and relatively brief study period is sufficient to support the development of new orthographic and semantic word knowledge that is automatically accessed during reading. We also consider the question of whether consolidation plays a role in learning new orthographic and semantic word forms.

In order to address these issues, we employed a task that has not previously been used in this context; namely, the PWI paradigm. In this task, participants name pictures depicting simple objects. At the same time, they are presented with written distractor words. Participants are instructed to name the picture as fast as possible and to ignore the distractor word. Despite these instructions, participants process the distractor words at the level of form and meaning, with categorically related words slowing down picture naming in comparison to unrelated words. This is a form of Stroop interference, and indeed PWI and classic color–word Stroop interference are often modeled in the same way (see Roelofs, 2003, for detailed discussion). Thus any interference obtained with newly learned words would likely reflect the fact that these items were processed automatically.

Another important advantage of this task is that it assesses semantic rather than associative relations. For example, naming of a picture of a dog is inhibited by the categorically related word *cat* but not by the associatively related word *bone* (e.g., Alario, Segui, & Ferrand, 2000). Accordingly, this task offers a potentially useful means to investigate the acquisition of semantic rather than associative knowledge.

We also take advantage of a related finding that semantically unrelated but familiar words provide more interference than nonwords (Lupker, 1979). Accordingly, there appear to be two different forms of interference in the PWI task; namely, interference due to the distractor activating a similar meaning to the target (what we will call *specific interference*) and interference due to the distractor activating an unrelated word (what we will call *general interference*). The former effect presumably reflects the activation of the semantics of written word distractors given the effect is driven by a difference in the semantic relation between the words and pictures in the two conditions. The locus of the latter effect is less clear, as it could be driven by the familiar written words activating semantic representations unrelated to the pictures or, alternatively, activating unrelated lexical–orthographic and lexical–phonological representations (whereas the nonwords do not activate any semantic or lexical knowledge). But in any case, both effects are relevant to assessing the extent to which orthographic processing is automatic for newly learned words, and the specific effect provides a measure of automatic semantic processing.

To preview our study, we assessed PWI effects (both specific and general) immediately after teaching participants new words and following a one-week delay (during which there was no additional training). The inclusion of the delay provided a test of the hypothesis that skilled word processing requires a period of consolidation. We also manipulated the letter case in which the new words were studied and tested. Various findings suggest that orthographic representations of familiar words are coded in an abstract format, with uppercase and lowercase words sharing common representations (cf. Bowers, 2000). The question here is whether newly acquired orthographic word forms are coded in an abstract or visually specific format.

## Method

### Participants

Forty-eight students from the University of Bristol (Bristol, England) participated. All were native English speakers and had normal or corrected vision. Eighty-five percent were women, 15% were men, and the average age was 20 years.

### Materials and Design

Two sets of 12 new words (the to-be-learned words) were included. Half the participants learned one set, and half learned the other set. The new words were one letter different from real words, pronounceable, and morphologically legal. In order to assign these items new meanings in the study phase, 12 definitions and 12 novel pictures were also constructed for each set. The novel pictures and definitions were selected from three categories: fruit, vehicles, and items of clothing. For example, the new word *kosla* might be defined as a bitter and spiky fruit. These novel pictures and definitions were used to enable the participants to learn the new words and were presented only in the study phase. In order to assess the extent of orthographic and semantic learning for these words, a PWI task was carried out that included a set of 12 familiar pictures selected from the same three categories (based on Snodgrass & Vanderwart, 1980). So, for example, participants were asked to name a picture of an apple when the new word *kosla* was presented as a distractor, which should produce PWI if *kosla* is automatically identified to the level of orthography and semantics. None of the familiar pictures were seen during the study phase.

In addition to assessing PWI effects for new words, we assessed semantic interference for familiar words. Twelve familiar (preexisting) words from the same three categories were selected for the PWI task. The familiar words were matched with the new words in terms of length and number of syllables, and they were paired with the 12 familiar pictures in the PWI task. There was no study phase for these words. The new and familiar words and pictures are listed in the Appendix.

