Integrative and Semantic Relations Equally Alleviate Age-Related Associative Memory Deficits

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Abstract

Two experiments compared effects of integrative and semantic relations between pairs of words on lexical and memory processes in old age. Integrative relations occur when two dissimilar and unassociated words are linked together to form a coherent phrase (e.g., *horse-doctor*). In Experiment 1, older adults completed a lexical decision task where prime and target words were related either integratively or semantically. The two types of relation both facilitated responses compared to a baseline condition, demonstrating that priming can occur in older adults with minimal preexisting associations between primes and targets. In Experiment 2, young and older adults completed a cued recall task with integrative, semantic and unrelated word pairs. Both integrative and semantic pairs showed significantly smaller age differences in associative memory compared to unrelated pairs. Integrative relations facilitated older adults' memory to a similar extent as semantic relations despite having few preexisting associations in memory. Integratability of stimuli is therefore a new factor that reduces associative deficits in older adults, most likely by supporting encoding and retrieval mechanisms.

Keywords: associative deficits, lexical decision, integrative priming, semantic priming, cued recall, encoding, retrieval, aging

Word count: 7,065

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Cognitive aging impairs performance in a range of memory tasks, with some tasks showing greater age-related differences than others (e.g., Zacks, Hasher, & Li, 2000). In particular, episodic and contextual memory tend to exhibit larger age differences than content or item memory (Spencer & Raz, 1995). Naveh-Benjamin (2000) thus proposed an *associative deficit hypothesis* whereby older adults show specific deficits in forming associations between items. Naveh-Benjamin presented for study several pairs of unrelated words and then tested young and older adults' item memory (i.e., recognizing studied vs. new words) and their associative memory (i.e., recognizing intact vs. rearranged pairs). Older adults showed greater age deficits for associative memory than for item memory. A recent meta-analysis demonstrated that many studies have shown similar results (Old & Naveh-Benjamin, 2008).

Research into age-related associative deficits has attempted to establish factors that can alleviate this memory deficit. One such factor is the semantic relatedness between to-be-associated items. Items are *semantically related* if they belong in the same category, such as *shirt* and *sock*, or are otherwise featurally similar, such as *apple* and *ball*. Naveh-Benjamin (2000, Exp. 4), Naveh-Benjamin, Hussain, Guez, and Bar-On (2003, Exp. 2) and Naveh-Benjamin, Craik, Guez, and Kreuger (2005) showed a reduction in age differences for associative memory with semantically related word pairs (e.g., *shirt* and *sock*) compared to unrelated word pairs (e.g., *shirt* and *apple*). Therefore, older adults are able to use semantic relations to enhance their associative memory performance relative to young adults. This finding suggests that older adults' associative memory deficit may be specific to *new* associations; older adults' memory for *preexisting* associations appears to be relatively unimpaired. Indeed, MacKay and Burke (1990) and Naveh-Benjamin and colleagues (2003) both suggested that age-related memory deficits increase on tasks that require more novel associations. Several recent studies support this claim (e.g., Castel, 2005, 2007; Patterson, Light, Van Ocker, & Olfman, 2009).

Semantic relations may alleviate older adults' associative deficits in multiple ways. First, semantic relations may allow older adults to capitalize on overlapping neural representations: The co-activation of features shared by semantically related items may strengthen the associative memory representation that links them (MacKay & Burke, 1990). In contrast, because semantically unrelated items have more distinct neural representations, that lack of co-activation would produce weaker associative memory representations. Second, older adults may use semantic relations to initiate encoding and retrieval strategies during memory tasks. A consistent finding in the literature is that older adults are less likely than young adults to implement an encoding strategy (e.g., Luszcz, Roberts, & Mattiske, 1990; Witte, Freund, & Sebby, 1990). Therefore, semantically related word pairs could show smaller age deficits than unrelated word pairs because with semantic relations young and older adults are better equated in their use of encoding and retrieval strategies. That is, with semantically related word pairs, older adults may more easily adopt a strategy to aid the memory process, whereas with unrelated word pairs older adults may not produce encoding and retrieval strategies as well as young adults.

Whereas prior studies have successfully reduced older adults' associative memory deficits by utilizing preexisting relations between items, the current study aims to reduce this memory deficit without recourse to preexisting relations. Specifically, we examined the age-related associative deficit with three different types of word pairs: integrative word pairs, semantically related word pairs and unrelated word pairs. The novel element of this study was the use of integrative word pairs, where the two words of the pair can be linked to produce a coherent phrase (e.g., *horse-doctor, plastic-toy*). Essentially, any word pair in which the first word modifies the second word involves integration. Although this includes simple adjective-noun pairs such as *red apple*, it also includes noun-noun pairs such as *thesis idea*, which are more common among studies of memory. Integrative relations entail a modifier (i.e., first word) that specifies a subclass of the head noun (i.e., second word). For example, a *thesis idea* is a specific type of idea, and a *trick rabbit* is a specific type of rabbit that differs in important respects from the more general class of rabbits (e.g., Glucksberg & Estes, 2000; Springer & Murphy, 1992).

Notably, many words can be integrated easily despite being semantically dissimilar, unassociated, and unfamiliar as a phrase (for review see Estes, Golonka, & Jones, 2011). *Monkey foot*, for instance, is easily understood despite the fact that *monkey* and *foot* are dissimilar and do not occur together frequently in language. Such integrative word pairs lack preexisting relations: They are from different semantic categories, they share few features (if any), they are rarely spoken or written together, and they rarely occur together in a free association task (Estes & Jones, 2009). This novel aspect of integration allowed us to test older adults' processing of and memory for integrative word pairs that have few preexisting relations between them (like the unrelated word pairs) but could very easily be encoded together (like the semantic word pairs). If integrative word pairs produced small age-related associative deficits like semantic word pairs, then this would indicate that ease of encoding/retrieval can reduce associative deficits. Alternatively, if integrative word pairs produced larger age-related associative deficits than semantic word pairs (like unrelated word pairs), then this would indicate that preexisting relations are a key factor that reduces associative deficits.

Integrative Priming and Memory

Integrative relations facilitate processing of words. Estes and Jones (2009) demonstrated integrative priming in young adults. In their Experiment 2, integrative priming was directly compared to semantic priming. Participants were presented with trials where a prime was followed by a target. They completed a lexical decision task where they had to decide if each target was a word or a nonword. Prime-target pairs were either integrative or semantic word pairs. There was also a baseline condition where the prime word was replaced by a row of asterisks. Both integrative and semantic primes facilitated the lexical decisions as responses were significantly faster than responses to the baseline condition. There was also no significant difference between the magnitudes of integrative and semantic priming.

