Maintenance of Item and Order Information in Verbal Working Memory

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Abstract

Although verbal recall of item and order information is well-researched in short-term memory paradigms, there is relatively little research concerning item and order recall from working memory. The following study examined whether manipulating the opportunity for attentional refreshing and articulatory rehearsal in a complex span task differently affected the recall of item- and order-specific information of the memoranda. Five experiments varied the opportunity for articulatory rehearsal and attentional refreshing in a complex span task, but the type of recall was manipulated between experiments (item and order, order only, and item only recall). The results showed that impairing attentional refreshing and articulatory rehearsal similarly affected recall regardless of whether the scoring procedure (Experiment 1 and 4) or recall requirements (Experiments 2, 3, and 5) reflected item- or order-specific recall. This implies that both mechanisms sustain the maintenance of item and order information, and suggests that the common cumulative functioning of these two mechanisms to maintain items could be at the root of order maintenance.

Keywords: Working Memory, Serial Recall, Item and Order Recall, Refreshing, Rehearsal

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Maintenance of Item and Order Information in Verbal Working Memory

Working memory (WM) is the immediate memory system responsible for maintaining and manipulating information and events in the service of task-related goals. It is frequently tested using complex span tasks that interleave a distracting processing component (e.g., deciding the parity of a number) with memoranda (e.g., letters) that are to be recalled in the original order of presentation (i.e., serial recall). Accordingly, complex span tasks are among the many immediate memory tasks that require retrieval of both the specific items and their order. A great deal of research has concerned the underlying processes and mechanisms that support WM recall, particularly verbal WM (e.g., Baddeley, 1966; 1986; Barrouillet, Bernardin, & Camos, 2004). However, the distinction between item and order maintenance is rarely if ever mentioned in this literature. This contrasts strongly with the state of affairs in the related domain of short-term memory (STM). Numerous models of STM have tried to characterize how underlying mechanisms support recall of both the specific memoranda and their original serial order of presentation (e.g., Botvinick & Plaut, 2006; Brown, Preece, & Hulme, 2000; Brown, Neath, & Chater, 2007; Burgess & Hitch, 1999; Farrell & Lewandowsky, 2002; Henson, 1998; Majerus, 2009; Marshuetz, 2005; Page & Norris, 1998). The purpose of the following study was to explore how item and order information is maintained and recalled from verbal WM using complex span tasks, and how the maintenance mechanisms are differently involved in maintaining item and order information.

Many studies regarding verbal STM support the distinction between item and order information. Accordingly, a wide range of models of STM suggests different processes to account for item and order maintenance (e.g., Botvinick & Plaut, 2006; Brown, Preece, & Hulme, 2000; Brown, Neath, & Chater, 2007; Burgess & Hitch, 1999; Farrell & Lewandowsky, 2002; Henson, 1998; Majerus, 2009; Marshuetz, 2005; Page & Norris, 1998).

While most models propose that different maintenance mechanisms underlie either type of information (see Marshuetz, 2005, for a review), some models describe a single mechanism that supports the maintenance of item and order information. For example, the serial-order-in-a-box (SOB) model posits that items are encoded with decreasing strength across serial positions, and at retrieval, each recalled item is suppressed (Farrell & Lewandowsky, 2002, 2004). Order maintenance is thus a consequence of maintaining the items themselves, and the differentiation between mechanisms that support item and order maintenance is not relevant. Conversely, Majerus (2009) has argued that, though attention is involved in both item and order maintenance, some supplementary attentional network is specifically activated by the maintenance of order, and two brain networks supporting item and order information can be distinguished. The maintenance of item-specific information relies on the activation of long-term language knowledge and of a left-sided fronto-parietal network, which is related to attentional control processes. The order maintenance relies on the same fronto-parietal region than item maintenance, with some supplementary activation of the right-sided fronto-parietal network, which could indicate either a stronger involvement of attention or the implication of spatial attention. This distinction is evident from neuropsychological double dissociations that indicate preserved STM for item information but impaired order information and vice versa in different patients (e.g., Attout, Van der Kaa, George, & Majerus, 2012).

Contrary to models of STM, WM models have been less concerned with the distinction between item and order memory. Prominent models of WM (for reviews, Baddeley, 1986; Barrouillet & Camos, 2015; Cowan, 1999; Engle, 2002) do not focus on this question, most likely because research concerns other issues, such as the role of attention or the relationship between processing and storage. One central question regarding the maintenance of information distinguishes these models, with some models supporting that WM functioning relies on a general mechanism (as in Cowan or Engle’s models), whereas others posit that maintenance is domain-specific according to the stimuli to remember (e.g., visuo-spatial versus verbal; as in Baddeley’s model). For example, Cowan (1995, 1999) suggested that memoranda are maintained in WM through attentional focusing. This rapid and attention-based mechanism can be applied to any memoranda, regardless of domain-specific characteristics. Conversely, Baddeley's (1986) multi-component model emphasizes the specificity of the maintenance mechanisms, with verbal items being maintained by rehearsal in a phonological loop and visuo-spatial information in a visuo-spatial sketchpad. The time-based resource sharing (TBRS) model (Barrouillet & Camos, 2010, 2015; Barrouillet et al., 2004, 2007; Barrouillet, Portrat, & Camos, 2011) proposes a middle-ground, such that two types of maintenance mechanisms independently contribute to verbal information (Camos, 2015; Camos et al., 2009, 2011, 2013; Loaiza & McCabe, 2013; Mora & Camos, 2013). A domain-specific, phonological-based maintenance mechanism operates by covertly repeating memoranda in order to maintain them for recall. This articulatory rehearsal is the more traditionally studied mechanism, and its functioning is posited to be supported by a phonological loop in the WM system, like in Baddeley's multi-component model. Conversely, attentional refreshing is a domain-general, attention-based maintenance mechanism, thought to operate by prolonging or foregrounding the activation of a memorandum after attention has been distracted from its maintenance (Camos et al., 2009; Johnson, Reeder, Raye, & Mitchell, 2002; Raye et al., 2007, 2002).

Behavioral (Camos et al., 2009; 2011; 2013; Hudjetz & Oberauer, 2007; Loaiza & McCabe, 2013; Mora & Camos, 2013) and neuroimaging (Johnson et al., 2002; Gruber & von Cramon, 2003; Raye et al., 2007) data have shown that attentional refreshing and articulatory rehearsal are functionally distinct in maintaining verbal information (see Camos, 2015, for review). For example, factors that are considered to specifically affect the phonological representation of memoranda, such as the phonological similarity (Baddeley, 1966) or the length of the words (Baddeley et al., 1975), only influence WM recall when articulatory rehearsal is possible during the task. When rehearsal is constrained (e.g., by a concurrent articulation), the phonological similarity or length of the memoranda have no impact on recall (Camos et al., 2011, 2013; Mora & Camos, 2013). Conversely, impeding attention affects refreshing. The TBRS model proposes that processing and storage demands of a complex span task compete for a limited resource of attention. As a consequence, increasing the ratio during which attention is captured by a concurrent task (with respect to the total amount of time allowed to complete it) reduces the availability of refreshing and WM recall (Barrouillet et al., 2004; Camos et al., 2009). However, such a reduction of the availability of refreshing has no impact on the phonological similarity or word length effects (Camos et al., 2009, 2011, 2013; Mora & Camos, 2013). Importantly, the factors affecting the opportunity for rehearsal (e.g., a concurrent articulation) and refreshing (e.g., a concurrent task) do not interact, further supporting their independence (Camos et al., 2009; Hudjetz & Oberauer, 2007). This behavioral dissociation in recall is also supported by neurological evidence, such that articulatory rehearsal is associated with activity in the left ventrolateral prefrontal cortex (PFC; Raye et al., 2007), whereas attentional refreshing is associated with activity in the left dorsolateral PFC (Raye et al., 2002, 2007). Thus, there has been a growing body of converging evidence that supports the distinctive roles of articulatory rehearsal and attentional refreshing in verbal WM.