Four within-participant variables were included in order to assess specific and general PWI effects for familiar and new words: time of testing (immediately after study or one week after study), lexical status (word vs. studied new word vs. nonstudied new word), category congruence (semantically related vs. unrelated), and letter case. For the studied new words, letter case either matched or mismatched at study and test, whereas for the familiar words, letter case was simply upper- versus lowercase at test (familiar words were not presented at study, so items could not match or mismatch).

At test each familiar picture was presented in all conditions. Specifically, each picture (× 12) was paired twice (× 2) with a given distractor at all levels of the lexical status (× 3), category congruence (× 2), and letter case (× 2) conditions, for a total of 24 repetitions of each picture and 288 trials overall in each test session. The two testing sessions were identical, with the same picture–word pairings repeated, for a total of 576 trials overall.

For counterbalancing purposes, 12 files were constructed. Half the participants learned one set of 12 new words, and the other participants learned the other 12 new words. In addition, new words were paired with different pictures and descriptions, so that *plock*, for example, was learned as an item of clothing in one file, as a fruit in another, and as a vehicle in yet another. Finally, each new word was studied in uppercase by half of the participants and in lowercase by the other participants.

### Procedure

Participants carried out a study phase followed by two identical test phases, one immediately following study and one approximately a week later (range = 6–10 days). During the study phase, participants were first presented with all of the correct pairings of the descriptions, pictures, and new words. They then performed a series of training trials in which they were shown either a written description or a novel picture in the middle of the screen and one of the new words, in bold typeface, in the lower part of the screen. Each description consisted of a three-word phrase, such as "women's sports clothing." Participants were required to decide whether the new word matched the description or picture. Items matched on half of the trials, and participants were instructed to press the right *shift* key for "yes" responses and left *shift* key for "no" responses. Once participants had responded they were given feedback that included the new word paired with both the correct definition and the correct picture. New words were paired with one of the following: a matching definition, a matching picture, a mismatching definition, or a mismatching picture. Each new word was practiced four times in each of these conditions, for a total of 16 study trials per item (forming a total of 192 study trials). In order to present the uppercase and lowercase new words at approximately the same size, the point size of the lowercase items was increased to cover the same amount of space as the uppercase items.

During the test phase, participants named aloud the line drawings of 12 familiar objects from the three categories. They were instructed to name the picture as quickly and as accurately as possible and to ignore the letter string (a familiar word, trained new word, or untrained new word, depending on the condition). The picture and letter string were simultaneously presented for 2,000 ms or until a response was made. The experiment was run with DMDX software (Forster & Forster, 2003). Naming latency was measured with the help of a head-mounted microphone and software voice key. The experimenter monitored response accuracy. Before each test phase, participants were given 24 practice items.

## Results

The data from three participants were excluded from the analysis, as they showed error scores of over 15% on the second half of the study phase. In the first PWI test session 71 errors were made across all 45 participants; these represented 0.6% of the items named. In the second PWI test session a total of 68 errors were made; these represented 0.5% of the items named. In both cases errors were removed from the results. Reaction times below 300 ms and above 2,000 ms were discarded as outliers (this was usually due to the voice trigger on the headset working incorrectly). Outliers accounted for 3.9% of results in the first test session and 5.4% in the second. There were no significant differences between the percentages of outliers in the various conditions.

### *General PWI Effect for Familiar Words*

Table 1 shows the mean naming latencies for pictures presented with semantically unrelated familiar word distractors versus unstudied new distractors, tested immediately after the study session and 1 week later (collapsing across the letter case manipulation). A three-way within-participants analysis of variance (ANOVA; Lexical Status × Time of Testing × Letter Case) revealed a significant main effect of lexical status; target pictures presented with words that were categorically unrelated to the target picture took longer to name (720 ms) than when presented with unstudied new words (698 ms), $F_1(1, 44) = 26.04$, $MSE = 1{,}592$, $p < .001$; $F_2(1, 11) = 5.91$, $MSE = 1{,}986$, $p < .05$. There was also a main effect of time of testing; picture-naming latency was slower on the first testing session (724 ms) compared with the second (694 ms), $F_1(1, 44) = 8.9$, $MSE = 9{,}076$, $p < .01$; $F_2(1, 11) = 23.2$, $MSE = 1{,}009$, $p < .01$. This presumably reflects repetition priming. There was no interaction between lexical status and time of testing, $F_1$ and $F_2 < 1$; thus, there was no evidence for consolidation effects. There was no main effect of letter case, $F_1$ and $F_2 < 1$, which reflects the fact that uppercase and lowercase words are equally effective in accessing semantics. There were no further interactions. Overall, these results demonstrate a robust general PWI effect, consistent with Lupker (1979).