The integrative priming effect is interesting because the faster response times following integrative primes cannot be explained by pre-processing of the prime before the target onset (Estes & Jones, 2009). For example, with the semantic prime-target pair *fox-dog,* semantic elaboration of the features of a fox will act before the target *dog* appears and therefore the response to *dog* is facilitated. However, with integrative pairs (e.g., *apartment-dog*), the prime is unlikely to activate the target as the two words were initially unrelated. This means that integrative priming processes occur *after* viewing the target. In terms of the current study, integrative word pairs are important for discriminating between memory processes that occur only upon encoding and retrieval (i.e., integrative pairs) and those that may also rely on preexisting relations (i.e., semantic pairs). However, because integrative priming has not yet been demonstrated in older adults, Experiment 1 of the current study replicated this effect in older adults. It is well established in the literature that older adults demonstrate semantic priming to at least the same extent as young adults and possibly to a greater extent (e.g., Laver, 2009; see Laver & Burke, 1993; Myerson, Ferraro, Hale, & Lima, 1992, for reviews). In the first experiment, integrative and semantic priming were compared in older adults to establish if older adults produce an integrative priming effect.

Integrative relations also facilitate memory. Jones, Estes, and Marsh (2008) argued that conceptual integration may elicit elaboration during encoding and may act as a contextual cue during retrieval. In support of this argument, Jones and colleagues reported two experiments in which integrative relations affected memory in young adults. First they presented word pairs that were significantly easier to integrate in one order (e.g., *horse doctor*) than in the reverse order (e.g., *doctor horse*). They subsequently presented those individual words in a surprise recognition memory test. They found that the words were more reliably recognized if they had been studied in their more easily integrated order (i.e., *horse doctor*) than if they had been studied in their less integratable order (i.e., *doctor horse*). In another experiment, Jones and colleagues showed that a given item was more reliably recognized at test when it instantiated the same integrative relation at study than when it instantiated a different relation. For example, the item *cookie* was better recognized in *cookie plate* when it had been studied as *cookie jar* than when it was studied as *cookie crumb*. Because *cookie jar* and *cookie plate* both instantiate a containment relation (i.e., Y contains X), the target item was more reliably recognized. Thus, both of these experiments indicate that integrative relations facilitate item memory.

Demonstrating integrative priming in older adults (Exp. 1) would validate the use of integrative word pairs in a memory test with older adults (Exp. 2), in that the observation of integrative priming among older adults would justify the assumption that encoding and retrieval of integrative word pairs is relatively easy for older participants. Given that integrative relations facilitate word processing (Estes & Jones, 2009) and item memory (Jones et al., 2008) in young adults, we hypothesized that integrative relations might similarly facilitate word processing and associative memory in older adults, despite the lack of preexisting relations between the words.

Experiment 1

Method

Participants. Eighteen older adults (13 female) aged 61-85 years (*M* = 73.2, *SD* = 6.9) took part in the experiment.[1] They were recruited from the University of Warwick Age and Memory Study volunteer panel that was populated by local advertisements; they were offered no financial incentives for participation. To assess cognitive functioning, participants completed the Digit Symbol Substitution task (Wechsler, 1981) as a measure of processing speed (*M* = 47.1, *SD* = 9.3). They also completed the multiple choice part of the Mill Hill vocabulary test (Raven, Raven, & Court, 1988) as a measure of crystallized intelligence (*M* = 23.7, *SD* = 3.6).

Materials. The integrative and semantic prime-target word pairs (see Appendix) were acquired from Estes and Jones (2009) where the stimuli were selected based on results from pretesting: Twenty-four participants rated the stimuli based on a 7-point integratability scale (1 = *not linked* to 7 = *tightly linked*) and on a 7-point semantic similarity scale (1 = *not similar* to 7 = *very similar*). In addition, integrative and semantic pairs were chosen to have low levels of both forward (i.e., *prime-target*) and backward (i.e., *target-prime*) association probabilities taken from the University of South Florida free association norms (Nelson, McEvoy, & Schreiber, 2004); see Table 1 for a summary and Estes and Jones (2009) for further details. For a given target there was an integrative and a semantic prime. Integrative primes were selected to have a high rating of integratability and a low rating of semantic similarity to the target. Semantic primes were selected to have a high rating of semantic similarity and a low rating of integratability to the target.

In total there were 45 target words, each corresponding to one of 45 integrative primes and one of 45 semantic primes (e.g., for the target *foot*, the integrative prime was *monkey* and the semantic prime was *paw*). For the lexical decision task, there were 45 nonword targets which were also those employed by Estes and Jones (2009). Three separate lists were produced for counterbalancing, each containing 90 prime-target pairs. For each list there were 15 integrative primes, 15 semantic primes, and 15 baseline primes (the baseline primes were a row of 8 asterisks). The remaining 45 pairs consisted of nonword targets, 15 with asterisk primes and 30 with word primes. The lists were counterbalanced so that for a given real word target, one list would contain an integrative prime, one a semantic prime and one a baseline prime. In this way, no two counterbalanced lists had any of the same prime-target pairs: There were six participants in each counterbalancing condition who saw different combinations of prime-target pairs.

Procedure. Participants were informed that they would be shown strings of letters on a computer screen and that their task was to identify whether they were words or nonwords. Participants were then informed that they would see a red word or row of asterisks before each target word and that they were not to respond to it but to base their word/nonword judgment on the white word that followed it. For each trial, a red fixation cross appeared on a blank black computer screen for 500 ms. This was then immediately followed by a prime word/asterisks in red for 950 ms. There was then a 50-ms delay with a blank black screen followed by the target word in white.[2] Once the target appeared on the screen, participants were required to press the 'j' key on the keyboard if the target was a real word and to press the 'f' key if the target was a nonword. After a response was made, the screen displayed the instruction 'Press space when ready' in white and participants needed to press the space bar to activate the next trial. The entire block of 90 trials was randomized separately for each participant.

Words were presented in a lower case font size of 40 pt with a height corresponding to roughly 1.4º viewing angle at a distance of 60 cm. Participants were required to keep their index fingers ready on the ‘f’ and ‘j’ keys and to press the space bar between each trial with their thumb. Before the main test, participants completed a practice block with 10 trials of mixed prime type using separate stimuli to the main study. If participants were not confident with the procedure, they were encouraged to practice again by the experimenter. Participants were also given a reminder sheet that identified which button was which.