The aim of the current study was to explore the role of these two mechanisms in the maintenance of item and order information. In three experiments using a complex span task, we manipulated the opportunity for attentional refreshing and articulatory rehearsal on recall of item and order information from WM. Participants studied series of six letters while responding to the parity of successively presented digits (i.e., deciding whether digits were even or odd). Half of the participants completed the task silently using key presses to make their decision, while the other half responded aloud by saying "odd" or "even". Because responding aloud depends on the same language processes than those supporting articulatory rehearsal, the aloud-response condition reduces the opportunity to use rehearsal to maintain memory items compared to the silent-response condition. Furthermore, the trials presented the digits using either a fast pace or a slow pace. A fast pace increases the cognitive load of the task, i.e., the proportion of time during which the parity judgment task distracts attention from the memoranda, reducing the availability of attentional refreshing (Barrouillet et al., 2004; Camos et al., 2009). We used two methodologies to assess order and item memory: scoring (Experiment 1) and instructions (Experiments 2 and 3). In Experiment 1, participants had to recall both the item and its original serial order (i.e., item and order), and item and order memory were assessed through different scoring procedures. The typically used *correct-in-position* score (i.e., an item is correct when recalled in the original serial position of its presentation) does not distinguish the maintenance of item versus order information. Thus, scoring for *correct item* (i.e., the proportion of letters recalled regardless position) assessed item maintenance, whereas scoring for *order accuracy* (i.e., the proportion of letters recalled in correct position as a function of letters recalled regardless position, or *correct-in-position* score / *correct item* score) assessed order maintenance (cf. Fallon, Groves, & Tehan, 1999). In Experiments 2 and 3, we distinguished between item and order maintenance through instructions. Using similar complex span tasks as in Experiment 1, participants had to either reconstruct the order of the same six letters (i.e., order maintenance only; Experiment 2) or to recall the letters with no regard to order (i.e., item maintenance only; Experiment 3). Although participants in Experiment 3 received instructions to perform free recall, we can not entirely discard the possibility that participants relied on serial recall. Thus, in a subsequent experiment (Experiment 5), participants performed a similar complex span task in which they had to maintain six words pertaining to six different semantic categories. To minimize the use of order information, the recall of these words was cued by the name of each category. Finally, in a preliminary experiment (Experiment 4), participants performed serial recall with the same list of words used in Experiment 5 to allow a comparison of item recall with serial recall of the same type of material. Moreover, by using the same scoring procedure as in Experiment 1, we were able to examine the maintenance of item and order information in Experiment 4 but with another type of material (words instead of letters).

Comparing the impact of refreshing and rehearsal on these different indexes of the maintenance of order and item information should indicate how they are maintained in WM. Moreover, this should clarify if refreshing and rehearsal are differently involved in the maintenance of order and item information. What we know about these two mechanisms give some insights about such a role. Refreshing is an attention-based mechanism, and Majerus (2009, 2013) proposed that item maintenance depends on language and attention processes while order maintenance depends on different attentional processes, some being common with item maintenance. Thus, it might be expected that increasing the pace of the concurrent task, thereby reducing the availability of attention, should have a stronger detrimental effect on order rather than on item recall performance. On the contrary, some models of STM (like SOB model in Oberauer & Lewandowsky, 2008) implement refreshing as a repetitive mechanism (i.e., that only re-encodes the last item), which should then sustain item maintenance and not order maintenance. Thus, it might be expected that increasing the pace of the concurrent task, thereby reducing the availability of attention, should have a detrimental effect on item rather than on order recall performance. Conversely, other models like the TBRS (Barrouillet, Plancher, Guida, & Camos, 2013; Vergauwe, Camos, & Barrouillet, 2014) and the covert retrieval (Loaiza & McCabe, 2012; McCabe, 2008) model both propose that refreshing is cumulative always starting by the first item in the list. The cumulative nature of refreshing may imply that maintaining the order of information during complex span tasks is a byproduct of maintaining the specific items. For example, Loaiza and McCabe (2012) showed that attentional refreshing promotes the likelihood of using the original serial order of the memoranda as cues during retrieval from episodic memory. Impeding refreshing would then similarly affect item and order maintenance.

With regard to articulatory rehearsal, some authors have conceived that rehearsal also operates in a cumulative fashion. Participants may incorporate each newly presented memorandum of a trial when rehearsing previously presented memoranda in a forward manner (Bhatarah, Ward, Smith, & Hayes, 2009; Ferguson & Bray, 1976; Palmer & Ornstein, 1971; Rundus, 1971). Accordingly, rehearsal may also maintain order-based information as a consequence of rehearsing item-based memoranda in a cumulative manner. Thus, constraining articulatory rehearsal should reduce recall of order and item information similarly. However, rehearsal may be more involved in the maintenance of item than order information by preserving the phonological features of the to-be-maintained items. As suggested by Majerus (2009), the language processes and language brain networks sustaining rehearsal is more involved in the maintenance of phonological representations than their order.

The design of the current study allowed the test of these respective predictions using a complex span paradigm. Specifically, we examined the retrieval of item and order information using scoring procedures that disentangled item and order accuracy in WM recall (Experiments 1 and 4) and recall instructions that required item or order maintenance (Experiments 2, 3 and 5). We were further able to examine how item and order information may be distinguishable in WM by manipulating attention- (i.e., varying pace) and rehearsal-based (i.e., varying concurrent articulation) factors in the complex span task in each experiment. This would specifically indicate whether item and order maintenance in WM are differently affected when impairing attention- or rehearsal-based maintenance.

Experiment 1

Method

Participants and Design.

Thirty-two undergraduate psychology students (29 females; age *M* = 20.50, *SD* = 1.54) at the University of Bourgogne received partial course credit for participating. They were randomly assigned to one of the two experimental groups that varied the concurrent articulation of the parity judgment component of the complex span task (key response vs. aloud response). The pace of the trials (slow or fast) was manipulated within-subjects.

Materials and Procedure.

Participants in both groups were presented with the same series of consonants (excluding “W”, which is trisyllabic in French) in 30 trials, each trial comprising 6 memoranda. The task required participants to remember both the letters and their serial positions within each trial. During each trial, a ready signal was displayed for 1000 ms, and then immediately replaced by the first to-be-remembered letter that was displayed for 1000 ms and read aloud. Following each letter, a series of 6 single digits (i.e., 1 to 9) to judge were presented. Depending on the condition, participants either responded to the parity of the digits out loud (e.g., saying “even” or “odd”) or silently using a key response (e.g., pressing a right key for even and a left key for odd). The experimenter marked the responses for the aloud condition. For half of the trials, the digits were presented at a slow pace for 1125 ms with an inter-stimulus interval (ISI) of 375 ms, while the other half of the trials presented the digits at a fast pace for 600 ms with an ISI of 200 ms. Thus, the total duration a digit was presented was 1500 and 800 ms for slow- and fast-paced trials, respectively. The pace of the trials was blocked and counterbalanced, and each block began with two practice trials. At the end of each trial, the word “rappel” (recall) appeared, and the participants wrote the 6 letters in their original order.

Results

All reported significant results met a criterion of $p < .05$ unless otherwise stated. Measures of effect size (Cohen's *d* or partial eta squared, η_p^2) are reported for all significant *t* or *F* values > 1, and Greenhouse-Geisser correction was used when Mauchly's Test of Sphericity was significant.

A 2 (group: oral, key) x 2 (pace: slow, fast) x 6 (serial position: 1, 2, 3, 4, 5, 6) mixed analysis of variance (ANOVA) was performed on the proportion of recall *correct-in-position*, i.e., the proportion of letters recalled in correct position. The analysis showed that participants in the key response group recalled more letters ($M = .69$, $SD = .14$) than participants who performed the parity judgment task aloud ($M = .47$, $SD = .14$), $F(1, 30) = 19.02$, $\eta_p^2 = .39$. In addition, recall from the slow pace presentation of the parity judgment task ($M = .68$, $SD = .19$) was greater than the fast pace ($M = .48$, $SD = .18$), $F(1, 30) = 87.96$, $\eta_p^2 = .75$. The interaction between group and pace was not significant, $F < 1$ (Figure 1, Panel A). The serial position effect was significant, $F(2.64, 79.22) = 52.93$, $\eta_p^2 = .64$, and significantly interacted with group, $F(5, 150) = 4.69$, $\eta_p^2 = .14$, and pace, $F(3.23, 96.91) = 14.92$, $\eta_p^2 = .33$, although the three-way interaction was not significant, $F < 1$. Figure 1A reveals that the serial position effect was larger on the fast, $F(3.01, 93.15) = 59.34$, $\eta_p^2 = .66$, than the slow pace trials, $F(2.63, 81.38) = 18.91$, $\eta_p^2 = .38$. The serial position effect was also stronger in the key (silent) group, $F(3.39, 50.80) = 31.82$, $\eta_p^2 = .68$, than the oral group, $F(2.06, 30.82) = 27.38$, $\eta_p^2 = .65$. However, this difference relied mostly on the last position. Indeed, when the last position was removed from the analysis, the serial position effect was larger in the oral, $F(2.07, 31.07) = 55.03$, $\eta_p^2 = .79$, than in the silent group, $F(2.77, 41.52) = 28.30$, $\eta_p^2 = .65$.

