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Disruption of Relational Processing Underlies Poor Memory for Order

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McDaniel and Bugg (2008) proposed that relatively uncommon stimuli and encoding tasks encourage elaborative encoding of individual items (item-specific processing), whereas relatively typical or common encoding tasks encourage encoding of associations among list items (relational processing). It is this relational processing that is thought to result in better memory for the serial order of a study list. We report 4 experiments examining memory for order demonstrating that (a) both semantic and orthographic tasks can impair memory for order when performed on individual items, (b) item-specific processing is not necessary for impairment because even an item-generic key press task harms memory for order, (c) impaired memory for order is due primarily to distraction during the processing of an item rather than between list items, and (d) even an unusual processing task will preserve memory for order as long as that task encourages the encoding of item-to-item relations. These findings suggest that an encoding task will disrupt order memory only when it is both attention grabbing (either through its atypicality or by requiring an overt response) and nonrelational.

Keywords: item-order account, temporal order, relational processing, design effect, production effect

Memory is only useful if information was encoded and stored in the first place. Depending on the tasks that occur during initial exposure, however, the quality of encoding and the types of information subsequently available vary greatly. For over 30 years, the distinction between item-specific and relational information has been influential with respect to the goal of understanding what is being encoded (Einstein & Hunt, 1980; Guynn et al., 2014; Hunt & Einstein, 1981). Underlying this distinction is the fundamental tenet that some encoding tasks enhance information about individual items in memory, whereas others enhance information about the connections between items in memory. In a recent review and meta-analysis, McDaniel and Bugg (2008) extended this idea, proposing that encoding tasks that are relatively unusual or uncommon prompt elaborative encoding of individual items, resulting in more item-specific information, whereas encoding tasks that are relatively typical prompt encoding of relations among list items, resulting in more relational information. For example, generating a list of target words from cues (e.g., *good–b__?* for the target "bad") is uncommon; therefore, item-specific information would be well encoded but at a cost to relational information. In contrast, silently reading a list of words is a common encoding process that would consequently result in relatively strong interitem associations but with weaker item-specific information.

This trade-off between item and relational information has been observed in a number of paradigms. For example, Nairne, Riegler, and Serra (1991) examined the effects of generation versus silent reading on recognition memory and memory for the serial order of the study list. During the recognition test, participants were presented with individual words and were to indicate whether they had studied each word (either by having silently read it or by having generated it from a cue); this test is thought to measure item-specific information because each test word is presented alone, without any associative information. During the test of memory for order, participants were presented with all of the studied words in a scrambled order and were to reconstruct the studied order; this test is thought to be a measure of relational memory because it requires participants to reconstruct the sequence of all of the studied words in relation to one another. In their study, Nairne et al. found that participants were more likely to recognize generated words relative to read words but that they were more likely to correctly reconstruct the order of read words relative to generated words.

McDaniel and Bugg (2008) referred to Nairne et al.'s (1991) findings, as well as those of other investigators, as support for the notion that participants differentially encode relational and item-specific information depending on the processing task. They argued that uncommon stimuli or encoding tasks require some interpretation, which results in rich encoding of item-specific features. This rich encoding results in better recognition performance because an item recognition test relies primarily on item-specific information. It comes at a cost, however, to tests of memory for order (for a discussion of how item and relational information affect recall, see McDaniel &

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Bugg, 2008). Previous work has also shown that mixing unusual (e.g., generation) and common (e.g., silently reading) encoding tasks within one list results in relatively poor memory for order for both types of items (e.g., Serra & Nairne, 1993). According to McDaniel and Bugg, this occurs because the presence of unusual stimuli or tasks within the list disrupts the encoding of relational information for the common items. In summary, then, relational information is best encoded for common processing tasks, but only in a pure list without any unusual or uncommon processing tasks to interrupt ongoing relational encoding.

This pattern in memory for order has been observed across a range of encoding tasks, such as the enactment effect (acting out vs. passively reading sentences or watching others act; e.g., Engelkamp & Dehn, 2000), the bizarreness effect (bizarre images or sentences vs. common ones; e.g., McDaniel, Einstein, DeLosh, May, & Brady, 1995; McDaniel, DeLosh, & Merritt, 2000), the perceptual interference task (partially masked vs. unmasked items; e.g., Mulligan, 1999), and the word frequency effect (infrequent vs. common words; e.g., DeLosh & McDaniel, 1996). Recently, we observed this same pattern in the production effect, which involves reading words aloud versus silently (Jonker, Levene, & MacLeod, 2014): In pure lists, participants better reconstructed the order of words read silently relative to words read aloud, whereas in mixed lists, order reconstruction of silent and aloud words did not differ and was poor relative to memory for order of pure lists of silently read words. This suggests that in pure lists, participants encode relatively more item-specific information for aloud items and relatively more relational information for silent items.

In their article, McDaniel and Bugg (2008) speculated on what impairs encoding of relational and order information: "Less typical presentation formats or stimuli [e.g., generation, reading aloud, bizarre items] attract or require attention for individual item processing and reduce encoding of order information" (p. 240). This statement has two implications: (a) The typicality of the task is important, such that uncommon tasks will impair memory for order, and (b) decreased encoding of order information is a by-product of attention to item-specific processing. Although McDaniel and Bugg make clear statements about the conditions that should result in poor memory for order (unusual stimuli or presentation formats, item-specific processing), to our knowledge, these have not been systematically examined. Therefore, in this article, we present a series of experiments that investigated the factors that impair memory for order. In our first experiment, we explored whether the semantic richness of the encoding task determines the degree of impairment to memory for order. In our second experiment, we investigated whether item-specific processing is necessary for the impairment of order memory. In our third experiment, we examined whether attention-grabbing tasks must occur during stimulus presentation or whether their presence between items is sufficient to impair memory for order. Finally, in our fourth experiment, we determined whether encoding that encourages relational processing can preserve memory for order even when that encoding is relatively unusual and requires an overt response. Collectively, these experiments were designed to evaluate the role that item-specific processing and attentional demand play in impairing memory for order.