Results

Correct responses to word targets in the lexical decision task were used to formulate response speed averages. For each prime type, the average reaction time of correct responses was calculated on an individual basis for each participant; responses falling outside of 2.5 standard deviations from each average were excluded as outliers (4% of the total data).

A 3 (Prime type: integrative, semantic, baseline) x 3 (list type: 3 levels of counterbalancing between subjects) repeated measures ANOVA was conducted on the reaction time data. Throughout this study, Greenhouse–Geisser corrections to the degrees of freedom were performed where appropriate, and corrected p values are reported. There was a main effect of prime type, $F(2, 30) = 25.62$, $MSE = 7{,}902$, $p < .001$, indicating priming effects because baseline reaction times were slower than integrative and semantic reaction times (see Figure 1). There was no main effect of list type, $F < 1$, and no interaction between prime type and list type, $F < 1$. This demonstrates that the counterbalancing did not influence the pattern of results.

Measures of integrative and semantic priming were produced by subtracting the mean reaction time for targets following integrative and semantic primes from reaction times for words following baseline primes (integrative priming, M = 186 ms, SD = 148 ms; semantic priming, M

= 181 ms, *SD* = 136 ms). One sample *t*-tests were conducted to establish priming effects. There was a significant integrative priming effect, $t(17) = 5.35$, $p < .001$, and a significant semantic priming effect, $t(17) = 5.64$, $p < .001$, with targets following integrative and semantic primes showing faster responses than targets following the baseline (asterisks prime) condition. There was no significant difference in the magnitude of the integrative and semantic priming effects, $t(17) = 0.25$, *ns*.

The percentage of correct responses to words was also analyzed for each prime type. The means were all identical and close to ceiling: Mean percentage correct was 99.6% for integrative, semantic and baseline conditions.

Discussion

Experiment 1 demonstrated an integrative priming effect in older adults that was not significantly different to the size of the semantic priming effect. Estes and Jones (2009, Exp. 2) also found no difference in the overall magnitude of integrative priming compared to semantic priming with young adults. Although the current experiment did not have enough power to statistically differentiate between the semantic and integrative priming magnitudes, the presence of integrative priming was reliably established. This indicates that preexisting relations linking prime-target pairs (e.g., shared semantic features) are not necessary to elicit priming effects in older adults.

Integrative compounds form a vital part of language by reducing the number of words required to convey a specific concept. For example, a *plastic toy* is a more concise way of saying a “toy made from plastic”. Such compounds are common in language and they are useful for accelerating the communication of information. It is therefore perhaps unsurprising that such relationships facilitate the comprehension of a target word following an integrative prime.

Language comprehension is largely unaffected by the aging process (e.g., Burke, Mackay, & James, 2000) and it was noted earlier that semantic priming is present in older adults (Laver & Burke, 1993). The presence of integrative priming with older adults as well as young adults is therefore consistent with these observations.

Having demonstrated in Experiment 1 that integrative priming occurs in older adults just as it does in young adults (Estes & Jones, 2009), Experiment 2 tests whether integrative relations also facilitate memory in older adults just as they do in young adults (Jones et al., 2008). More specifically, Experiment 2 compares age differences in associative memory for integrative, semantic and unrelated word pairs. The experimental procedure was based closely on the cued recall element of Naveh-Benjamin's (2000) Experiment 4. If integrative relations alleviate the age-related deficit like semantic relations do (e.g., Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2005; Naveh-Benjamin et al., 2003), this would indicate that stimuli that assist encoding and retrieval strategies can improve associative memory. Alternatively, if integrative relations fail to alleviate the age-related deficit, this would suggest that preexisting relations (shared features) between items are more important for supporting associative memory formation in older adults.

Experiment 2

Method

Participants. Thirty-six young adults (30 female) aged 18-32 years (*M* = 19.5, *SD* = 2.7) and 36 healthy older adults (20 female) aged 61-86 years (*M* = 73.1, *SD* = 6.9) took part in the experiment. Young participants were undergraduates at Warwick University (UK) who participated in exchange for course credit. Older participants were recruited from the University of Warwick Age and Memory Study volunteer panel that was populated by local advertisements;

they were offered no financial incentives for participation. None of the participants had previously taken part in Experiment 1.

To assess cognitive functioning, participants completed the Digit Symbol Substitution task (Wechsler, 1981) as a measure of processing speed. They also completed the multiple choice part of the Mill Hill vocabulary test (Raven et al., 1988) as a measure of crystallized intelligence. The results were consistent with the literature (e.g., Salthouse, 1991, 2010). Young participants were significantly faster at the Digit Symbol Substitution task, $t(70) = 11.02$, $p < .001$ (young $M = 72.9$, $SD = 10.2$; older $M = 45.5$, $SD = 10.9$). For the vocabulary test, young participants scored significantly lower than older participants, $t(70) = 5.89$, $p < .001$ (young $M = 15.6$, $SD = 4.2$; older $M = 21.9$, $SD = 4.8$).

Materials. The main memory stimuli were taken from a set of 180 words formed from 4 groups of 45 words (see Appendix). There were 45 target words, each paired with a corresponding integrative, semantic and unrelated cue word. This produced three sets of 45 cue-target pairs, all with the same 45 target words. For example the target word ‘book’ could appear in one of three combinations: integrative – *travel book*, semantic – *article book*, or unrelated – *lapel book*. In the experiment, participants would see two words; they would later be cued by being shown the left word of each pair and would be asked to recall the corresponding target word. Stimuli were arranged so that each participant would only see each and every target word once. Therefore every participant was recalling the exact same words, but not necessarily from the same cues (see details of counterbalancing below).

The target, integrative and semantic words were taken from Estes and Jones (2009) and were the same words as used in Experiment 1. The unrelated words were chosen such that they would be unrelated to their corresponding target words yet have similar length and frequency of occurrence in the English language as target, integrative and semantic words. Target, integrative and semantic words were grouped together and compared to unrelated words: Non-significant *t*-tests revealed that these two sets of words were of similar length, $t(177) = 1.20$, *ns*, and frequency of occurrence, $t(66.37) = 1.33$, *ns*, using log HAL frequency (Lund & Burgess, 1996). Twelve additional pairs of words, four of each category (integrative, semantic and unrelated) were created to be used as buffers and for a practice test.