Following Fallon et al. (1999), we scored the proportion of letters recalled regardless position (*correct item*), and the proportion of letters recalled in correct position (the performance measure used in the previous analysis) as a function of letters recalled regardless position (i.e., correct-in-position score / correct item score; *order accuracy*). As the previous analysis for the correct-in-position scores, an ANOVA assessing *correct item* scores also revealed that concurrent articulation in the oral response group (M = .61, SD = .18) reduced recall relative to the key response group (M = .79, SD = .15), $F(1, 30) = 17.18$, $\eta_p^2 = .36$, and that the fast pace (M = .61, SD = .16) resulted in worse recall than the slow pace (M = .79, SD = .16), $F(1, 30) = 98.38$, $\eta_p^2 = .77$ (Figure 1, Panel B). However, the interaction between the pace and articulation factor was not significant, $F < 1$. There was a significant effect of serial position, $F(3.71, 111.19) = 40.90$, $\eta_p^2 = .58$, which significantly interacted with group, $F(5, 150) = 5.54$, $\eta_p^2 = .16$, and pace, $F(5, 150) = 10.42$, $\eta_p^2 = .26$. Finally, the three-way interaction was significant, $F(5, 150) = 2.62$, $\eta_p^2 = .08$, such that the oral group showed a larger effect of serial position than the key group, particularly during the fast pace trials. However, we suspected that this three-way interaction was driven by the ceiling effect from the key group in the slow condition because the *SD*s in this condition ranged from .06 to .15, whereas the *SD*s for the other conditions ranged from .13 to .28.

For *order accuracy*, the effects were similar: the oral group (M = .74, SD = .14) showed worse performance than the key group (M = .86, SD = .08), $F(1, 30) = 12.31$, $\eta_p^2 = .29$, and the fast pace (M = .69, SD = .14) led to worse performance than the slow pace (M = .84, SD = .12), $F(1, 30) = 19.93$, $\eta_p^2 = .40$. However, the interaction between these factors was not significant, $F < 1$ (Figure 1, Panel C). A similar main effect of serial position was observed, $F(3.01, 90.26) = 24.37$, $\eta_p^2 = .45$, with two significant interactions between group and serial position, $F(5, 150) = 4.01$, $\eta_p^2 = .12$, and pace and serial position, $F(5, 150) = 8.52$, $\eta_p^2 = .22$, but no significant three-way interaction, $F < 1.31$. As shown in Figure 1C and consistent with the previous measures, there were stronger serial position effects in the oral group and fast pace than the key group and the slow pace, respectively.

Discussion

These results fit well with other research indicating the independent contributions of articulatory rehearsal and attentional refreshing to verbal WM (Camos et al., 2009, 2011, 2013). In particular, there were significant effects of constraining articulatory rehearsal and increasing the pace of the complex span task on immediate serial recall. Importantly, however, these factors did not interact when assessing either overall recall (including item and order accuracy) or recall as a function of serial position. Using established scoring methods (Fallon et al., 1999) to disentangle the maintenance of item- and order-specific information in typical serial recall, we replicated the same pattern of results: articulatory rehearsal and attentional refreshing independently contribute to recall from working memory. This suggests articulatory rehearsal and attentional refreshing independently affect recall regardless of how it is scored, and thus both mechanisms appear to contribute to item- and order-specific maintenance in verbal WM.

In the next two experiments, we assessed the maintenance of item- and order-information by manipulating instructions, which complemented the results issued from the scoring method analysis of the first experiment. Specifically, in the second experiment, we manipulated the same factors but required the reconstruction of order-specific information, as the same six letters were randomly ordered within each trial.

Experiment 2

Experiment 2 exclusively tested order recall to determine whether the effects of articulatory rehearsal and attentional refreshing were similar to those shown in Experiment 1, particularly the results that assessed order-specific information.

Method

Participants and Design.

Thirty-two undergraduate psychology students (26 females, age *M* = 21.30, *SD* = 1.87) from the University of Bourgogne participated for partial course credit, and had not participated in Experiment 1. As in Experiment 1, the participants were randomly assigned to complete the processing component of the complex span task aloud or using a key response. The pace of the trial (slow or fast) was manipulated within-subjects.

Materials and Procedure.

The method of Experiment 2 was very similar to Experiment 1, except that we used a reconstruction-of-order paradigm. Participants recalled the order of the same 6 to-be-remembered letters (i.e., H, J, L, Q, R, and T) that varied in order of presentation with each trial. Depending on the condition, participants again verified the parity of 6 single digits either aloud or with a silent key response. The digits were presented in either a slow (1125 ms with 375 ms ISI) or fast pace (600 ms with 200 ms ISI). At the end of each trial, the “rappel” screen prompted participants to write the 6 letters in their original order. A board with the 6 letters was in front of them to avoid any errors about the identity of the letters.

Results

A 2 (group: oral, key) x 2 (pace: slow, fast) x 6 (serial position: 1, 2, 3, 4, 5, 6) mixed ANOVA assessed proportion of *correct-in-position* recall. The pattern of results was similar to what was observed in Experiment 1.The analysis showed that participants in the key response group recalled more letters (M = .78, SD = .13) than participants who performed the parity judgment task aloud (M = .58, SD = .13), $F(1, 30) = 17.08$, η_p^2 = .36. In addition, recall from the slow pace presentation of the parity judgment task (M = .77, SD = .17) was greater than the fast pace (M = .58, SD = .19), $F(1, 30) = 48.00$, η_p^2 = .62. The interaction between group and pace was not significant, $F < 1$ (Figure 2). The effect of serial position was significant, $F(2.15, 64.49) = 44.16$, η_p^2 = .60. The interactions between group and serial position, $F(5, 150) = 3.51$, η_p^2 = .11, and pace and serial position, $F(2.63, 78.91) = 9.62$, η_p^2 = .24, were also significant, but the three-way interaction was not, $F < 1$. As shown in Figure 2, the source of these interactions was similar to Experiment 1: there were stronger effects of serial position in the oral group, $F(2.29, 34.32) = 32.23$, $\eta_p^2 = .68$, and the fast pace, $F(2.53, 78.52) = 38.69$, $\eta_p^2 = .56$, than the key/silent group, $F(1.93, 28.93) = 16.80$, $\eta_p^2 = .53$, and slow pace, $F(2.12, 65.57) = 16.42$, $\eta_p^2 = .35$, respectively.

In order to assess whether proactive interference from use of the same letters for each trial affected recall, we submitted recall performance to a 2 (group: key, oral) x 2 (pace: slow, fast) x 2 (trials: first third, last third) mixed ANOVA. The results of the first two factors and their interaction were the same as reported previously, and the analysis further showed that the effect of trials was significant such that recall was slightly worse on the first third of the trials ($M = .67$, $SD = .09$) than the last third ($M = .71$, $SD = .11$), $F(1, 30) = 5.43$, $\eta_p^2 = .15$. Nonetheless, none of the interactions with the trials factor were significant, Fs < 1. This indicates that proactive interference from use of the same letters with each trial did not make the task differentially difficult according to the articulation group or the pace of the trial, and in fact recall improved across the task.

Discussion

The results of Experiment 2 comport with those of Experiment 1 and previous research indicating the independent contributions of articulatory rehearsal and attentional refreshing to WM recall. That is, both experiments showed effects of articulation group and pace of the span task, but no interaction between these factors, either at the overall level of recall or as a function of serial position. This suggests that articulatory rehearsal and attentional refreshing still independently contribute to the recall of order information in WM even when the item-specific information is irrelevant to the complex span task. Furthermore, these effects are similar between the types of recall (serial in Experiment 1 and order reconstruction in Experiment 2), thus suggesting that these rehearsal and refreshing mechanisms that support verbal WM recall support both item and order maintenance. The following experiment tested whether this was also true when recall requires only the maintenance of item information.

Experiment 3

Experiment 3 examined the effects of rehearsal and refreshing when participants are instructed to recall the studied items without regard to their original serial order, i.e., in a free recall task.

Method

Participants.

Thirty-two participants (32 females, age *M* = 21.41, *SD* = 1.16) from the University of Fribourg participated for partial course credit. As in the previous two experiments, participants were randomly assigned to completing the parity judgment task either aloud or using a silent key response. The pace of the task (slow or fast) was manipulated within-subjects.

Materials and Procedure.

The materials and procedure were identical to Experiment 1, except that it was a free recall task, in which participants were instructed to recall the letters with no respect to their original order of presentation.

Results

We assessed free recall in a 2 (group: oral, key) x 2 (pace: slow, fast) x 6 (serial position: 1, 2, 3, 4, 5, 6) mixed ANOVA. Overall, the results were similar to the two previous experiments. The analysis of free recall showed that participants in the key response group recalled more letters (*M* = .82, *SD* = .10) than participants who performed the parity judgment task aloud (*M* = .68, *SD* = .10), $F(1, 30) = 15.62$, $\eta_p^2 = .34$. In addition, recall from the slow pace presentation of the parity judgment task (*M* = .83, *SD* = .12) was greater than the fast pace (*M* = .67, *SD* = .13), $F(1, 30) = 95.98$, $\eta_p^2 = .76$. The interaction between group and pace was not significant, $F < 1$ (Figure 3). The serial position effect was significant, $F(3.80, 113.88) = 26.62$, $\eta_p^2 = .47$, and qualified by two significant interactions between group and serial position, $F(3.80, 113.88) = 3.45$, $\eta_p^2 = .10$, and pace and serial position, $F(4.14, 124.22) = 8.42$, $\eta_p^2 = .22$, although the three-way interaction was not significant, $F < 1$. As in the previous two experiments, the source of these interactions was a stronger effect of serial position for the oral group, $F(5, 75) = 22.24$, $\eta_p^2 = .60$, and the fast pace, $F(5, 155) = 20.73$, $\eta_p^2 = .40$, than the key group, $F(2.87, 43.022) = 9.43$, $\eta_p^2 = .39$, and the slow pace, $F(5, 155) = 9.69$, $\eta_p^2 = .24$, respectively.