Table 1
*Mean (SD) Picture-Naming Latency (in Milliseconds) With Semantically Related and Unrelated Familiar Word Distractors and Unstudied New Word Distractors*

| Variable | Time of testing: Directly after study | Time of testing: One week after study |
|---|---|---|
| Distractor–picture relationship | | |
| 1. Related word | 767 (101) | 728 (121) |
| 2. Unrelated word | 735 (100) | 705 (108) |
| 3. Unstudied new word | 713 (85) | 684 (98) |
| Difference score | | |
| General PWI effect (2 vs. 3) | 22 | 21 |
| Specific PWI effect (1 vs. 2) | 32 | 22 |
| General + specific effect (1 vs 3) | 54 | 44 |

*Note.* PWI = picture–word interference.

### *Specific PWI Effect for Familiar Words*

Table 1 also shows picture-naming latencies for pictures presented with semantically related familiar word distractors versus semantically unrelated familiar word distractors. These results show a robust specific PWI effect immediately after and one week after study. A three-way within-participants ANOVA (Category Congruence × Time of Testing × Letter Case) was carried out on these data. There was a main effect of category congruence, $F_1(1, 44) = 36.61$, $MSE = 1{,}868$, $p < .001$; $F_2(1, 11) = 6.16$, $MSE = 3{,}138$, $p < .05$, with naming latency slower when distractors were from the same category (747 ms) versus different category (720 ms). As above, there was also a main effect of time of testing, $F_1(1, 44) = 10.02$, $MSE = 10{,}638$, $p < .01$; $F_2(1, 11) = 24.32$, $MSE = 1{,}132$, $p < .01$, with naming latency slower in the first test session (751 ms) versus second (716 ms). There was no main effect of letter case, $F_1$ and $F_2 < 1$, and no interactions. These results replicate the well-established specific PWI effect.

### *General PWI Effect for Newly Acquired Words*

Table 2 shows picture-naming latencies for pictures presented with semantically unrelated new words versus unstudied new words immediately after study and following one week. In order to assess the nature of the newly acquired orthographic representations, we report whether the distractors were presented in the same or different case at study and test.

A three-way within-participant ANOVA (Lexical Status × Time of Testing × Letter Case Match) revealed a main effect of lexical status, $F_1(1, 44) = 14.23$, $MSE = 936$, $p < .001$; $F_2(1, 11) = 6.84$, $MSE = 555$, $p < .05$; pictures named in the presence of semantically unrelated new words were named slower (710 ms) than those named in the presence of unstudied new word distractors (698 ms). As with the familiar words, there was a significant main effect of time of testing, $F_1(1, 44) = 11.45$, $MSE = 8{,}042$, $p < .01$; $F_2(1, 11) = 111.5$, $MSE = 225$, $p < .01$, with average naming latency slower directly after (720 ms) versus one week after study (688 ms). There was no significant interaction between lexical status and time of testing, $F_1$ and $F_2 < 1$. Finally, neither

Table 2
*Mean (SD) Picture-Naming Latency (in Milliseconds) With Semantically Related and Unrelated Studied New Word Distractors and Unstudied New Word Distractors, as a Function of the Letter Case Match Between Study and Test*

| Variable | Time of testing and case manipulation: Directly after study — Matched | Directly after study — Unmatched | One week after study — Matched | One week after study — Unmatched |
|---|---|---|---|---|
| Distractor–picture relationship | | | | |
| 1. Studied new word (related) | 723 (90) | 718 (90) | 706 (102) | 711 (107) |
| 2. Studied new word (unrelated) | 726 (113) | 730 (90) | 689 (97) | 697 (111) |
| 3. Unstudied new word[a] | 714 (86) | 712 (86) | 681 (98) | 686 (100) |
| Difference score | | | | |
| General PWI effect (2 vs. 3) | 12 | 18 | 8 | 11 |
| Specific PWI effect (1 vs. 2) | −3 | −12 | 17 | 14 |
| General + specific effect (1 vs. 3) | 9 | 6 | 25 | 25 |