Procedure. Stimuli were arranged into blocked sets each consisting entirely of integrative, semantic or unrelated pairs. Each block contained 15 pairs of words from the memory stimuli as well as 2 additional pairs (with the same type of relationship – integrative, semantic or unrelated), one at the start and one at the end, which were used as buffers. A total of 17 pairs were therefore displayed to participants for each memory test. Participants completed a separate memory test for each of the three pair types. Word pairs were presented in black with a white background in the center of a laptop computer screen. Words were presented in lower case with a font size of 40 pt with a height corresponding to roughly 1.4º viewing angle at a distance of 60 cm.

Pilot studies were conducted with young adults to determine the optimal presentation of the memory set pairs. To avoid both ceiling effects for young adults and floor effects for older adults, the main experiment presented stimuli at a rate of 5 s per pair for young participants but 10 s per pair for older participants. These are the same presentation rates as used in Naveh-Benjamin’s (2000) Experiment 4.

Before the main memory tests, participants completed a practice version of the experiment which presented 6 pairs of words sequentially (2 of each relationship type, integrative, semantic and unrelated). Participants were informed that they would be required to memorize the words in each pair and that later they would be shown the left word of each pair and would be required to recall the corresponding right word. Practice pairs were shown sequentially at the same rate as the main experiment.

After the presentation of the last pair there was a 1-minute delay which was filled with counting backwards in threes from 200. Following this, a single cue word (which was always the left word of each pair) was shown on the screen. Participants were required to say the corresponding target word for each cue word and their responses were noted by the experimenter. After each response the next cue word was shown on the screen by the experimenter pressing a button. Cue words appeared in a randomized order for each participant.

In the main experimental procedure, the entire memory task was completed three times, once with each type of word pair relationship. In each case, participants viewed a sequential memory set of 17 pairs (15 pairs for the cued recall test and 2 buffers) at 5 s per pair for young participants and 10 s per pair for older participants. This was followed by a delay and then a cued recall test, which were conducted in the same way as described for the practice. Participants were offered the chance to rest between conditions.

Counterbalancing and randomization was conducted throughout the experiment. Crucially, the condition order was fully counterbalanced so that every possible order of integrative, semantic and unrelated test was covered (6 combinations of condition order). Furthermore, the target words were matched to different combinations of integrative, semantic and unrelated cue words in six different lists. This produced a 6 x 6 design such that no participants within each age group received the same conditions with the same stimuli in the same order. There were 36 different test combinations and one participant from each age group completed each one. Within experimental blocks, individual stimuli were presented in randomized order both during presentation and during cued recall.

Results

To assess whether integrative, semantic, and unrelated pairs were remembered differently between young and older participants, a 2 (Age: young, older) x 3 (Condition: integrative, semantic and unrelated pairs) repeated measures ANOVA was conducted on the cued recall data (see top of Figure 2). There was a main effect of age, $F(1, 70) = 27.95$, $MSE = 0.08$, $p < .001$, with older participants recalling significantly less than young participants. There was also a main effect of condition, $F(2, 140) = 147.71$, $MSE = .02$, $p < .001$, with performance in the unrelated condition being much lower than both the integrative and semantic conditions. The interaction between age and condition was also significant, $F(2, 140) = 13.86$, $MSE = 0.02$, $p < .001$. This is because although older participants performed lower than young participants in all conditions, the age difference was much larger for unrelated word pairs than for integrative and semantic word pairs. Despite performance levels being high for integrative and semantic pairs and low for unrelated pairs, the proportion of participants hitting ceiling and floor performance was low and comparable between young and older adults. For integrative, semantic and unrelated pairs the proportion of young adults performing at ceiling was 0.11, 0.17 and 0.03, respectively, and floor was 0 for all pair types; for older adults the proportion performing at ceiling was 0.17, 0.19 and 0.03, respectively, and floor was 0.03, 0 and 0.19, respectively. It is also important to note that although the integrative and semantic conditions yielded age differences that were very small, age differences were also reduced by increased presentation times for older adults. Therefore, integrative and semantic relations did not completely abolish age deficits; rather they reduced them relative to unrelated pairs.

Further tests revealed that there was no age by condition interaction between integrative and semantic conditions ($p = .13$), but the interaction was present between integrative and unrelated conditions ($p = .001$), and between semantic and unrelated conditions ($p < .001$). In order to establish if the lack of interaction between age and integrative and semantic memory performance was determinable, power analysis was conducted to measure the power we had to detect this effect. The experiment had sufficient power to detect a medium size of effect for the interaction.[3] This means that if there is a difference in the effect of age between memory for integrative and semantic word pairs, it is likely to be only a small effect size.

In case of carry–over effects from one condition to another, the analysis was re-conducted using data only from the first condition that each participant completed (see bottom of Figure 2). Thus both age and condition were between subjects factors, with 12 young and 12 older participants in each condition. A 2 (Age: young, older) x 3 (Condition: integrative, semantic and unrelated pairs) factorial ANOVA revealed a qualitatively identical pattern of results. There was a main effect of age, $F(1, 66) = 42.59$, $MSE = 0.03$, $p < .001$. There was also a main effect of condition, $F(2, 66) = 47.66$, $MSE = 0.03$, $p < .001$, and an interaction between age and condition, $F(2, 66) = 13.97$, $MSE = 0.03$, $p < .001$. This demonstrates that the overall pattern of results was not unduly influenced by a particular condition order.

Intrusions. Intrusions were categorized to ascertain if participants were aware of relationships between the word pairs they memorized. An intrusion was defined as a word response produced during the cued recall test that was not the correct answer. (Trials when participants made no response were categorized as omissions.) Intrusions were further coded on the basis of their congruence with the list type. For integrative and semantic lists, a congruent intrusion was when there was any relation between the cue and the intrusion. For unrelated lists, a congruent intrusion was when there was no relation between the cue and the intrusion. The classification of intrusions was conducted independently by two coders, both blind to the experimental condition and the age of participants. Initially the relatedness coding between coders was in agreement for 86% of intrusions - the remaining discrepancies were then resolved by discussion.