Although participants received instructions to perform a free recall, it remained possible that they relied on the serial position of the items to recall them. To assess this possibility, we computed the likelihood probability that, when an item was recalled, it was in the serial position in which it was presented. Overall, memoranda were recalled in the position of presentation above chance ($M = .38$, $SD = .23$), $t(31) = 5.24$ (Figure 4). A 2 (group: oral, key) x 2 (pace: slow, fast) x 6 (serial position: 1, 2, 3, 4, 5, 6) mixed ANOVA showed that it was especially the case for the key than oral group, $F(1, 30) = 12.53$, $\eta_p^2 = .30$, and for the slow than fast pace, $F(1, 30) = 34.98$, $\eta_p^2 = .54$; the two factors did not interact, $F(1, 30) = 2.28$. Moreover, items were less likely to be recalled in the position of presentation with increasing serial positions, $F(5, 150) = 43.08$, $\eta_p^2 = .59$. Though the four experimental conditions similarly exhibited this pattern, this effect slightly varied across them, as indicated by the group x pace x serial position interaction, $F(5, 150) = 2.44$, $\eta_p^2 = .08$.

Discussion

The purpose of Experiment 3 was to further test whether attentional refreshing and articulatory rehearsal have similar independent effects on item-only maintenance in WM as they have for item-and-order (Experiment 1) and order-only (Experiment 2) maintenance. The pattern of results was the same as in the two previous experiments: articulation group and pace had independent effects on free recall, but there was no interaction between the variables. Furthermore, these effects were of a similar strength as the previous experiments, thereby converging upon the findings of the previous experiments of this study and of the recent literature that articulatory rehearsal and attentional refreshing are independent maintenance mechanisms in WM (Camos et al., 2009, 2011, 2013). It is also noteworthy that the effect of cognitive load was also shown for free recall, thus extending previous results regarding the profound effects of cognitive load on serial recall from working memory (Barrouillet et al., 2004, 2007). Overall, the results indicate that refreshing and rehearsal maintenance mechanisms support recall regardless of whether item- and/or order-specific information is required for immediate recall.

Finally, though participants were instructed to recall items without paying attention to order of presentation, they showed the tendency to recall memoranda in their original position. Three reasons could be put forward to account for this phenomenon. First and the most straightforward, participants did not comply with the instructions, and although asked to perform a free recall task, they did a serial recall task. Second, it is possible that order information is automatically encoded when encoding item information. As a consequence at recall, items have an increased probability to be recalled in their original order of presentation. Third, and as proposed by Loaiza and McCabe (2012), serial position is a cue to retrieve item information. The current experiment cannot distinguish between these three proposals. However, such a tendency for forward order output even in free recall has been previously reported (Beaman & Morton, 2000; Bhatarah, Ward, & Tan, 2008; Howard & Kahana, 1999; Klein, Addis, & Kahana, 2005), and some authors suggested that the processes underpinning the recall and rehearsals in free and serial recall may be more similar than has been previously assumed (Tan & Ward, 2008). Thus, we re-examined the maintenance of item information in Experiment 5, using another type of task in which the recall of words was cued by their category. Contrary to a free recall task, the cued task should reduce recourse to order information for recalling items. For sake of comparison, the same material was tested in a preliminary experiment with a serial recall task (Experiment 4). Before presenting these two experiments, we performed a comparison across Experiments 1 to 3 to compare scoring vs. instructing method in assessing order and item information.

Comparison across Experiments 1 to 3

As stated previously, there are two main ways to assess order and item information, either through instructing or scoring methods. Most work in STM literature used either one or the other. However, to our knowledge, there is no systematic analysis across methods to evaluate if they lead to comparable findings. For this reason and also because this study is among the first dissociating order and item information using complex span tasks, we conducted two additional analyses to compare the two methods used in the present study in their ability to assess the maintenance of item- and order-specific information.

The first analysis focused on the maintenance of order and compared order accuracy in Experiment 1 to the recall of order-specific information in Experiment 2, whereas the second analysis compared the proportion of correct items in Experiment 1 to the recall of item-specific information in Experiment 3. These analyses better examined whether the exhibited independent effects of rehearsal and refreshing on WM recall in the previous experiments were the same regardless of whether recall was scored or instructed for item- or order-specific information between experiments. The effects of pace, group, and serial position were similar to those described previously, and thus for the sake of brevity we only report on the significant effects and interactions of experiment and serial position.

Accordingly, we ran a 2 (experiment: 1, 2) x 2 (group: key, oral) x 2 (pace: fast, slow) x 6 (serial position: 1, 2, 3, 4, 5, 6) mixed ANOVA on the recall of order-specific information. The analysis showed that order accuracy was higher in Experiment 1 than Experiment 2, *F*(1,

60) = 17.40, η_p^2 = .23 (compare Figure 1C to Figure 2). Furthermore, the interaction between pace and experiment was significant, $F(1, 60) = 9.96$, η_p^2 = .14, due to a larger effect of pace for Experiment 2, $F(1, 31) = 48.58$, η_p^2 = .61, than Experiment 1, $F(1, 31) = 20.08$, η_p^2 = .39. However, the two-way interaction between experiment and group, and the three-way interaction were not significant, *F*s $\leq$ 1.62, *p*s $\geq$ .21. Serial position significantly interacted with experiment, $F(5, 300) = 8.97$, η_p^2 = .13, and a three-way interaction between experiment, pace and serial position was also significant, $F(3.86, 231.79) = 5.42$, η_p^2 = .08. The source of this interaction was a stronger effect of serial position for Experiment 2, $F(2.53, 78.52) = 38.69$, η_p^2 = .56, relative to Experiment 1, $F(3.62, 112.28) = 21.01$, η_p^2 = .40, during fast pace trials (experiment x serial position interaction, $F(3.40, 210.80) = 9.45$, η_p^2 = .13), whereas the experiment x serial position interaction was smaller for slow pace trials, $F(2.80, 173.82) = 3.41$, η_p^2 = .05. However, the three-way interaction between experiment, group, and serial position and the four-way interaction were not significant, *F*s $\leq$ 1.36, *p*s $\geq$ .25.

The second analysis concerned recall of item-specific information using a 2 (experiment: 1, 3) x 2 (group: key, oral) x 2 (pace: fast, slow) x 6 (serial position: 1, 2, 3, 4, 5, 6) mixed ANOVA. The analysis indicated that participants in Experiment 3 had higher item accuracy than participants in Experiment 1, $F(1, 60) = 2.88$, η_p^2 = .05, but all of the two-way interactions and the three-way interaction were not significant, *F*s < 1 (compare Figure 1B to Figure 3). The serial position effect significantly interacted with experiment, $F(5, 300) = 5.92$, η_p^2 = .09, and the three-way interaction between experiment, pace, and serial position was significant, $F(5, 300) = 3.80$, η_p^2 = .06. This interaction was due to the result that serial position affected both experiments similarly for recall during the slow pace trials (experiment x serial position, $F < 1$), whereas the effect of serial position for the fast pace trials was smaller for Experiment 3, $F(3.87, 119.85) = 20.73$, η_p^2 = .40, relative to Experiment 1, $F(3.79, 117.40) = 37.16$, η_p^2 = .55 (experiment x serial position, $F(4.08, 253.22) = 6.86$, η_p^2 =

.10). Finally, the three-way interaction between experiment, group, and serial position and the four-way interaction were not significant, Fs $\leq$ 1.20, ps $\geq$ .31.

These results suggest that, relative to disentangling item and order accuracy from serial recall (Experiment 1; Fallon et al., 1999), instructions to recall order-specific information may overestimate the effect of pace on recall, while instructions to recall item-specific information may underestimate the effect of pace on recall. This suggests that while attentional refreshing and articulatory rehearsal may independently yet similarly affect item- and order-specific maintenance and recall, researchers should be aware that impairing attentional refreshing, in particular, may over- or under-estimate recall when instructing participants to recall order- or item-specific information, respectively.

Experiment 4

The aim of Experiment 4 was to provide data on the serial recall of words that we would compare with the recall of items in the cued recall paradigm used in Experiment 5. It also allowed us to examine the maintenance of order and item information through scoring method as in Experiment 1, but with another type of verbal material (words instead of letters).

Method

Participants.

Thirty-two participants (28 females, age M = 20.10, SD = 1.45) from the University of Bourgogne participated for partial course credit. As in the previous experiments, participants were randomly assigned to complete the parity judgment task either aloud or using a silent key response. The pace of the task (slow or fast) was manipulated within-subjects.

Materials and Procedure.