Experiment 1

To better understand the influence of encoding tasks on memory for order, we first examined whether semantic elaboration impairs memory for order. McDaniel and Bugg (2008) have argued that elaborative processing enhances item information at the cost of relational information (i.e., order); however, it is unclear which types of elaboration impair memory for order. The purpose of Experiment 1 was to determine whether item-specific elaboration must be semantic in nature to impair memory for order. For some of the known design effects, the uncommon encoding process is plausibly semantic. For example, the generation effect typically involves word-stem completion from some sort of cue. This cue can be semantic in nature, as is the case for antonym generation (e.g., *good–b__*). The enactment effect might also involve deeper semantic processing for the enacted items because participants might activate more of the semantic features of the sentences when they have to act them out themselves. Furthermore, in the case of the bizarreness effect, bizarre stimuli might result in more extensive semantic processing because of the unusual relations among the features of the stimuli.

In Experiment 1, therefore, we examined whether the common thread underlying impaired memory for order is semantic elaboration. To accomplish this, we compared memory for order for pure lists in which participants made a semantic judgment ("Is this a living thing?") with memory for order for pure lists in which participants made an orthographic judgment ("Does this word have an 'o' in it?"). If semantic elaboration impairs the encoding of order information, then a manipulation encouraging semantic elaboration should result in poorer memory for order than a manipulation encouraging orthographic elaboration. Alternatively, it is possible that any sort of item-specific processing impairs the encoding of order information. If this is the case, then any manipulation involving an item-specific judgment—whether semantic or orthographic—should result in poor memory for order.

Method

Participants. Twenty-six students from the University of Waterloo (five men, 21 women) with an average age of 19.8 years participated in exchange for partial course credit. Participants were eligible for the study only if they reported fluency in written and spoken English, normal or corrected-to-normal vision, and normal color vision.

Materials and procedure. Two hundred seventy-six common nouns with word frequency scores lower than 500 were selected from the MRC Psycholinguistic Database (Coltheart, 1981). From this set of words, we constructed 24 lists of eight words each. Words were randomly selected for each participant and were not repeated across lists. Twelve lists were assigned to be pure lists, with four lists in each of the three encoding conditions: semantic judgment, orthographic judgment, and silent reading. The remaining 12 lists were mixed lists. Each mixed list involved two of the three processing types (semantic, orthographic, silent reading), with four words of the eight words randomly assigned to each of the two processing types. There were four of each type of mixed list (semantic–orthographic, semantic–read, orthographic–read). In the experiments in this article, we are primarily interested in the results from the pure lists, but we included mixed lists to ensure that our new encoding conditions were not resulting in relatively poor relational memory irrespective of list type (i.e., mixed or pure). If there were significant differences in memory for order in the mixed lists, this would suggest that our new encoding manipulations were not functioning in the same way as other design effects (i.e., in mixed lists, memory for order for elaborated items should be equivalent to that for silent reading).

Participants completed 24 blocks of study and test. Each block began with a study list in which eight words were presented individually, each for 2 s at the center of a computer monitor and with a 500-ms interstimulus interval. Participants were instructed to silently read blue words, to say "yes" or "no" to the question "Does this word have an 'o' in it?" for white words and to say "yes" or "no" to the question "Is this a living thing?" for red words. After studying the eight items, participants completed a 30-s distractor task, during which they saw a random series of single digits (1–9). They were to indicate with a keypress whether each digit was odd or even. The distractor trials were self-paced and continued until 30 s had passed.

During the test phase, the eight study items were presented on the screen in a scrambled order in a vertical list; all were presented in black font on a white background. Participants were to write the words on a sheet of paper in the order that they remembered them having appeared during study. Participants had as much time as they needed to reconstruct the studied order of the words.

Prior to the 24 experimental blocks, participants familiarized themselves with the tasks in a single practice block. All three encoding conditions (semantic, orthographic, read silently) were presented during this practice block.

Results and Discussion

As in previous work (e.g., Jonker et al., 2014; Nairne et al., 1991), we used a strict scoring criterion: Items were scored as correctly ordered only if they were written in their exact serial position. For example, if *muffin* was studied in Serial Position 3, it was scored correct only when placed on the third line of the test sheet. Although this scoring method ignored the relative accuracy of placing *muffin* in Position 4 as opposed to Position 8, we were interested only in the differences across lists and all lists were scored in the same way. Accuracy was scored as the proportion of items correctly ordered. For mixed lists, the proportions were computed separately for each encoding condition. Thus, for a mixed list containing semantic and orthographic encoding conditions, semantic items would be scored out of a total of 4, as would orthographic items.

A 2 × 3 repeated-measures analysis of variance (ANOVA) assessed the effects of list type (mixed, pure) and encoding condition (semantic judgment, orthographic judgment, read silently) on the proportion of items correctly ordered. There were significant main effects both of list type, $F(1, 25) = 28.48$, mean square error (MSE) = .01, $p < .001$, $\eta_p^2 = .53$, and of encoding condition, $F(2, 50) = 17.49$, $MSE = 0.01$, $p < .001$, $\eta_p^2 = .41$, but their interaction was not significant, $F(2, 50) = 2.20$, $MSE = 0.02$, $p =$ .12. The means for each item type are shown in Figure 1.

In the present experiments, we were primarily interested in the differences in order reconstruction accuracy from the pure lists because these lists are relevant to McDaniel and Bugg's (2008) propositions regarding memory for order. However, we also present the results of two other analyses to give a complete picture of

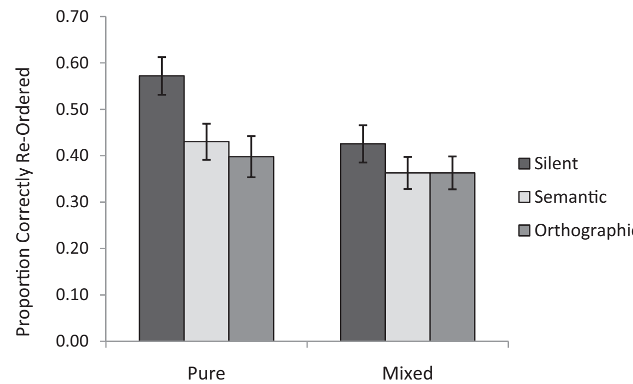

Figure 1. Experiment 1: Proportion of items correctly assigned to their studied positions on the order reconstruction test. Error bars represent 1 standard error of the mean.

the data. The first is an analysis of the order reconstruction scores from the mixed lists. According to McDaniel and Bugg's account, memory for order following different types of encoding operations should not differ, because the presence of unusual encoding (e.g., making a semantic judgment) even among silently read items disrupts item-to-item associative encoding. Therefore, we expected that memory for order would not differ following various encoding operations in mixed lists. The second analysis is an examination of differences in pure lists across serial positions. This analysis allowed us to determine whether encoding tasks affect memory for order only at certain positions in the list (e.g., primacy, asymptote, recency). This type of analysis has been performed in prior work (e.g., Nairne et al., 1991) and has demonstrated that memory for order for different types of encoding tasks is consistent across all serial positions (with the exception of the first position in some cases, possibly due to a ceiling effect). Therefore, including an analysis of serial position provided the opportunity to replicate the findings from previous work.