A 2 (Age: young, older) x 3 (Condition: integrative, semantic and unrelated test) x 2 (Congruency: congruent, incongruent) repeated measures ANOVA was conducted on the proportions of responses that were intrusions (see Figure 3 for means and Table 2 for summary of response types). There was a main effect of age, $F(1, 70) = 10.92$, $MSE = 0.03$, $p < .01$, with older participants producing more intrusions than young participants.[4] There was a main effect of condition, $F(1.72, 120.56) = 9.00$, $MSE = 0.01$, $p < .001$, with more intrusions for the unrelated condition than for the integrative or semantic condition. There was also a main effect of congruence, $F(1, 70) = 63.55$, $MSE = 0.01$, $p < .001$, with more congruent than incongruent intrusions. This is important as it shows that participants were aware of relations between words they were recalling. There was a significant interaction between age and congruency, $F(1, 70) = 13.13$, $MSE = 0.01$, $p < .001$. Both young and older participants made more congruent than incongruent intrusions but the difference was larger for older participants. There was also a marginal interaction between condition and congruency, $F(1.38, 96.30) = 3.19$, $MSE = 0.02$, $p = .06$. This was because there was a smaller difference between the number of congruent and incongruent intrusions for the unrelated test than for the integrative or semantic tests. Finally, the triple interaction between age, condition and congruency was not significant, $F(1.38, 96.30) = 1.97$, $MSE = 0.02$, *ns*.

Preexisting relations. To examine the possibility that integrative word pairs had been encountered before and may therefore contain some preexisting relations, further analysis was conducted for each word pair within the integrative category: In total, the experiment used 45 different integrative word pairs. For each word pair, a measure of local co-occurrence was calculated using the British National Corpus (BNC, 2007) which is a collection of 100 million texts taken from written and spoken language. The database was used to calculate how frequently the individual words of each integrative pair occurred adjacently in the corpus of text. This measure of familiarity was highly suitable for integrative pairs as they are coherent when put together in language. Therefore, it provides an indication of the amount of prior exposure to links between the words. Across the 45 integrative word pairs there was a mean number of adjacent occurrences of 5.84 (SD = 11.44). That is, these word pairs occurred on average less than 6 times in 100 million texts.

In the experiment, each pair was tested with 12 young and 12 older participants, so for every pair there was a measure of both young and older participants' memory performance. The BNC co-occurrence measure was not significantly correlated with the proportion of correct responses for either young or older participants, $r(45) = -.01$, $p = .97$, $r(45) = .08$, $p = .58$, respectively. This indicates that for these items, amount of prior exposure did not affect memory performance. Within the integrative word pairs, there were 20 pairs that had no adjacent occurrences in the BNC, while the remaining 25 pairs had 1 or more occurrences. The memory data (proportion correct for each word pair) were therefore split and entered into a repeated measures ANOVA with co-occurrence as a 2-level independent factor (BNC co-occurrence: none, 1 or more) and age as a 2-level repeated factor (Age: young, older). Importantly there was no main effect of co-occurrence, $F < 1$, with no BNC co-occurrence memory performance (M =

.76, *SD* = 0.11) showing similar levels to higher BNC co-occurrence memory performance (*M* = .79, *SD* = 0.11). There was a main effect of age, $F(1, 43) = 44.29$, $MSE = 0.01$, $p < .001$, with young participants (*M* = .86, *SD* = 0.12) recalling a higher proportion than older participants (*M* = .69, *SD* = 0.15). There was no interaction between BNC co-occurrence and age, $F < 1$. This indicates that memory performance for integrative word pairs was not attributable to preexisting relations in either young or older adults.

Discussion

Four main results were obtained. First, relative to young adults, older adults exhibited an overall memory deficit. This finding replicates much prior research (e.g., Salthouse, 2010; Zacks et al., 2000) thus validating our methods and samples. Second, this age-related memory deficit was significantly reduced among semantically related word pairs (e.g., *paw foot*), again replicating much prior research (e.g., Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2005). Third, the age-related memory deficit was also significantly attenuated among integratively related words pairs (e.g., *monkey foot*). Although integrative relations were known to facilitate memory among young adults (Jones et al., 2008), this is the first demonstration that such integrative relations also facilitate memory among older adults. In fact, these integrative word pairs were similarly as powerful as the semantic word pairs in reducing the age-related memory deficit. Given that the words in integrative pairs were semantically dissimilar and unassociated, their attenuation of the age-related memory deficit cannot be directly attributed to preexisting relations. Rather they formed concepts that were consistent with world knowledge, which is perhaps why they could have been easier to encode and/or retrieve than unrelated word pairs. Finally, analysis of intrusion errors revealed that participants most often recalled words with similar relatedness to the cue as the actual target word. For instance, when prompted with a word from an integrative or semantic list, intrusions were more likely to be related to the cue. Likewise, when prompted with a word from an unrelated list, intrusions were somewhat more likely to be unrelated to the cue. This is in line with previous research, where intrusions have been shown to share similar attributes to target stimuli (e.g., Underwood & Hughes, 1950). Also the use of a blocked design would have enhanced awareness of the relation types within each condition. In general, the results from Experiment 2 provide strong evidence that integrative relations provide effective cues for associative memory, especially among older adults.

General Discussion

Experiment 1 demonstrated that integrative priming was present in older adults. This established that integrative relations, like semantic relations, facilitate word processing among older adults. In Experiment 2, integrative, semantic and unrelated word pairs were used to assess cued recall performance in young and older adults. Age differences were significantly larger for unrelated word pairs than for both integrative and semantic word pairs. The reduction in associative deficits in older adults with integrative pairs therefore demonstrates a new type of support for associative memory performance in older adults. Previous research has suggested that semantic relations are easier for older adults to encode because fewer new connections need to be formed in memory (MacKay & Burke, 1990). This explanation cannot be applied to the integrative relations memorized in our experiment, because the integrative word pairs were unassociated and semantically dissimilar. Instead, the results suggest that integrative word pairs may reduce associative deficits in older adults because they are easier to encode and perhaps more importantly easier to retrieve than unrelated word pairs. Furthermore, the guiding of encoding and retrieval processes could equally apply to semantically related word pairs where it is also easy to perceive relations between stimuli. Given that semantically and integratively related stimuli support associative memory performance in older adults to a similar extent and that integrative word pairs have no preexsiting relations, the present study suggests that ease of encoding and retrieval processes may be more important than preexisting relations for reducing age-related associative deficits.