The method of Experiment 4 was very similar to Experiment 1, except that we presented series of 6 words to be memorized in correct serial order instead of letters. Each word belonged to a different semantic category (i.e., animal, clothe, flower, fruit, musical instrument, vehicle). A different word was presented for each category in each trial, and the order of the categories was randomized for each trial. In a pre-test, we asked 17 adults (9 females) to name exemplars of these categories to choose the most frequently named exemplars of each category. In the experiment, participants again verified the parity of 6 single digits either aloud or with a silent key response depending on the condition. The digits were presented in either a slow (1125 ms with 375 ms ISI) or fast pace (600 ms with 200 ms ISI). At the end of each trial, the “rappel” screen prompted participants to write the 6 words in their original order.

Results

As in Experiment 1, a 2 (group: oral, key) x 2 (pace: slow, fast) x 6 (serial position: 1, 2, 3, 4, 5, 6) mixed ANOVA was performed on the proportion of *correct-in-position* recall (Figure 5, Panel A). The analysis replicated the findings observed in Experiment 1 for the maintenance of letters. Participants in the key response group recalled more words (M = .63, SD = .15) than participants who performed the parity judgment task aloud (M = .40, SD = .10), $F(1, 30) = 25.54$, $\eta_p^2 = .46$. In addition, recall from the slow pace presentation of the parity judgment task (M = .61, SD = .19) was greater than the fast pace (M = .42, SD = .18), $F(1, 30) = 82.49$, $\eta_p^2 = .73$. The interaction between group and pace was not significant, $F < 1$. Though the main effect of serial position was significant, $F(2.02, 60.68) = 35.55$, $\eta_p^2 = .54$, it did not significantly interact with other factors, contrary to previous experiments.

As this experiment followed a similar design than Experiment 1, we took the opportunity to analyze the *correct item* and *order accuracy* scores. For *correct item*, the pattern of results was similar to what we observed in Experiment 1 with the maintenance of letters. As the previous analysis for the correct-in-position scores, an ANOVA assessing *correct item* scores also revealed that concurrent articulation in the oral response group (M = .60, SD = .10) reduced recall relative to the key response group (M = .79, SD = .13), F(1, 30)

= 21.24, η_p^2 = .41, and that the fast pace (*M* = .64, *SD* = .09) resulted in worse recall than the slow pace (*M* = .76, *SD* = .09), $F(1, 30) = 78.11$, η_p^2 = .72 (Figure 5, Panel B). However, the interaction between the pace and articulation factors was not significant, $F < 1$. There were a significant effect of serial position, $F(2.55, 76.27) = 10.39$, η_p^2 = .26, and a significant two-way interaction between pace and serial position, $F(5, 150) = 4.14$, η_p^2 = .12. The three-way interaction was also significant, $F(5, 150) = 2.46$, η_p^2 = .08, but no other interaction was significant. For *order accuracy*, the effects were similar: the oral group (*M* = .63, *SD* = .13) showed worse performance than the key group (*M* = .77, *SD* = .09), $F(1, 30) = 12.04$, η_p^2 = .29, and the fast pace (*M* = .62, *SD* = .17) led to worse performance than the slow pace (*M* = .79, *SD* = .13), $F(1, 30) = 37.26$, η_p^2 = .55 (Figure 5, Panel C). The main effect of serial position was also significant, $F(2.53, 75.81) = 27.49$, η_p^2 = .48, but none of the interactions, *F*s < 1.

Discussion

Although the aim of Experiment 4 was mostly to provide data for comparison with Experiment 5, the results allowed us to replicate the main findings of Experiment 1 with a different type of material (i.e., words). As the findings of Experiment 1, these results brought further evidence in favor of the idea that articulatory rehearsal and attentional refreshing independently contribute to the maintenance of verbal information in WM (Camos et al., 2009, 2011, 2013). The only divergence with Experiment 1 is related to the serial position effect and the absence of interaction with either the pace or the group. We can only speculate that the maintenance of words may benefit more from long-term memory than maintaining letters, which may change the pattern of interaction.

Experiment 5

Experiment 5 aimed at examining the maintenance of item information with a cued recall task. Using a similar paradigm with the same memory words as in Experiment 4, the recall of these words was cued by giving their category names one by one, and participants had to recall the word belonging to each category that was presented in the memory list.

Method

Participants.

Thirty-two participants (27 females, age *M* = 20.34, *SD* = 1.04) from the University of Bourgogne participated for partial course credit. As in the previous experiments, participants were randomly assigned to completing the parity judgment task either aloud or using a silent key response. The pace of the task (slow or fast) was manipulated within-subjects.

Materials and Procedure.

In Experiment 5, we used the same material and procedure as in Experiment 4, except for the recall. At the end of each trial, participant had to recall the 6 words, but the recall of each word was cued by the name of a category (i.e., animal, clothes, flower, fruit, musical instrument, vehicle). To minimize the use of serial recall, the order of categories at recall was random and different from the order in which they were presented at encoding.

Results

As in Experiment 3, a 2 (group: oral, key) x 2 (pace: slow, fast) x 6 (serial position: 1, 2, 3, 4, 5, 6) mixed ANOVA was performed on the proportion of *correct item* recall (Figure 6). The analysis replicated the findings observed in Experiment 3 for the maintenance of letters. Participants in the key response group recalled more words (*M* = .84, *SD* = .11) than participants who performed the parity judgment task aloud (*M* = .73, *SD* = .13), $F(1, 30) = 7.36$, $\eta_p^2 = .20$. In addition, recall from the slow pace presentation of the parity judgment task (*M* = .83, *SD* = .13) was greater than the fast pace (*M* = .74, *SD* = .14), $F(1, 30) = 38.55$, $\eta_p^2 = .56$. The interaction between group and pace was not significant, $F < 1$. The main effect of serial position was significant, $F(3.32, 99.54) = 7.53$, $\eta_p^2 = .20$, but no interaction was significant as in Experiment 4 with the serial recall of words.

Discussion

In Experiment 3, we previously examined the maintenance of item information using free recall instruction. However, detailed examination of recall pattern showed that participants were inclined to recall memory items in their position of presentation despite the instructions to disregard order. The paradigm of cued recall in Experiment 5 presented the advantage that there was clearly no benefit to encode order or to use serial position as retrieval cue, which was one of the proposed explanations for the findings in Experiment 3. Nevertheless, despite the change of paradigm, results in Experiment 5 showed the same pattern as all the other experiments. In a final analysis between the two last experiments, we compared the scoring and instructing method to assess the maintenance of item information. A 2 (experiment: 4, 5) x 2 (group: key, oral) x 2 (pace: fast, slow) mixed ANOVA recall of item-specific information when words were the memoranda. Despite the fact that cued recall in Experiment 5 lead to better recall performance than the scoring of item accuracy in Experiment 4, $F(1, 60) = 9.36$, $\eta_p^2 = .14$, the manipulation of the two maintenance mechanisms had similar impact across the two experiments, as indicated by the absence of relevant interactions, *p*s > .06.

General Discussion

The goal of the present study was to establish how attentional refreshing and articulatory rehearsal affect item- and order-specific maintenance in verbal WM. Moreover, the study compared two different methods for disentangling item and order information, namely, recall scoring methods (Experiments 1 and 4) and recall instructions (Experiments 2, 3 and 5). The critical finding of this study was that constraining the use of articulatory rehearsal by a concurrent articulation or impairing the use of attentional refreshing by increasing the pace of a concurrent task in a complex span task independently affected recall from WM, regardless of whether item- and/or order-specific information was used for analysis (Experiments 1 and 4) or required for recall (Experiments 2, 3 and 5). This converges with previous research indicating that articulatory rehearsal and attentional refreshing function independently to contribute to WM recall (Camos, 2015, for a review). Though the manipulation of the concurrent articulation in the present study depended on the pace of the secondary task, which could allow more time to rehearse in the slow than fast pace condition, we replicated the additive effect of these two factors in *correct-in-position*, *correct item*, and *order accuracy* scores as previously reported in studies in which the two manipulations were independent from each other (Camos, et al., 2013; Mora & Camos, 2013). Moreover, the present study further extended this finding to different types of recall from WM. Specifically, the results suggest that these maintenance mechanisms do not differentiate between item- and order-specific recall. Instead, the results indicated that item- and order-specific information are similarly maintained and recalled from complex span tasks. Before proposing some theoretical implications of the current findings for the maintenance of order and item information, we discussed the methods used to assess order and item recall.