A one-way repeated-measures ANOVA assessed the effect of encoding condition on order reconstruction accuracy for mixed lists only. The effect of encoding condition in mixed lists was marginally significant, $F(2, 50) = 2.80$, $MSE = 0.01$, $p = .07$. Although in mixed lists, silent reading led to slightly better memory for order relative to semantic encoding, $t(25) = 1.92$, $SE = 0.03$, $p = .07$, and orthographic encoding, $t(25) = 2.09$, $SE = 0.03$, $p = .05$, this finding was not replicated in any of the subsequent experiments; in particular, it was not replicated in Experiment 4, which used similar encoding conditions.

Of principal interest were the pure lists. A 3 × 8 repeated-measures ANOVA assessed the effect of encoding condition and serial position on order reconstruction accuracy for pure lists. The main effects of list, $F(2, 50) = 11.11$, $MSE = 0.16$, $p < .001$, $\eta_p^2 = .31$, and serial position, $F(7, 175) = 23.89$, $MSE = 0.04$, $p < .001$, $\eta_p^2 = .49$, were both significant, but the interaction was not, $F(14, 350) = 0.50$, $MSE = 0.05$, $p = .93$, demonstrating that differences between pure lists are consistent across all serial positions, as has been found previously (e.g., Nairne et al., 1991). These results are displayed in Figure 2. Follow-up analyses collapsing across serial position revealed that memory for order for read items was better than that for

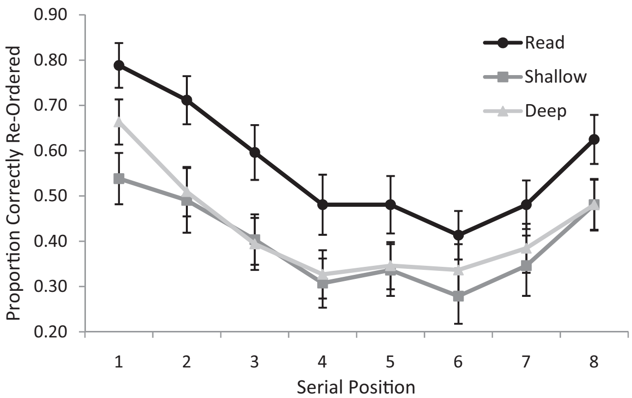

Figure 2. Experiment 1: Proportion of items correctly assigned to their studied positions on the order reconstruction test as a function of serial position. Error bars represent 1 standard error of the mean.

orthographic items, $t(25) = 5.32$, $SE = 0.03$, $p < .001$, $d = 1.04$, and for semantic items, $t(25) = 3.50$, $SE = 0.04$, $p = .002$, $d = 0.69$. Memory for order for orthographic and semantic items did not differ, $t(25) = 0.74$, $SE = 0.04$, $p = .47$. Thus, memory for order was poorer following both semantic and orthographic elaboration in pure lists than following silent reading, indicating that the encoding task does not have to involve semantic elaboration to impair memory for order. Instead, relative to silently reading items, both types of item-specific processing—semantic and nonsemantic—impaired memory for order equivalently.

Experiment 2

Experiment 1 demonstrated that both semantic and orthographic encoding can impair memory for order and that they can do so equivalently. A key feature of the semantic task ("Is this a living thing?") and of the orthographic task ("Does this word have an 'o' in it?") is that they both involve item-specific processing: The response that is made in these tasks depends on the unique features (semantic or orthographic) of the particular word presented on that trial. McDaniel and Bugg (2008) theorized that it is this item-specific processing that is critical for impairing order memory because the encoding of item information distracts attention from encoding relational information. Therefore, we were interested in whether item-specific processing is indeed necessary for impairing memory for order or whether any type of processing task—even one that is not item specific—would impair memory for order. Some work suggests that enhancing item-specific information is not necessary for disrupting memory for order. For example, Mulligan (2002) found that generating nonwords did not result in better recognition performance relative to simply reading nonwords, suggesting that item-specific information was not enhanced for generated nonwords, but that order memory for these generated nonwords was poorer than that for read nonwords, suggesting that memory for order can be disrupted by an item-specific processing task (i.e., generation) in the absence of enhanced item-specific information (see also Mulligan, 2001).

To date, encoding tasks that disrupt memory for order have involved both item-specific processing and an overt response. Thus, memory for order might be disrupted by (a) item-specific processing or (b) making a response. If making a response alone disrupts memory for order, then it would not matter whether that response is item specific or item generic (i.e., not contingent on the unique features of the presented item). Therefore, in Experiment 2, we included an encoding task that required a response but not an item-specific response; the task involved a generic keypress. The response to be made in this task did not differ on the basis of the unique features of each word: Irrespective of the word, participants were to press the *Enter* key. Previous work has demonstrated that a generic keypress or saying "yes" when a word appeared resulted in no memorial benefit relative to simply reading the word silently (MacLeod, Gopie, Hourihan, Neary, & Ozubko, 2010, Experiment 4), lending support to our claim that a generic keypress does not enhance item-specific information.

If item-specific processing is necessary to impair memory for order, then memory for order for the keypress words should be similar to that for the silent reading condition because a button press is not item specific. Alternatively, if making any sort of overt response—whether item-specific or generic—impairs memory for order, then order reconstruction performance for button press lists should be poorer than for silently read lists.

Method

Participants. Twenty-eight students from the University of Waterloo (seven men, 21 women) with an average age of 20.7 years participated in exchange for partial course credit. Participants were eligible for the study only if they reported fluency in written and spoken English, normal or corrected-to-normal vision, and normal color vision.