Encoding. Integrative and semantic relations could alleviate the age-related memory deficit by inducing encoding strategies. Indeed, older adults are less likely than young adults to implement encoding strategies (e.g., Luszcz et al., 1990; Witte et al., 1990), and implementing encoding strategies has been shown to attenuate the age-related memory deficit (e.g., Naveh-Benjamin, Brav, & Levy, 2007; Park, Smith, Morrell, Puglisi, & Dudley, 1990; Treat & Reese, 1976). It is reasonable to conclude then that both integrative and semantic word pairs may show reduced age differences compared to unrelated word pairs because it is easier to meaningfully encode them. This conjecture is consistent with the popular view in cognitive aging research that less effortful processes show smaller age-related decline (e.g., Fastenau, Denburg, & Abeles, 1996; Hasher & Zacks, 1979; Salthouse, 1988). It is also supported by the observation in Experiment 2 that participants' intrusion errors most often instantiated the same general relation as the studied items. Given that such occurrences were errors, the target words themselves clearly did not induce retrieval of the correct relation. Rather, it appears that the correct relation was retrieved but the correct item was not, thereby suggesting that the integrative and semantic relations might have been utilized as encoding strategies.

Retrieval. Alternatively, or additionally, integrative and semantic relations could alleviate the age-related memory deficit by inducing retrieval strategies. Indeed, there is evidence to suggest that associative deficits in older adults are a result of retrieval deficits more so than encoding deficits (Cohn, Emrich, & Moscovitch, 2008). In Naveh-Benjamin et al.'s (2005)

Experiment 2, young and older adults completed an associative memory task with and without a secondary task to divide attention during recall. Young adults' recall performance was unaffected by dividing attention but older adults showed reduced memory performance with the presence of the secondary task. In contrast, Naveh-Benjamin et al.'s (2005) Experiment 1 showed that dividing attention during encoding affected both young and older adults equally. This evidence suggests that older adults may require more resources during recall. Naveh-Benjamin et al. (2005) also showed that performance on the secondary task dropped more for older adults than young adults during recall, especially when older adults were instructed to use memory strategies. This also indicates that older adults require more cognitive resources during associative memory recall. Finally, Naveh-Benjamin et al. (2007) found that encouraging participants to use encoding strategies reduced age-related associative deficits but encouraging participants to use encoding *and* retrieval strategies almost eliminated associative deficits in older adults.

The main demonstrations of associative deficits come from recognition tests of item and associative memory where older adults show smaller deficits for item than for associative memory compared to young adults (e.g., Naveh-Benjamin, 2000). The age-related deficits in associative recognition tests are often driven by increased false alarms to lures whilst endorsement of seen-before associations remains relatively intact (e.g., Castel & Craik, 2003; Healy, Light, & Chung, 2005). This means that older adults have formed associative memories but that they experience difficulty using recollection to reject lures. Therefore, this provides more evidence that encoding is intact in older adults and that it is retrieval that causes the age-related associative deficits observed.

The current results may thus be explained in terms of retrieval differences between the word pair types. The knowledge of relations between the words of integrative and semantic pairs during recall may have helped to narrow the search in memory for the corresponding target. It is well established in the literature that recognition tests yield smaller age differences than recall tests as there is greater environmental support during retrieval (e.g., Craik & McDowd, 1987; Light, Prull, La Voie, & Healy, 2000; Naveh-Benjamin, 2000; Schonfield & Robertson, 1966). Therefore knowledge of the integrative and semantic relations during retrieval may have provided environmental support that benefited the older adults more than the young adults.

Integrative relations. In addition to demonstrating that the age-related memory deficit can be alleviated with previously unassociated word pairs, these experiments also contribute much to our understanding of integrative relations and their effects. Integrative priming has only recently been identified as a distinct influence on word processing (Estes & Jones, 2009), and similarly little research has examined the influence of integrative relations on memory (Jones et al., 2008). The present research demonstrates for the first time that integrative priming remains intact among older adults, and that integrative relations serve as powerful facilitators of memory across the lifespan. These findings are nontrivial, in that they contradict the common assumption that older adults are disproportionately impaired at forming all types of new associations.

In both of the present experiments, integrative relations and semantic relations induced similar effects. That is, in neither experiment were the two types of relations dissociated behaviorally. This is consistent with the results of Estes and Jones (2009, Exp. 2), who found statistically indiscernible priming effects from integrative relations and semantic relations across a range of timing conditions. In other experiments, however, Estes and Jones did observe a dissociation between integrative priming and semantic priming. Surprisingly, they found that integrative priming was actually more robust than semantic priming across manipulations of context. They presented integrative pairs in a list with either many other integrative pairs or few other integrative pairs. The rationale was that if integrative priming was under participants' strategic control, then the integrative priming effect should be larger among many other integrative pairs than among few integrative pairs, because the list with few integrative pairs would discourage integration. However, the magnitude of the integrative priming effect was equally large in the two lists, suggesting that integration occurred uncontrollably. Semantic priming, in contrast, was only significant in a list with many other semantically related pairs. It was not significant in a list with few other semantic pairs (see also Hutchison, 2007). Thus, whereas semantic priming is under strategic control, integrative priming appears to be beyond strategic control. This finding has important implications for the age-related associative memory deficit. Although integrative relations and semantic relations similarly reduced the memory deficit, integrative relations may actually provide a more robust effect. Notably, in our Experiment 2 the three relation-types were studied in separate blocks, which effectively rendered them like a list with many of the same relations in Estes and Jones's study. It remains for future studies to determine whether integrative relations would induce a larger memory effect than semantic relations in older adults when the various relation-types are presented in a mixed list, but the prior research suggests that they might. Thus, the present experiments reveal much about integrative relations, and they also suggest important hypotheses for further investigation.

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Footnotes

[1] One 87-year-old participant was excluded from the analysis and replaced by another participant. This is because he was more than 2 standard deviations away from the mean and sometimes more than 3 standard deviations from the mean on several measures of performance.

[2] The presentation times used were determined after piloting. Originally, the study aimed to replicate the 500-ms stimulus onset asynchrony condition of Estes and Jones (2009, Exp. 2): The fixation was 500 ms followed by a 100-ms prime then a 400-ms delay before the target. The 100-ms prime was too short to have an effect on older participants as there was no evidence of either integrative or semantic priming. Therefore, in the main study, the salience of the prime was increased by lengthening its duration on screen to 950 ms.