Assessing the maintenance of item and order information in working memory

The comparison of two different methods to disentangle the maintenance of item- and order-specific information in WM is of practical and methodological relevance for researchers. Specifically, the study is among the first to compare between item and order recall in verbal WM. Until now, most investigations of WM have concerned, for example, how processing and storage operate in WM (Barrouillet et al., 2004; Barrouillet & Camos, 2010) or how information is forgotten from WM (Oberauer & Lewandowsky, 2008). Conversely, the question of item and order maintenance is widespread in the STM literature (e.g., Burgess & Hitch, 1999; Marshuetz, 2005; Page & Norris, 1998). For example, much research has identified factors that dissociate between item and order recall, such as the lexicality (Fallon, Mak, Tehan, & Daly, 2005) and phonological similarity (Fallon et al., 1999, 2005) of verbal information. In addition to such intrinsic features of the memoranda, the STM literature has also focused on how external features of the memoranda (such as the format of presentation or recall requirements) differentially promote the recovery of item- and order-specific information. For example, much research has focused on the conditions under which temporal isolation of memoranda increases the likelihood of serial order recall in STM (e.g., Farrell, Wise, & Lelièvre, 2011; Lewandowsky, Nimmo, & Brown, 2008). Despite these heavily researched intrinsic and extrinsic factors that differentially affect item and order recall, there is little research on whether mechanisms underlying ongoing maintenance in STM differentially support retrieval of item- and order-specific information.

Likewise, few studies with complex span tasks have examined item- and order-based recall, with most studies relying on only serial recall to examine other factors affecting WM performance. Disentangling item and order maintenance in WM recall may present a new angle with which to approach more frequently-studied topics in the WM literature. For example, the predictive utility of the WM construct is regularly investigated in the literature, but decomposing serial recall from WM into item- and order-specific recall using Fallon and colleagues' procedure may further inform the relationship between WM recall and other measures of higher order cognitive ability. Rather than instructing free or serial recall or utilizing methods that allow participants to focus on the reconstruction of the original order of information (e.g., Lewandowsky et al., 2008), researchers can easily use this method with their existing data. Further, as is discussed later, using Fallon and colleagues' method of disentangling item and order accuracy may also inform the growing literature concerning content-context binding in WM (e.g., Loaiza & McCabe, 2012; Mitchell, Johnson, Raye, Mather, & D'Esposito, 2000). Researchers should be aware, however, that instructing item- or order-specific recall can underestimate and overestimate the effect of the attentional demand of the secondary task on recall relative to utilizing item and order accuracy measures, respectively. In sum, the current study presents a bridge between the WM and STM areas while also informing WM researchers of applications of common methods to disentangle item- and order-specific information in immediate recall (cf. Fallon et al., 1999).

Theoretical implications on the maintenance of order and item information

Furthermore, the two methods used in the present study also provided a unique perspective on the investigation of the mechanisms that support maintenance of verbal information in WM. There is a growing literature supporting the distinction between two maintenance mechanisms in verbal WM: a domain-specific, phonological mechanism articulatory rehearsal versus a domain-general, attention-based mechanism attentional refreshing (Camos et al., 2009, 2011, 2013; Loaiza & McCabe, 2013; Mora & Camos, 2013; Raye et al., 2007). However, models which contain one or both of these two mechanisms have not described their specific role in the maintenance of item and order information.

Our results provided a very congruent pattern across the five experiments, the different scoring methods, and tasks. The results support the notion that item- and order-specific information are not differentially supported in verbal WM. Both rehearsal and refreshing are involved in the maintenance of item and order information, as if the two types of information were jointly maintained. Two different accounts can be put forward to understand the current results. Our findings could either rely on a particular characteristic shared by the two maintenance mechanisms, or we should seek the origin of the joint maintenance of item and order information outside the rehearsal and refreshing mechanisms themselves.

First, the joint maintenance of order and item information could be an intrinsic by-product of the nature of the maintenance mechanisms. Attentional refreshing is assumed to operate cumulatively by reactivating all of the previous memoranda studied up until that point in the trial (Barrouillet et al., 2013; McCabe, 2008; Vergauwe et al., 2014). Similarly, using covert rehearsal to maintain memoranda is assumed to operate by covertly articulating the previously presented memoranda in a trial (Baddeley, 1986; see also Burgess & Hitch, 1999; Page & Norris, 1998). Thus, the two maintenance mechanisms are predicted to function with respect to each incoming memorandum, thereby emphasizing the order of the memoranda in addition to the items themselves. This study supports this conception because impairing attentional refreshing and articulatory rehearsal similarly affected WM recall, regardless of the type of recall required during the experiment (e.g., free, cued, or serial recall). Nevertheless, it could be argued that perhaps participants rehearse or refresh item-specific information in the original order so as to increase the likelihood of correct recall according to the instructions of the task. Indeed, complex span tasks typically require serial recall of the memoranda. However, Experiment 3 required only free recall, but the same pattern of results emerged as in Experiments 1 and 2 that required serial recall of information and reconstruction of order, respectively. Experiment 5 provided stronger evidence as the same pattern appeared when word recall was cued by category as in the serial recall task in Experiment 4. Thus, recall instructions cannot explain the effects of attentional refreshing and articulatory rehearsal on maintenance of item and order information, effects which could result from the shared cumulative nature of these mechanisms.

Alternatively, the fact that both refreshing and rehearsal have similar impacts on the maintenance of order and item-information may suggest that maintenance mechanisms per se are not at the root of the maintenance of these two types of information. As Farrell and Lewandowsky (2002) proposed, the two types of information are likely incorporated within the same representation during WM encoding. Order information could be then encoded as one feature of a multi-feature integrated memory representation built in WM at encoding, which could be maintained in a domain-general buffer (Barrouillet & Camos, 2015). In agreement with this view, previous studies have shown in the maintenance of visual as well as cross-domain items (e.g., letters in location) that the maintenance of integrated objects relies on attention, but not more than the maintenance of the single features (e.g., Allen et al., 2006; Johnson et al., 2008; Langerock, Vergauwe & Barrouillet, 2014; Morey & Bieler, 2013). Alternatively, it is possible that the encoding of order into a WM representation is achieved by content-context binding (Mitchell et al., 2000; Oberauer & Vockenberg, 2009), and then, these contextual cues can be accessed to guide recall of content-specific information (Loaiza & McCabe, 2012, 2013), whatever the type of recall tasks to perform. Finally, it was also suggested that serial order is achieved by binding the to-be-maintained items to fixed positions in an oriented mental line (Abrahamse, van Dijck, Majerus, & Fias, 2014; van Dijck, Abrahamse, Majerus, & Fias, 2013). Congruent with Majerus (2013), item and order maintenance would rely on attention, but serial order is grounded in a spatial attention network. Within this perspective, it could be proposed that the spatial organisation of serial order constraints the reactivation of items by rehearsal or refreshing, accounting for the sequential functioning of these two mechanisms. Further work should aim at examining if the sequential functioning of rehearsal and refreshing results from the spatial organisation of order, or if serial order maintenance is an emergent property of cumulative (item) maintenance mechanisms.

Conclusion

In sum, the present study is among the first to examine the role of attentional refreshing and articulatory rehearsal in the maintenance of item and order information in verbal WM. The results show that the independent refreshing and rehearsal mechanisms similarly contribute to item- and order-specific recall in WM. This suggests that at least in verbal WM recall, there is some common characteristics between the two types of information. This suggests that the cumulative nature of the two maintenance mechanisms allows the simultaneous maintenance of order- and item-information, or that both types of information are intrinsic to representations in WM as a consequence of their coupling during encoding.

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Figure Captions

Figure 1. Mean recall as a function of serial position in Experiment 1, when scored as (A) correct in position, (B) item and (C) order accuracy as a function of the pace and the type of responses in the concurrent task. Error bars represent one standard error of the mean.