Materials and procedure. The materials and procedure were nearly identical to those of Experiment 1, with one main difference: Rather than reading silently, making semantic judgments, or making orthographic judgments during the study task, participants read words silently (in yellow), read words aloud (in blue), or read words silently and pressed the *Enter* key (in red). The button press condition was selected because it required an overt response, but the response was not specific to the unique features of the individual word (cf. MacLeod et al., 2010, Experiment 4). Therefore, the addition of this condition allowed us to test the importance of making an item-specific versus item-generic response. Order reconstruction performance was assessed as in Experiment 1.

Results and Discussion

A 2 × 3 repeated-measures ANOVA assessed the effects of list type (mixed, pure) and encoding condition (read silently, read aloud, button press) on the proportion of items correctly ordered. The main effects of list type, $F(1, 27) = 14.46$, $MSE = 0.02$, $p = .001$, $\eta_p^2 = .35$, and of encoding condition, $F(2, 54) = 3.39$, $MSE = 0.02$, $p = .04$, $\eta_p^2 = .11$, were both significant, and their interaction was also significant, $F(2, 54) = 10.92$, $MSE = 0.01$, $p < .001$, $\eta_p^2 = .29$. The means for each item type are shown in Figure 3. A one-way repeated-measures ANOVA assessing the effect of encoding condition on order reconstruction accuracy for the mixed lists revealed no effect of list type, $F(1.57,42.45) = 1.85$, $MSE = 0.01$, $p = .18$.[1]

Of main interest were the differences in memory for order of the pure lists. A 3 × 8 repeated-measures ANOVA assessed the effects of encoding condition and serial position on order reconstruction accuracy for pure lists. The main effects of encoding condition, $F(2, 54) = 8.53$, $MSE = 0.18$, $p = .001$, $\eta_p^2 = .24$, and serial position, $F(3.99,107.66) = 24.50$, $MSE = 0.11$, $p < .001$, $\eta_p^2 = .48$, were both significant, but the interaction was not, $F(7.67, 207.02) = 1.19$, $MSE = 0.08$, $p = .31$, demonstrating that differences in memory for order between lists were consistent across all serial positions.[2] These data are shown in Figure 4. Follow-up analyses revealed that memory for order was better for lists read silently than for lists read aloud, $t(27) = 3.67$, $SE = 0.04$, $p = .001$, $d = 0.69$, replicating our previous work (Jonker et al., 2014). Furthermore, memory for order was also better for lists read silently than for button press lists, $t(27) = 3.57$, $SE = 0.04$, $p = .001$, $d = 0.68$; memory for order for the aloud lists and for the button press lists did not differ, $t(27) = 0.38$, $SE = 0.04$, $p = .71$. Thus, memory for order was poorer following both reading aloud and making a button press compared with memory for order following silent reading. These findings indicate that the encoding task does not have to be specific to the unique features of the presented word to impair memory for order. Instead, even performing an item-generic task during study can impair the ability to reconstruct order on a test.

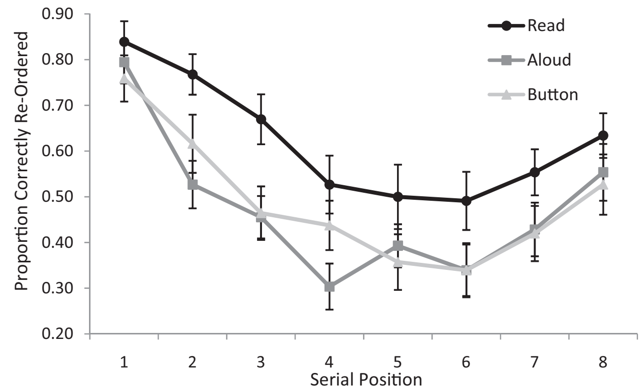

Figure 4. Experiment 2: Proportion of items correctly assigned to their studied positions on the order reconstruction test as a function of serial position. Error bars represent 1 standard error of the mean.

Experiment 3

The results of Experiment 2 raise an important issue regarding differences between silently read items and items accompanied by some sort of additional task: Additional tasks require a response, which necessitates the redirection of attention and absorbs processing time. Thus, even if the task does not entail any additional item-specific information (e.g., button press), executing the response directs attention away from relational encoding. Indeed, this possibility was suggested by McDaniel and Bugg (2008): They proposed that "unusual or uncommon items attract focus to the individual item, thereby distracting the learner from encoding the order in which the items are presented" (McDaniel & Bugg, 2008, p. 239). If poor memory for order is simply a matter of redirecting attention and thereby reducing time for relational encoding, then any type of additional processing during the presentation of an item should reduce relational encoding and result in impaired memory for order; furthermore, any additional processing between the presentations of items should not divert processing away from an item and consequently should not disrupt memory for order. Alternatively, it is possible that an additional task prevents interitem associations even if it occurs between items because it disrupts the flow from one item to the next, possibly disturbing item-to-item rehearsals. If this were the case, the inclusion of an additional task in a list would result in poorer memory for order irrespective of whether that task was performed during the presentations of items or between them.

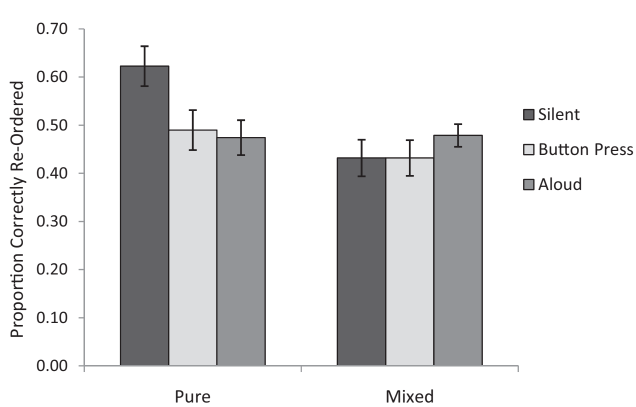

Figure 3. Experiment 2: Proportion of items correctly assigned to their studied positions on an order reconstruction test. Error bars represent 1 standard error of the mean.