[3] The most informative estimate of power would not be based upon the effect size measured in the data, as it cannot be assumed to represent the effect size of the population as a whole (O'Keefe, 2007). As would be expected from the null result (O'Keefe, 2007), the power based upon the actual effect size measured was low: Power = .33. Power analysis was therefore conducted with G*Power software (Faul, Erdfelder, Lang, & Buchner, 2007), using standard estimates of small and medium effect sizes taken from Murphy and Myors (1998). Power estimates were based on a repeated measures design and the correlation between integrative and semantic memory performance, $r(72) = .52$, $p < .001$, was used in the calculations. With 72 participants, and $\alpha = .05$, to detect a medium effect ($f^2 = .15$, $d = .5$) the experiment had a power of 1.00, and to detect a small effect ($f^2 = .02$, $d = .2$) the experiment had a power of .68. It is also worth noting that the main data had a larger age difference for integrative compared to semantic pairs but that the data from the first test only (see Figure 2, bottom) had the opposite pattern –

larger age differences for semantic than integrative pairs, which further indicates no differential effect of stimuli type on memory performance across age.

[4]Note that older adults produced around twice as many incorrect responses (intrusions plus omissions) as did young adults (see Table 2). Older adults also produced around twice as many intrusions as young adults; therefore the proportions of incorrect responses that were intrusions rather than omissions were approximately the same in the two age groups (M = 0.27, SD = 0.25, for young adults; M = 0.34, SD = 0.23, for older adults), $t(69) = 1.21$, $p = .23$.

Table 1

Integratability Ratings, Semantic Similarity Ratings and Forward and Backward Association Probabilities for the Materials Used in Experiments 1 and 2 (Adapted from Estes & Jones, 2009)

	Integratability		Semantic Similarity		Association			
					Forward		Backward	
Pair type	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Integrative	5.41	0.85	2.14	0.87	0.02	0.03	0.00	0.01
Semantic	3.00	0.74	4.68	0.77	0.02	0.02	0.01	0.02

Table 2

Mean (and SD) Proportion of Correct, Intrusion and Omission Responses for Integrative, Semantic and Unrelated Conditions in Experiment 2

		Response Type		
Condition	Age Group	Correct	Intrusion	Omission
Integrative	Young	.86 (.11)	.05 (.08)	.09 (.09)
	Older	.69 (.26)	.12 (.19)	.19 (.18)
Semantic	Young	.84 (.15)	.05 (.07)	.10 (.13)
	Older	.75 (.23)	.14 (.18)	.11 (.13)
Unrelated	Young	.59 (.20)	.08 (.12)	.33 (.18)
	Older	.24 (.24)	.22 (.22)	.54 (.26)

Figure 1. Reaction times to targets following integrative and semantic primes, and the baseline condition (Experiment 1). Error bars are 1 *SE*.

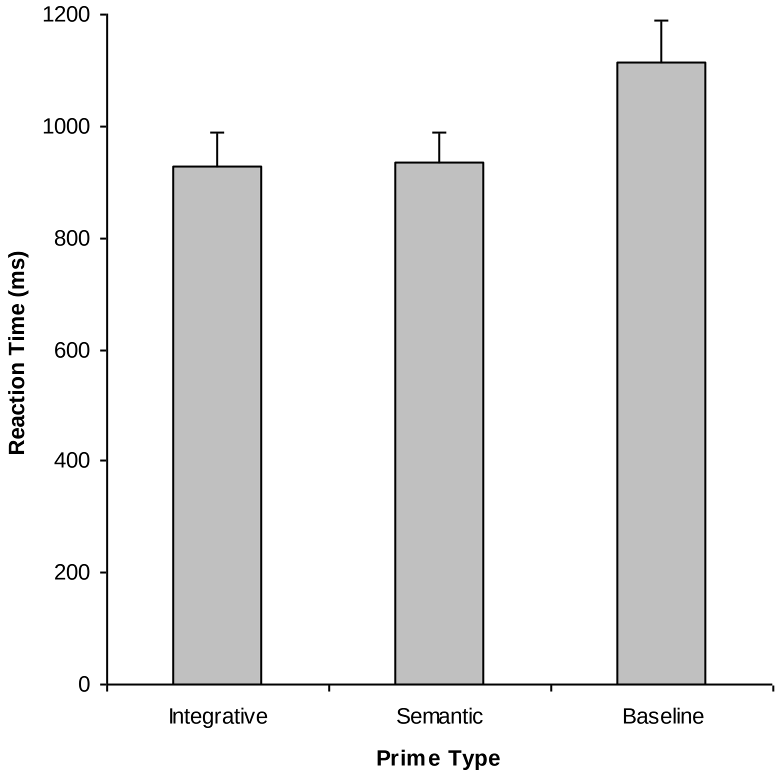
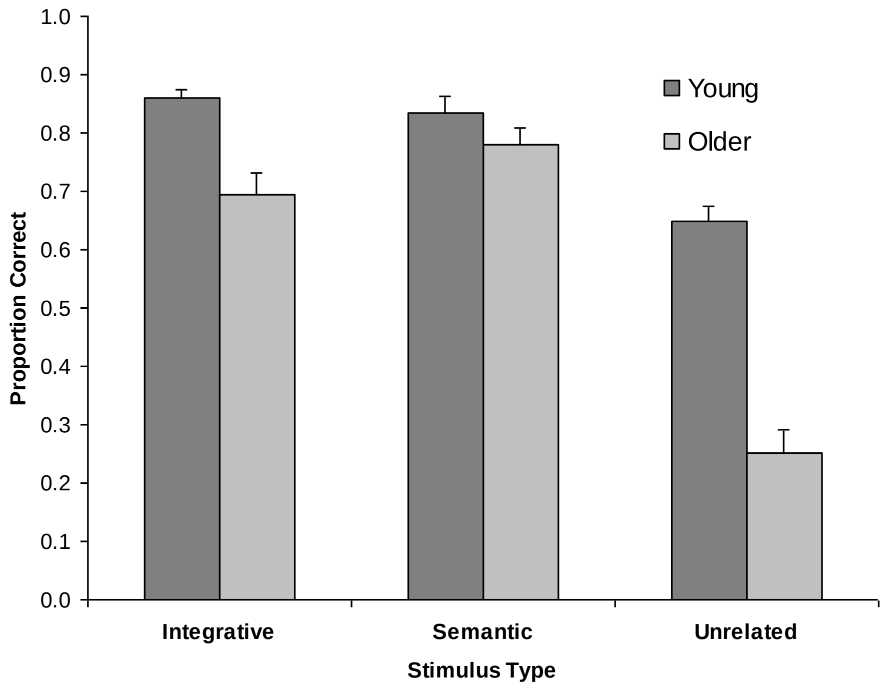


Figure 2. Young and older participants' performance for cued recall of integrative, semantic and unrelated word associations (Experiment 2). Top: all data. Bottom: data from first test block only. Error bars are 1 *SE*.