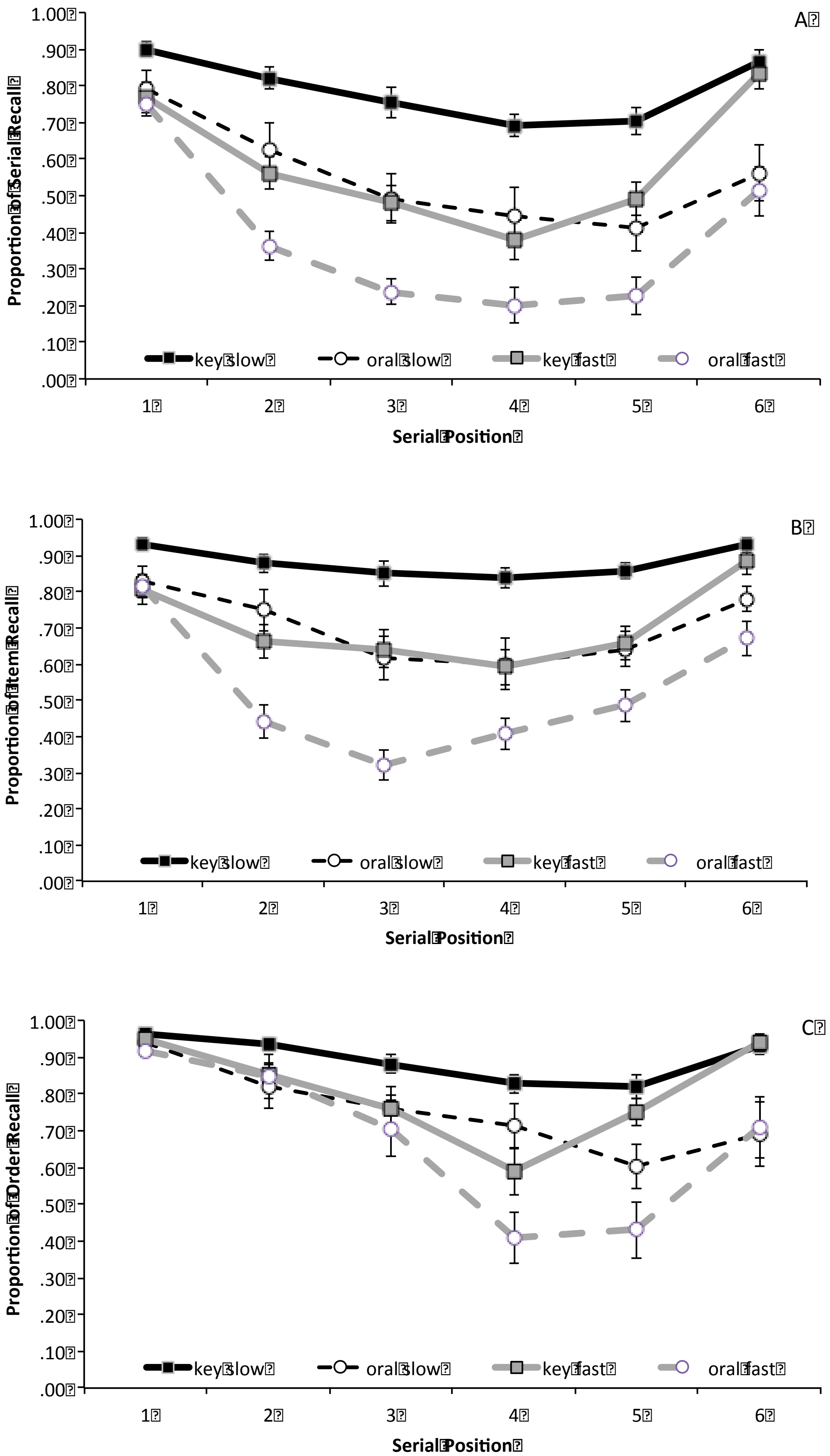
Figure 2. Mean recall as a function of serial position in Experiment 2. Error bars represent one standard error of the mean.

Figure 3. Mean recall as a function of serial position in Experiment 3. Error bars represent one standard error of the mean.

Figure 4. Mean likelihood probability for items to be recalled in their position of presentation as a function of serial position in Experiment 3. Error bars represent one standard error of the mean.

Figure 5. Mean recall as a function of serial position in Experiment 4, when scored as (A) correct in position, (B) item and (C) order accuracy as a function of the pace and the type of responses in the concurrent task. Error bars represent one standard error of the mean.

Figure 6. Mean recall as a function of serial position in Experiment 5. Error bars represent one standard error of the mean.


A
Proportion of Serial Recall
1.00
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.20
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.00
key slow
oral slow
key fast
oral fast
1
2
3
4
5
6
Serial Position
B
Proportion of Item Recall
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
.00
key slow
oral slow
key fast
oral fast
1
2
3
4
5
6
Serial Position
C
Proportion of Order Recall
1.00
.90
.80
.70
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key slow
oral slow
key fast
oral fast
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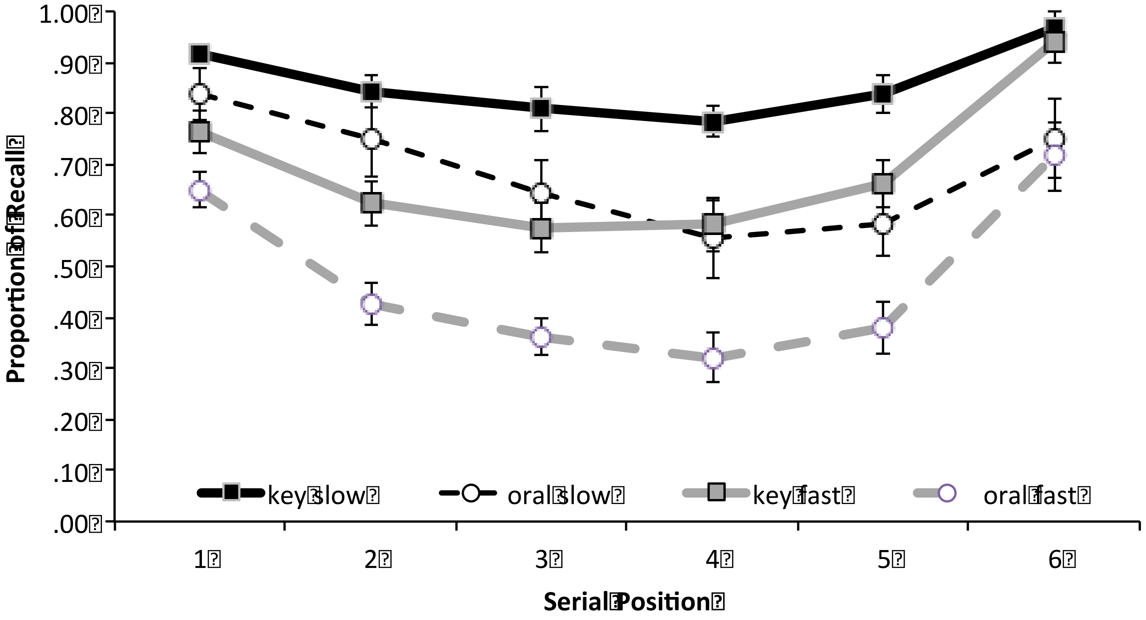
6
Serial Position

Figure 1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Proportion of Recall
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1
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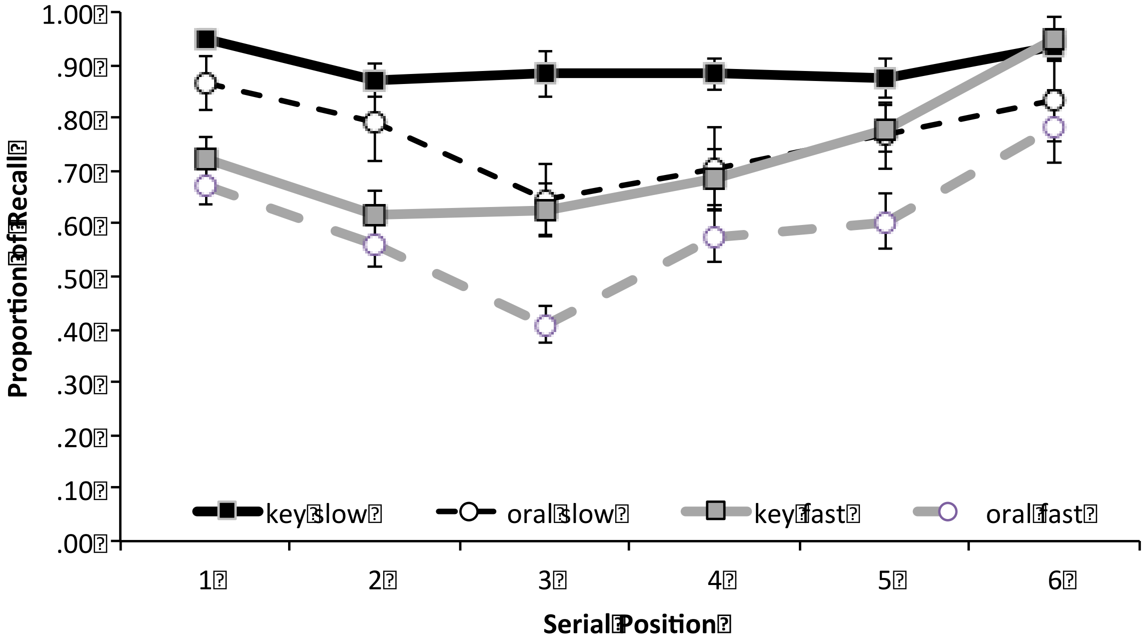
6
Serial Position