To test these two possibilities, we replicated the button press condition from Experiment 2 in which participants made a button press during items and added an additional manipulation in which participants made a button press between items. If disruption of item processing time impairs memory for order, then performing a button press between items should not result in poor memory for order; however, if uninterrupted flow from item to item is important, then performing a button press between items should disrupt memory for order, similar to the cost observed for a button press during the processing of the item.

Method

Participants. Forty students from the University of Waterloo (nine men, 31 women) with an average age of 19.3 years participated in exchange for partial course credit. Participants were eligible for the study only if they reported fluency in written and spoken English, normal or corrected-to-normal vision, and normal color vision.

[1] Mauchley's test of sphericity revealed that the assumption of homogeneity was violated for this analysis, $\chi^2(2) = 8.53$, $p = .01$. Therefore, the Greenhouse–Geisser correction for degrees of freedom was used.

[2] Mauchley's test of sphericity revealed that the assumption of homogeneity was violated for the serial position analysis, $\chi^2(27) = 53.65$, $p = .002$, and the interaction analysis, $\chi^2(104) = 153.93$, $p = .002$. Therefore, the Greenhouse–Geisser correction for degrees of freedom was used.

Materials and procedure. The materials and procedure were nearly identical to those of Experiment 2, but some of the pure silent and pure button press lists included an additional task. These lists each had six asterisks, which were randomly assigned to appear in red between words, and participants were instructed to press the *Enter* key whenever they saw an asterisk (see Figure 5). The asterisk disappeared once they pressed *Enter*. Asterisks were randomly assigned to the lists and repetitions of asterisks were not disallowed; therefore, sometimes two asterisks would appear sequentially between a pair of items (see Trials 5 and 6 of Figure 5).

As in the previous experiments, there were 24 lists with list distribution as follows: four pure read, four pure button press, four pure read with asterisks, two pure button press with asterisks, four pure aloud, six mixed lists (no asterisks). Each mixed list involved two of the three types of encoding manipulations (read silently, button press, read aloud). This distribution of lists allowed us to (a) replicate the findings from Experiment 2 and (b) examine memory for order for pure read lists and pure read lists with asterisks. Two button press lists with asterisks were included so that the asterisk manipulation was not exclusive to the read lists.

Results and Discussion

Two omnibus ANOVAs were conducted. The first was a 2 × 3 repeated-measures ANOVA that assessed the effects of list type (mixed, pure) and encoding condition (read silently, read aloud, button press; lists with asterisks were not included in this analysis) on the proportion of items correctly ordered, essentially assessing whether the effects from Experiment 2 were replicated. As in Experiment 2, the main effects of list type, $F(1, 39) = 6.99$, $MSE = 0.02$, $p = .01$, $\eta_p^2 = .15$, and of encoding condition, $F(2, 78) = 5.58$, $MSE = 0.02$, $p = .005$, $\eta_p^2 = .13$, were both significant, and their interaction was also significant, $F(2, 78) = 5.46$, $MSE = 0.02$, $p = .006$, $\eta_p^2 = .12$. To follow up on these effects, a one-way repeated-measures ANOVA assessed the effect of encoding condition on order reconstruction accuracy for the mixed list; it revealed no effect of list type, $F(2, 78) = 1.44$, $MSE = 0.03$, $p = .24$. The means for each item type are displayed in Figure 6.

As previously, our primary interest was in the pure lists. Therefore, a 3 × 8 repeated-measures ANOVA assessed the effect of encoding condition and serial position on order reconstruction accuracy for the read silently, read aloud, and button press pure lists. The effects of encoding condition, $F(2, 78) = 10.66$, $MSE = 0.02$, $p < .001$, $\eta_p^2 = .22$, and serial position, $F(3.60, 140.57) = 22.23$, $MSE = 0.12$, $p < .001$, $\eta_p^2 = .36$, were significant, and, unlike in previous experiments, the interaction was also significant, $F(9.09, 354.39) = 3.11$, $MSE = 0.07$, $p = .001$, $\eta_p^2 = .07$.[3] Visual inspection of the serial position curves in Figure 7 reveals that order reconstruction scores for aloud items increased dramatically at later serial positions. Although a significant interaction was not found in Experiment 2, a similar (although attenuated) pattern can be observed in Figure 4. This pattern was somewhat unexpected but is not without precedent in the literature. Immediate serial recall of lists of digits often yields a more pronounced recency effect for lists that were read aloud relative to lists read silently (Conrad & Hull, 1968; Crowder, 1970); this effect has also been observed when recall follows a retention interval (e.g., Watkins & Watkins, 1980). Thus, this pattern suggests that, relative to nonarticulatory encoding, articulatory encoding might enhance the recency effect even for a test of order reconstruction.

Follow-up analyses of these pure lists revealed that when collapsing across all serial positions, memory for order for silently read items was better than that for items read aloud, $t(39) = 4.73$, $SE = 0.03$, $p < .001$, $d = 0.75$, and was marginally better than that for button press items, $t(39) = 1.79$, $SE = 0.03$, $p = .08$, $d = 0.28$. Furthermore, memory for order for button press items was better than that for items read aloud, $t(39) = 2.95$, $SE = 0.03$, $p = .005$. The first two findings replicate those of Experiment 2; however, the finding that memory for order for button press items was better than for items read aloud was novel.

This novel finding may have emerged because the button press condition takes less time (and/or is easier) than reading aloud, leaving more time for relational encoding. However, we could not assess this possibility because response latencies were not recorded during encoding, and it is unclear why we did not obtain a similar effect in Experiment 2. Another possible explanation is that the inclusion of the asterisk manipulation led to increased practice with button pressing, making the task less demanding; this would not be the case for the read aloud condition. This seems plausible because participants in Experiment 3 made more button presses over the course of the experiment than did those in Experiment 2,