*Note.* PWI = picture–word interference.
[a] The unstudied new words were drawn from the set of nonwords that the participant had not been presented with during the study phase. These were assigned to matched and unmatched categories based on whether their presentation case during the test phase matched or did not match the presentation case of the newly acquired distractor words presented in the study phase.

the main effect of letter case match, $F_1(1, 44) = 1.06$, $p = .31$; $F_2 < 1$, nor the interaction between lexical status and letter case match approached significance. This reflects the similar PWI effects for the studied new words when items matched (10 ms) and mismatched (15 ms) in letter case. Overall results suggest a single study phase is sufficient to establish abstract orthographic (and perhaps semantic) representations for new words. Although the learning persisted over a week, there was no evidence for consolidation; if anything, the effects were slightly reduced over the course of the week.

### *Specific PWI Effect for New Words*

Table 2 also shows picture-naming latencies for pictures presented with semantically related compared with semantically unrelated new words immediately after study and following one week. A three-way within-participants ANOVA (Category Congruence × Time of Testing × Letter Case Match) revealed that there was no main effect of category congruence, $F_1$ and $F_2 < 1$, or of letter case match, $F_1(1, 44) = 1.07$, $p = .31$; $F_2 < 1$. Once again, there was a main effect of time of testing, $F_1(1, 44) = 5.9$, $MSE = 8{,}115$, $p < .05$; $F_2(1, 11) = 19.07$, $MSE = 685$, $p < .01$; picture-naming latencies were slower in Testing Session 1 (724 ms) than in Testing Session 2 (701 ms). Critically, there was a significant interaction between category congruence and time of testing, $F_1(1, 44) = 7.94$, $MSE = 1{,}461$, $p < .01$; $F_2(1, 11) = 9.91$, $MSE = 271$, $p < .01$, reflecting the lack of a congruence effect immediately after study (–8 ms) and an effect following a week (16 ms). Paired samples $t$ test confirmed that there was no congruence effect in Session 1, $t_1(44) = –1.18$, $p = .13$; $t_2(11) < 1$, whereas the effect in Session 2 was significant, $t_1(44) = 2.44$, $p < .001$; $t_2(11) = 2.31$, $p < .05$. The emergence of a specific PWI effect in Session 2 suggests a role for consolidation in semantic learning. In addition, there was no interaction between letter case and time of testing, $F_1$ and $F_2 < 1$, reflecting the similar PWI effects for new words when their case matched or mismatched at study and test. There were no other interactions. After a week, the overall PWI effect (general plus specific) for the new words (25 ms) was roughly half the size of the PWI effect obtained with the familiar words (44 ms).

## Discussion

The key finding is that PWI effects were obtained for newly acquired words following a single study session. There was both a general PWI effect (in which picture naming was delayed by semantically unrelated new words compared with unstudied new words) and a specific PWI effect (in which picture naming was delayed by semantically related compared with unrelated new words). Strikingly, the specific PWI effect was not obtained immediately following the study phase but was obtained after a week, despite the absence of any additional study. Accordingly, the results not only provide evidence for long-lasting orthographic and semantic word learning following a short study phase but also provide some evidence that consolidation plays a key role in word learning.

In addition, we observed similar PWI effects for the newly acquired words studied and tested in the same and different cases. That is, it appears that the newly acquired orthographic representations that served as access codes to semantics were visually abstract, consistent with findings obtained with familiar words (cf. Bowers, 2000). Critically, all of these learning effects were manifest in a version of the Stroop task, suggesting that the learning supported automatic orthographic and semantic processing.

The current findings lend support to the claim that adults can learn new words following relatively little training. In terms of the amount of training needed in order to support automatic orthographic and semantic processing, our results are in line with the Bowers et al. (2005) and Pecher and Raaijmakers (1999) findings, respectively. However, it is important to note that the previous evidence for fast semantic learning relied on a priming task that is sensitive to both associative and semantic relations and that the participants in the Pecher and Raaijmakers study did not learn anything meaningful about the new word pairs. By contrast, we taught participants meaningful information about the new words, and the PWI effect is sensitive to semantic (categorical) but not associative relations. Accordingly, the current study provides the first evidence that we are aware of that new semantic knowledge can be processed automatically following relatively little practice.