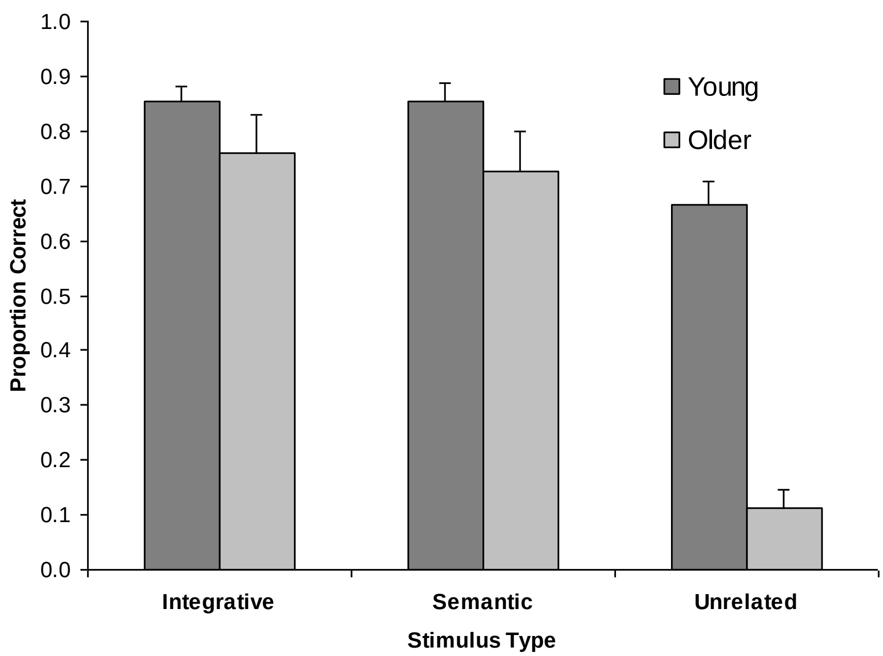
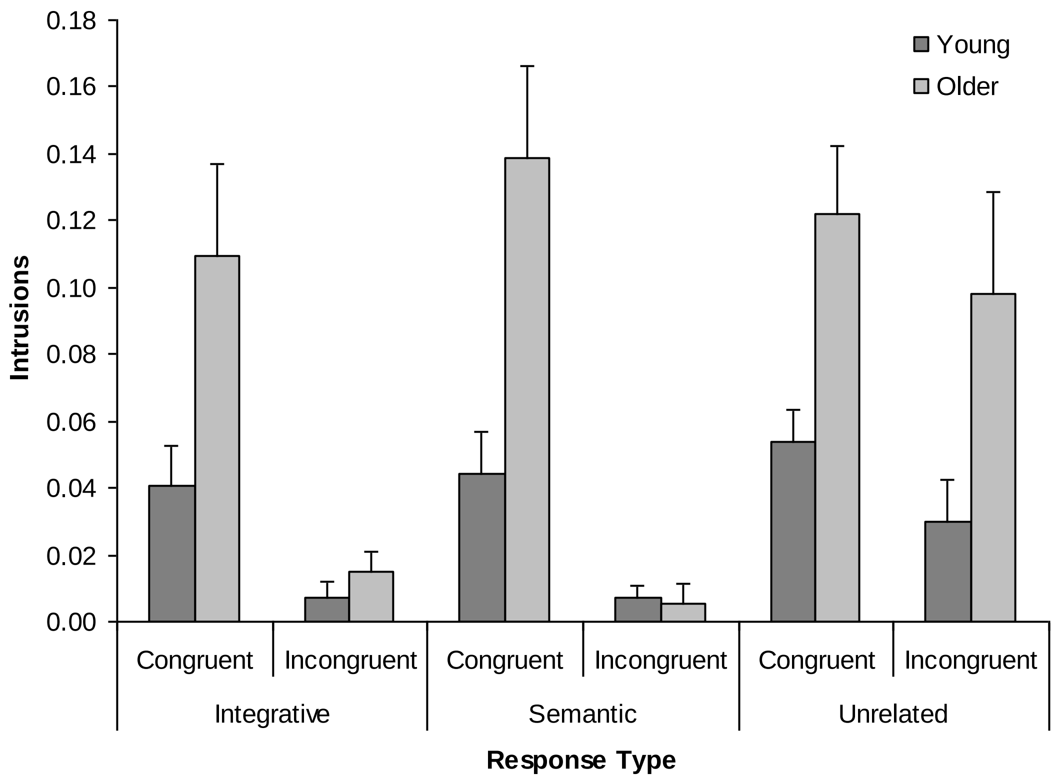


Figure 3. Mean proportion of responses that were intrusions, coded as congruent and incongruent with the test types for integrative, semantic and unrelated tests and for young and older participants (Experiment 2). Error bars are 1 *SE*.



Appendix

Stimuli used in Experiments 1 and 2

Prime/Cue			
Integrative	Semantic	Unrelated (Exp. 2 only)	Target
travel	article	lapel	book
lemon	muffin	affection	cake
soup	jug	stable	can
birthday	flashlight	pillow	candle
race	motorcycle	author	car
town	convent	athlete	church
necklace	pearl	stick	diamond
horse	sick	pub	doctor
apartment	fox	company	dog
velvet	lady	cow	dress
ocean	lobster	guide	fish
monkey	paw	campus	foot
herb	lawn	towel	garden
halloween	vampire	celebration	ghost
jelly	cherry	fence	grape
donor	liver	icing	heart
brass	clarinet	light	horn
parade	ox	theory	horse
beach	palace	mushroom	house
thesis	insight	fall	idea
border	field	party	land
maple	branch	valentine	leaf
government	fact	flower	lie
puppy	trust	pool	love
deer	vegetable	umbrella	meat
strawberry	juice	plumber	milk
copper	credit	carrot	money
farm	chipmunk	stairway	mouse
linen	blouse	estuary	pants
rice	envelope	gear	paper
concert	harp	square	piano
steel	tube	fight	pipe
corporate	rocket	plug	plane
trick	mole	industry	rabbit
summer	tornado	food	rain
law	office	acre	school
airplane	fatigue	glass	sleep
jungle	crocodile	hat	snake
mountain	wind	wick	snow
bathroom	shampoo	island	soap
winter	tennis	termite	sport
gold	tongue	lecture	teeth
plastic	game	smoke	toy
box	gin	remote	wine
fireplace	coal	chain	wood