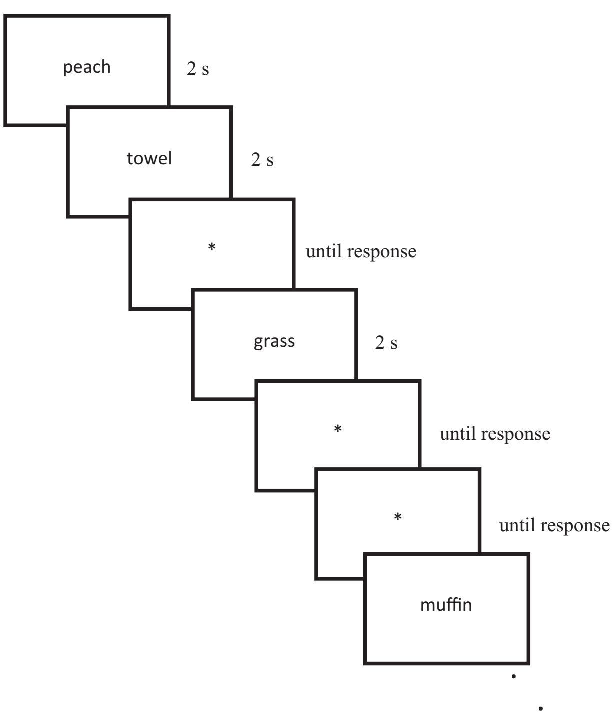

Figure 5. Example of a list with asterisks between the presentations of individual words. Each asterisk remained on the screen until the participant pressed *Enter*.

[3] Mauchley's test of sphericity revealed that the assumption of homogeneity was violated for the serial position analysis, $\chi^2(27) = 106.62$, $p < .001$, and the interaction analysis, $\chi^2(104) = 133.89$, $p = .03$. Therefore, the Greenhouse–Geisser correction for degrees of freedom was used.

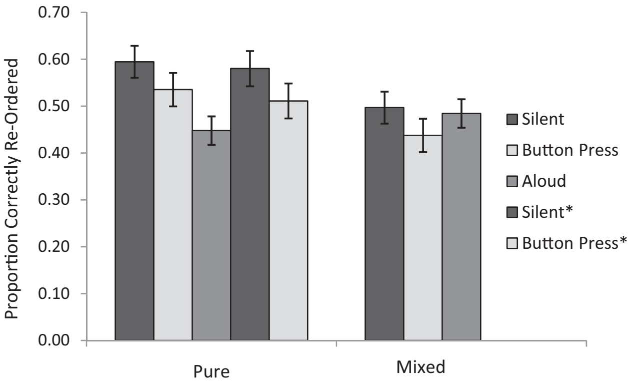

Figure 6. Experiment 3: Proportion of items correctly assigned to their studied positions on an order reconstruction test. Error bars represent 1 standard error. There were five types of pure lists. The first three were identical to those of Experiment 2: silent reading, button pressing, and reading aloud. The fourth list type—silent*—refers to silently read lists that contained asterisks between items. Similarly, the fifth list type—button press*—refers to lists that contained a generic button press both during item presentation and between item presentation using the asterisk stimulus.

whereas the read aloud condition did not change. If the button press task became easier or more fluent over the course of the experiment, then participants might have had more time to devote to encoding relations.

To examine the effect of silent reading versus button pressing with more power, as well as to incorporate the asterisk manipulation, we performed a 2 × 2 repeated-measures ANOVA to assess the effects of encoding condition (read silently, button press) and the presence of asterisks (asterisks, no asterisks) on the proportion of items correctly ordered. Here, we replicated the button press effect: Participants better reconstructed the order of silently read lists relative to button press lists, $F(1, 39) = 6.96$, $MSE = 0.02$, $p = .01$, $\eta_p^2 = .15$. There was, however, no main effect of asterisk presence versus absence, $F(1, 39) = 0.59$, $MSE = 0.03$, $p = .45$, and no significant interaction, $F(1, 39) = 0.04$, $MSE = 0.02$, $p = .85$. Thus, for pure lists of silently read items, memory for order without intervening asterisks did not differ significantly from that with intervening asterisks, $t(39) = 0.46$, $SE = 0.03$, $p = .65$.

These results replicated the pattern of Experiment 2 and extended the findings by demonstrating that including a button press manipulation between words did not impair memory for order, whereas a button press during words did. Thus, these findings suggest that various processing tasks might impair memory for order because they disrupt processing, using up some of the time that would otherwise be devoted to encoding order information, but these findings rule out the possibility that these encoding tasks simply disrupt the overall flow of the list.

It is worth acknowledging that we cannot and do not claim that the null hypothesis is true in this case; more specifically, we cannot state that including a task between the stimulus presentations has no effect on memory because our test might not have been sensitive to the effect of an intervening task on relational memory. However, the purpose of Experiment 3 was to determine whether impaired order memory was due solely to the presence of any processing task in a list. If the mere presence of an additional processing task impaired memory for order, then order memory should have been poor following button presses whether during or between words. Instead, we found impaired memory only when button presses were made during words, suggesting that impairment to relational memory is due primarily to disruption caused by processing carried out during stimulus presentation.

Experiment 4

At this point, all types of processing that require an overt response have impaired memory for order (i.e., reading aloud, semantic judgment, orthographic judgment, button press), as long as the processing occurred during the presentation of the word. In fact, it did not matter whether the response was item-specific or item-generic; having to produce a response consistently disrupted memory for order. This raises an important issue: Does a response task impair memory for order because making an overt response is disruptive in and of itself, or does it impair memory because a processing task takes time away from relational encoding?

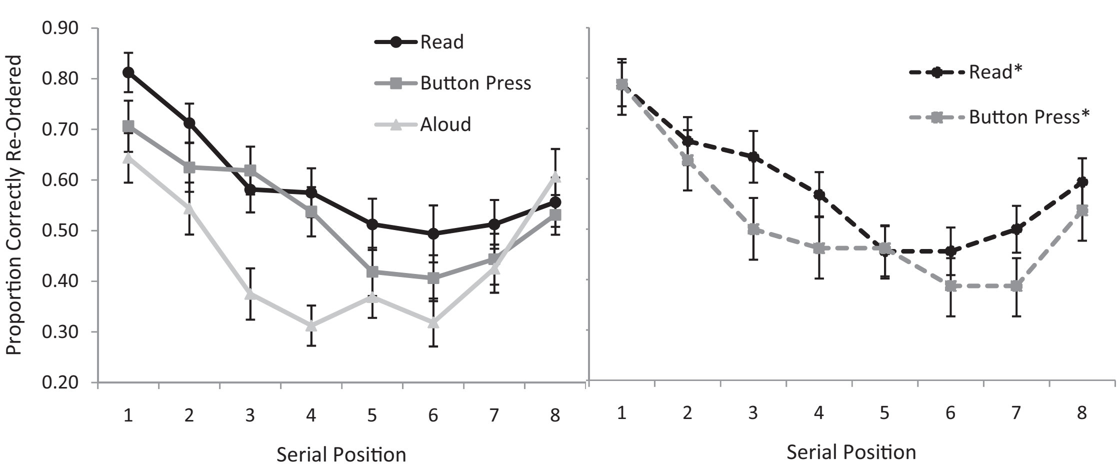

Figure 7. Experiment 3: Proportion of items correctly assigned to their studied positions on the order reconstruction test as a function of serial position. Error bars represent 1 standard error of the mean.