Although the key finding of the present study is that new words can be learned quickly, perhaps the most striking result is that the specific PWI effect increased over the course of the week without any additional practice. This was not the case for the general PWI effect, and future work will be needed to determine whether this difference is consistent and what this might mean. Nevertheless, the specific effect was reliable and suggests that consolidation may play a role in learning the semantics of new words. This finding converges with recent findings in which orthographic and phonological learning improved over the course of a day or a week in the absence of additional practice (e.g., Bowers et al., 2005; Gaskell & Dumay, 2003).

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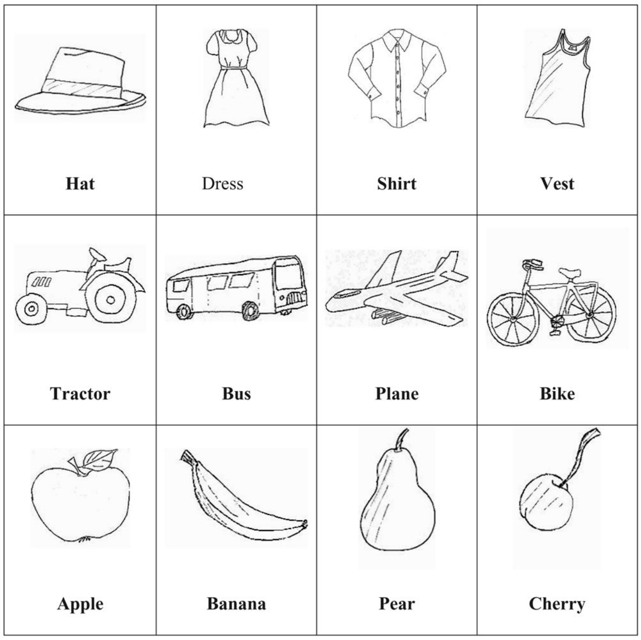
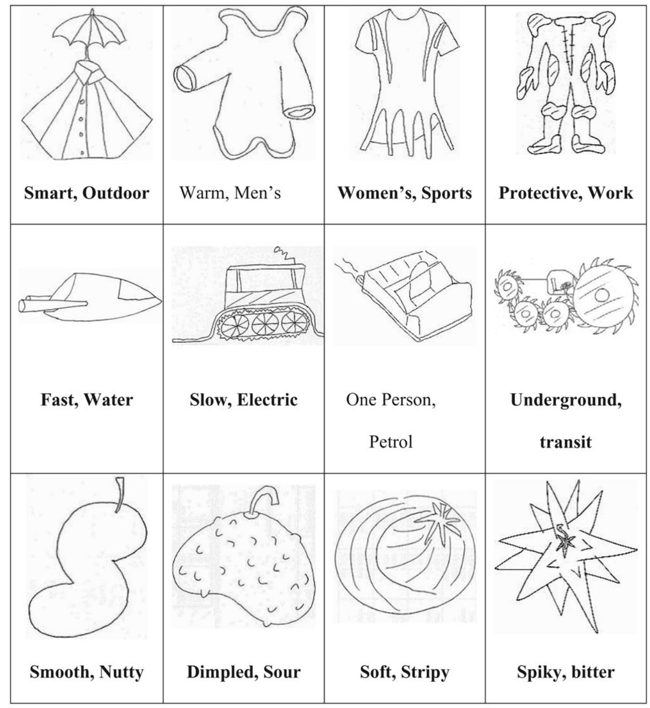
(*Appendix follows*)

# Appendix

## Pictures and Words




## New Pictures (Presented During Training)




## New (to-Be-Learned) Words and Familiar Words

| New word | | |
|---|---|---|
| Set 1 | Set 2 | Familiar word |
| kosla | skurk | blouse |
| emgle | tront | car |
| voper | romin | coat |
| buson | dirgo | grape |
| cadel | comra | lemon |
| liln | hedon | orange |
| sherf | videl | plum |
| fulon | siebe | ship |
| tozel | lafle | skirt |
| spron | miber | tie |
| flark | woisk | train |
| dumet | glill | van |

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