Figure 2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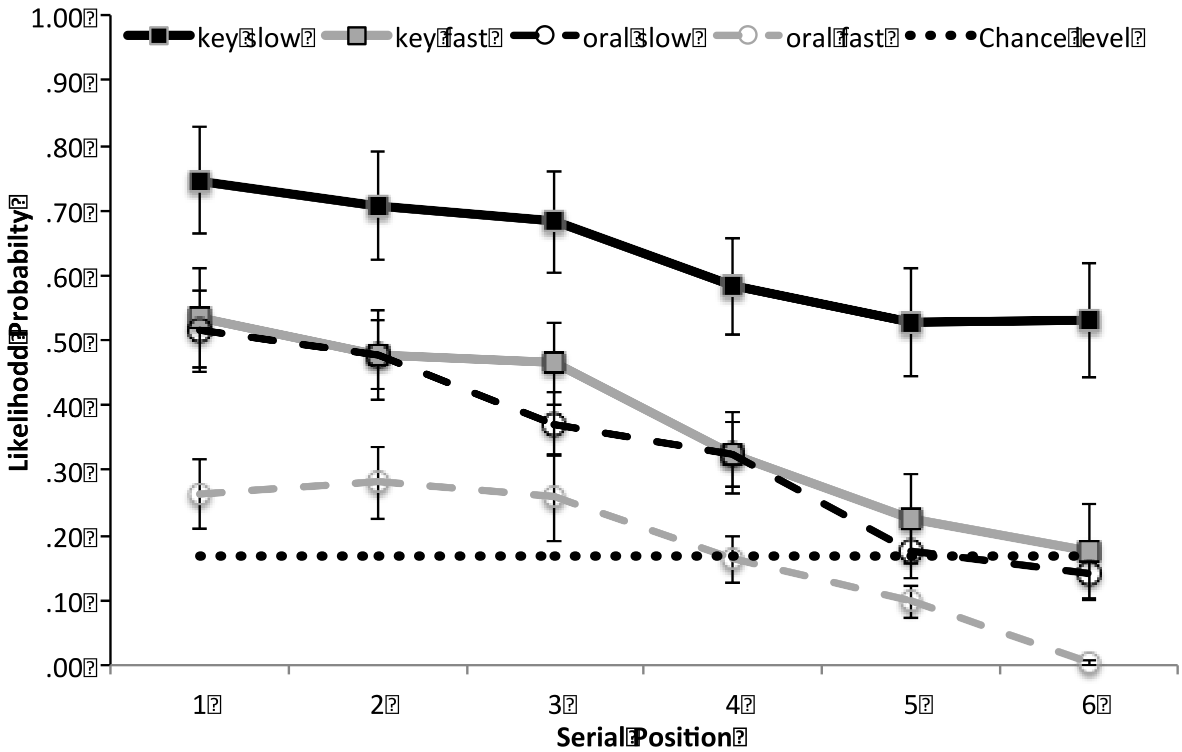
Serial Position

Figure 3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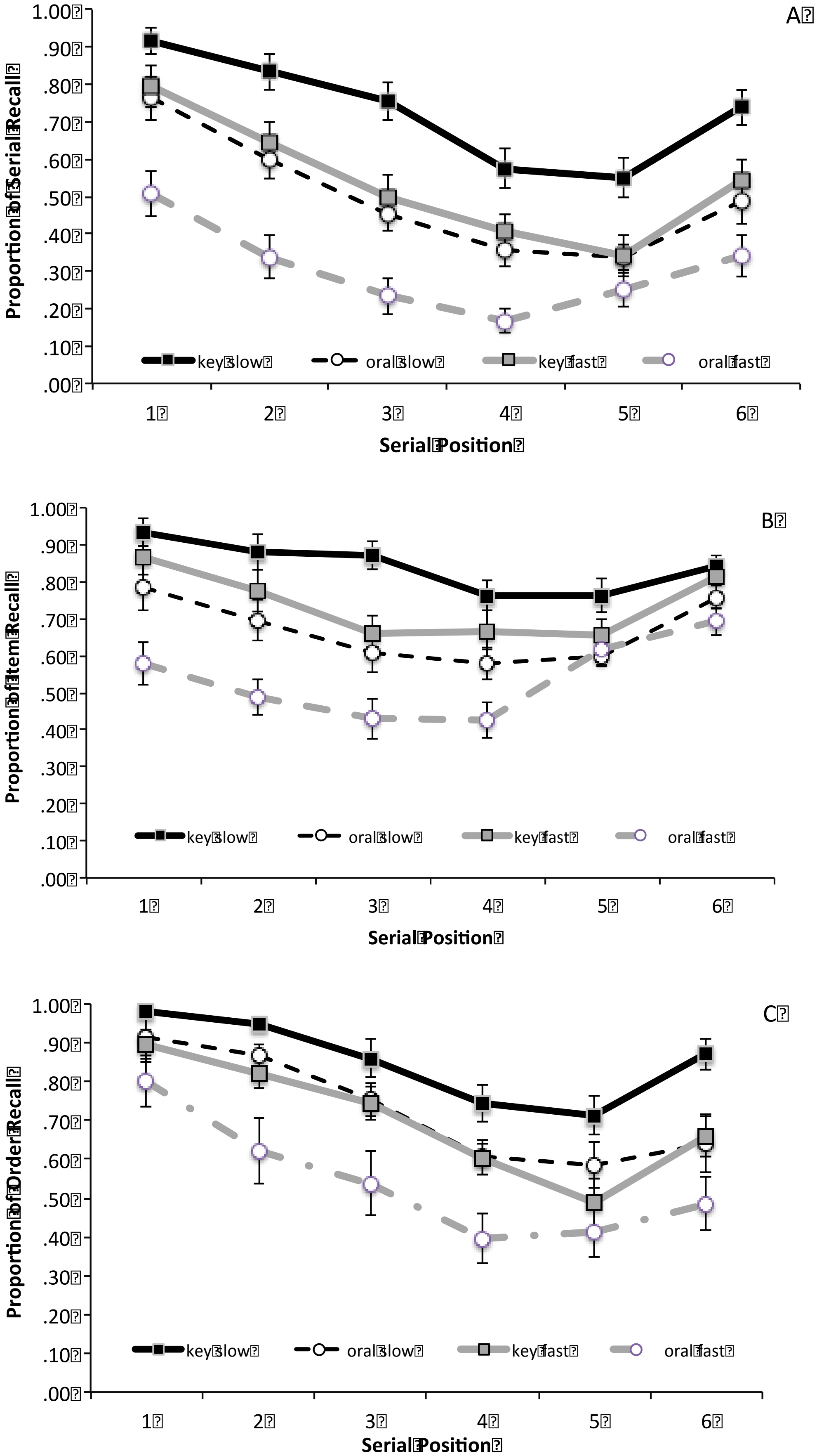
Serial Position

Figure 4


A
Proportion of Serial Recall
1.00
.90
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.60
.50
.40
.30
.20
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.00
key slow
oral slow
key fast
oral fast
1
2
3
4
5
6
Serial Position
B
Proportion of Item Recall
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
.00
key slow
oral slow
key fast
oral fast
1
2
3
4
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6
Serial Position
C
Proportion of Order Recall
1.00
.90
.80
.70
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key slow
oral slow
key fast
oral fast
1
2
3
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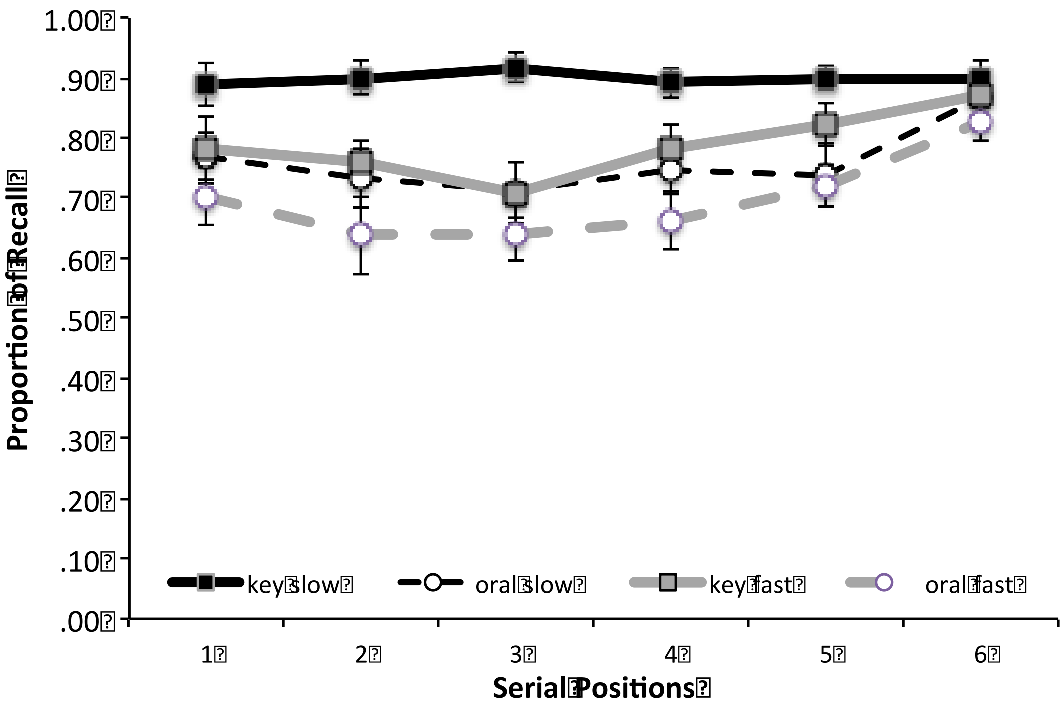
6
Serial Position

Figure 5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Proportion of Recall
key slow
oral slow
key fast
oral fast
1
2
3
4
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6
Serial Positions

Figure 6