In our final experiment, we included an encoding task that required an overt response but that encouraged relational encoding. This task prompted participants to compare the current word with the previous word (“Is this object larger or smaller than the previous object?”); we labeled this the *relational semantic judgment*. This was contrasted with a task that required participants to compare the present word with a constant (“Is this item larger or smaller than the average chair?”); we labeled this the *independent semantic judgment*. In both cases, the participant had to make an overt response, but the former case encourages relational processing, whereas the latter case encourages item-specific processing.

If relational encoding benefits memory for order, then there should be no difference in memory for order between the items that were read silently and the items for which participants made a relational semantic judgment. If, however, any sort of overt response to a word—relational or otherwise—impairs memory for order, then there should be no difference between items for which participants made a relational semantic judgment versus an independent semantic judgment.

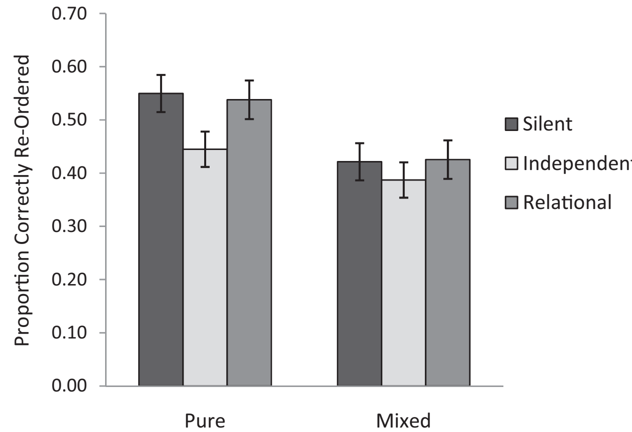

Figure 8. Experiment 4: Proportion of items correctly assigned to their studied positions on an order reconstruction test. Error bars represent 1 standard error.

Method

Participants. Thirty-one students from the University of Waterloo (16 men, 15 women) with an average age of 19.8 years participated in exchange for partial course credit. Participants were eligible for the study only if they reported fluency in written and spoken English, normal or corrected-to-normal vision, and normal color vision.

Materials and procedure. The materials and procedure were nearly identical to those of Experiment 1. The main difference was the encoding tasks, which involved reading silently (blue), making an independent semantic judgment (“Is this object larger or smaller than the average chair?” white), or making a relational semantic judgment (“Is this object larger or smaller than the previous object?” red). Of the 24 lists, there were six of each type of pure list and two of each type of mixed list (read–independent, read–relational, independent–relational).

Results and Discussion

A 2 × 3 repeated-measures ANOVA assessed the effects of list type (mixed, pure) and encoding condition (read, independent, relational) on the proportion of items correctly ordered. Both main effects were significant, $F(1, 30) = 22.86$, $MSE = 0.02$, $p < .001$, $\eta_p^2 = .43$, and $F(2, 60) = 5.42$, $MSE = 0.02$, $p = .007$, $\eta_p^2 = .15$, respectively, and their interaction was marginally significant, $F(2, 60) = 1.60$, $MSE = 0.01$, $p = .05$. For the mixed lists, a one-way repeated-measures ANOVA assessing the effect of encoding condition on order reconstruction accuracy revealed no effect of list type, $F(2, 60) = 0.94$, $MSE = 0.01$, $p = .40$. The means for each item type are shown in Figure 8.

As previously, our main interest was in the differences in memory for order for the pure lists. A 3 × 8 repeated-measures ANOVA assessed the effect of encoding condition and serial position on order reconstruction accuracy for the pure lists. There were significant main effects of encoding condition, $F(2, 60) = 6.25$, $MSE = 0.13$, $p = .003$, $\eta_p^2 = .17$, and of serial position, $F(3.49, 104.66) = 35.88$, $MSE = 0.08$, $p < .001$, $\eta_p^2 = .55$[4], but the interaction was not significant, $F(8.45, 253.58) = 1.54$, $MSE = 0.05$, $p = .14$ (see footnote 3).[4] These data are shown in Figure 9. Replicating Experiment 1, memory for order was better for silently read items than for independently judged items, $t(30) = 3.48$, $SE = 0.03$, $p = .002$, $d = 0.63$. As a novel extension, we found that memory for order for relationally judged items was better than that for independently judged items, $t(30) = 3.18$, $SE = 0.03$, $p = .003$, $d = 0.57$, and that memory for order for relationally judged items did not differ significantly from that for silently read items, $t(30) = 0.33$, $SE = 0.04$, $p = .75$. Memory for order was poorer following an independent semantic judgment, but memory for order was equally good following both silent reading and a relational semantic judgment. Therefore, an encoding task that encourages relational processing will preserve memory for order, even though this task requires an overt response.

General Discussion

This set of experiments demonstrates four things about memory for order: (a) A task does not have to be semantic in nature to impair memory for order because both semantic and orthographic tasks resulted in relatively poor order memory when they were performed on individual items; (b) item-specific processing is not necessary for impairment because even an item-generic task, such as a keypress, resulted in relatively poor memory for order; (c) distraction and/or reduced processing time during the presentation of an item rather than between items is primarily responsible for the cost to order memory because only a task during items impaired memory for order; and (d) a task that encourages the encoding of item-to-item relations will preserve memory for order because a relational task that involved an overt response and uncommon processing still yielded strong memory for order.

These findings further delineate the parameters of the item-order account and shed light on the mechanisms underlying memory for order. One of our key findings was that processing does not have

[4] Mauchley’s test of sphericity revealed that the assumption of homogeneity was violated for the serial position analysis, $\chi^2(27) = 53.65$, $p = .002$, and the interaction analysis, $\chi^2(104) = 153.93$, $p = .002$. Therefore, the Greenhouse–Geisser correction for degrees of freedom was used.

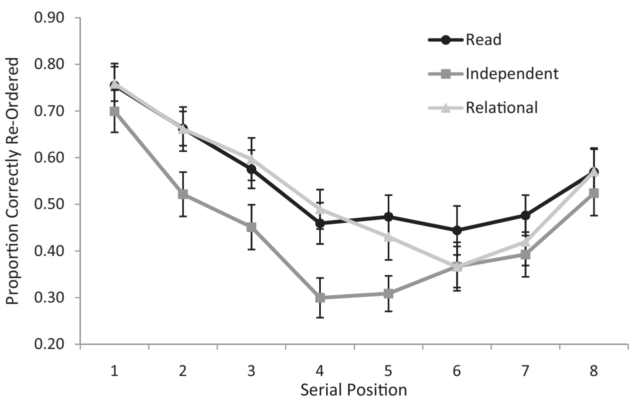

Figure 9. Experiment 4: Proportion of items correctly assigned to their studied positions on the order reconstruction test as a function of serial position. Error bars represent 1 standard error of the mean.

to be item specific to disrupt memory for order. In Experiments 2 and 3, a generic keypress disrupted order memory even though this task was not based on the unique features of the presented word. This indicates that having to make a response—irrespective of whether that response is item specific—has a negative impact on memory for order. This result was not predicted by McDaniel and Bugg's (2008) item-order account. According to their account, relational processing is disrupted when the encoding task encourages item-specific elaboration. However, our item-generic keypress condition did not involve item-specific processing (cf. MacLeod et al., 2010), and yet it impaired memory for order. Although our processing tasks were found to negatively impact memory for order, the type of encoding task did not seem to matter in our experiments because memory for order was more or less equally poor following semantic processing, articulatory processing (reading aloud), orthographic processing, and item-generic processing.

The only case where a processing task did not disrupt memory for order was the case of relational encoding in Experiment 4: When participants were encouraged to relate the current word to the previous word by judging their relative sizes, memory for order was relatively preserved. In fact, order reconstruction performance following a relational judgment was equivalent to that following silent reading. This suggests that whereas engaging in a task during the time-limited presentation of an item reduces the amount of time that can be devoted to encoding relations, a task that encourages relational encoding will not impair memory for order. It might be the case that memory for order is entirely a function of the amount of time devoted to relational encoding. More specifically, one might be able to predict memory for order by subtracting the amount of time required to perform the nonrelational processing task from the total item presentation time. We were not able to test this possibility in our experiments because response times were not recorded in all cases and, further, because many of our processing tasks took similar amounts of time to complete, suggesting that we might not have a sufficient range of times. This would, however, be a worthwhile avenue for future research.

To further specify the conditions that disrupt memory for order, we examined whether engaging in a task between the presentations of successive items would reduce memory for order. By having participants press a key in response to an asterisk between items, we required participants to engage in a nonrelational task but one that did not occur during the presentation of the words and therefore did not require diverting processing time to the nonrelational task. This manipulation did not significantly impact memory for order, suggesting that memory for order is impaired only in cases in which some of the word processing time must be devoted to a nonrelational task.

Our work also addresses the issue of the typicality of the encoding task. McDaniel and Bugg (2008) postulated that unusual or uncommon presentation formats or stimuli attract attention, which results in impoverished relational encoding. In the majority of circumstances, this may be true. However, in Experiment 4, we demonstrated that atypical encoding does not necessarily lead to poor memory for order; instead, an encoding task that is unusual or uncommon but that emphasizes relational encoding can preserve memory for order. In fact, in this situation, memory for order for relationally encoded words did not differ from memory for order for silently read words. It may be best, then, to think of atypical encoding tasks as ordinarily emphasizing item information over relational information but to recognize that this is not true of all atypical encoding tasks.

It is worth noting at this point that we observed no differences in memory for order for the mixed lists, apart from a small effect in favor of silent items from mixed lists seen only in Experiment 1 and not subsequently replicated. At face value, the lack of differences in mixed lists is consistent with McDaniel and Bugg's (2008) item-order account. According to their account, memory for order will be disrupted in any lists that feature item-specific processing because the presence of such elaborative processing will reduce relational encoding. In all cases of mixed lists, memory for order was impaired relative to memory for order for pure lists of silently read items, and memory reconstruction scores for mixed lists were approximately equivalent to reconstruction scores for pure lists involving a processing task (e.g., pure aloud lists). This suggests that engaging in a nonrelational processing task disrupts relational encoding because the participant cannot devote as much of his or her time to relational encoding. However, it is interesting to note the special case of the read–relational mixed list from Experiment 4. The read–relational mixed list contains two types of processing, both of which have been found to produce relatively good memory for order when performed in pure lists in our work. Thus, if memory for order is entirely a function of relational encoding, then it would be reasonable to expect that order reconstruction performance for the read–relational mixed list would be equivalent to performance for pure read and pure relational lists. This was not the case: Order reconstruction performance for the read–relational mixed list did not differ from that for other lists (read–relational = .41, read–independent = .42, relational–independent = .40). This suggests that task switching might result in a cost to memory for order. Again, further research on this issue is needed before we can reach a strong conclusion.

Conclusion

With these findings, we suggest a modification to the understanding of order memory and the item-order account. Specifically, we propose that a stimulus or encoding process will disrupt order memory only when (a) it is attention grabbing (either through its atypicality or by requiring an overt response) and (b) it does not encourage relational encoding among list items. Thus, if a process is attention-grabbing but emphasizes relational encoding (e.g., the semantic relational encoding in Experiment 4), order memory will be preserved; similarly, if a process emphasizes item-specific encoding but is not attention grabbing (e.g., reading silently), order memory will be preserved, possibly because the participant will encode relations by default. This latter case raises an important point. Perhaps all that is important for memory for order is relational encoding, and any attention-grabbing factor during the encoding phase (either stimulus or task feature) tends to reduce the ability to encode relations among items unless the task itself encourages relational encoding. This would imply that attention is essential for the encoding of relational information.

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