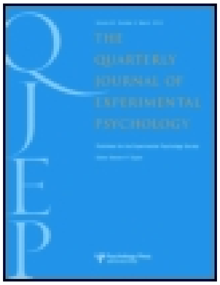

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Phonological similarity effect in complex span task

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Phonological similarity effect in complex span task

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The aim of our study was to test the hypothesis that two systems are involved in verbal working memory; one is specifically dedicated to the maintenance of phonological representations through verbal rehearsal while the other would maintain multimodal representations through attentional refreshing. This theoretical framework predicts that phonologically related phenomena such as the phonological similarity effect (PSE) should occur when the domain-specific system is involved in maintenance, but should disappear when concurrent articulation hinders its use. Impeding maintenance in the domain-general system by a concurrent attentional demand should impair recall performance without affecting PSE. In three experiments, we manipulated the concurrent articulation and the attentional demand induced by the processing component of complex span tasks in which participants had to maintain lists of either similar or dissimilar words. Confirming our predictions, PSE affected recall performance in complex span tasks. Although both the attentional demand and the articulatory requirement of the concurrent task impaired recall, only the induction of an articulatory suppression during maintenance made the PSE disappear. These results suggest a duality in the systems devoted to verbal maintenance in the short term, constraining models of working memory.

Keywords: Working memory; Phonological similarity; Complex span task; Rehearsal; Time-based resource-sharing model.

Working memory is a structure devoted to the maintenance of information at short term during concurrent processing activities. In this respect, the question regarding the nature of the mechanisms and systems fulfilling maintenance function is of particular importance and has received various responses in a recent past. The seminal approach put forward by Baddeley (1986; Baddeley & Logie, 1999) suggested that maintenance was achieved by separate domain-specific subsystems devoted to either visuospatial or verbal information. Subsequently, a domain-general system under the dependence of the central executive named the episodic buffer was added to the model for the maintenance of multimodal representations. Contrary to this structural view, other theories such as Engle, Kane, and Tuholski (1999) favoured an approach in terms of different strategies of maintenance, while other prominent theories like Cowan (2005) or Unsworth and Engle (2007) tended to leave unspecified the nature and functioning of maintenance mechanisms. In a first version of our time-based resource-sharing (TBRS) model, we assumed that

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maintenance is achieved through the recursive attentional refreshing of decaying memory traces (Barrouillet, Bernardin, & Camos, 2004). In the last version of this model, we added to this domain-general mechanism a system specific to the maintenance of verbal information, which is akin to the phonological loop in Baddeley's multicomponent model (Barrouillet, Portrat, & Camos, 2011; Camos, Lagner, & Barrouillet, 2009). Empirical evidence indicates that the two systems can concur for maintaining verbal information and have independent and additive effects (Camos et al., 2009; Camos, Mora, & Oberauer, 2011; Hudjetz & Oberauer, 2007).

The hypothesis of the coexistence of two distinct mechanisms for the maintenance of verbal information—one domain-general mechanism maintaining memory traces through attentional refreshing and the other, phonological-specific, mechanism maintaining memory traces through verbal rehearsal—leads to a series of predictions. The first, already verified by Camos et al. (2009), is that blocking one or the other of these mechanisms has a detrimental effect on verbal recall. A more precise prediction concerns the difference in nature of the representations maintained within the two mechanisms: One system exclusively maintains phonological representations while the other would maintain multimodal representations mainly made of semantic and orthographic features. The hypothesis of a system specifically devoted to the maintenance of phonological representations leads to the prediction that maintaining verbal information within this system should involve phenomena resulting from the phonological nature of the memory traces, whereas impeding maintenance within this system by blocking subvocal rehearsal should make these phenomena disappear. By contrast, blocking the attentional domain-general mechanism of maintenance should have a detrimental effect on verbal recall, as it has been already demonstrated, but should leave unchanged the effects related with the phonological characteristics of the memoranda.

The aim of our study was to test this prediction by exploring the occurrence of one of these phonologically related phenomena—namely, the phonological similarity effect (PSE). For this purpose, we used complex span tasks in which participants were asked to maintain lists of either phonologically similar or dissimilar words for further recall while performing secondary tasks designed to block one or the other (or both) of the two hypothesized mechanisms of maintenance.

PSE has been frequently reported in the literature of short-term memory. Several studies (e.g., Baddeley, 1966; Conrad, 1964; for a review, Baddeley, 2007) have shown that performance in immediate serial recall tasks was reduced when items to memorize were phonologically similar (e.g., *mad, man, mat, cap, cad, can, cat, cap*) rather than dissimilar (e.g., *cow, day, bar, few, hot, pen, sup, pit*).[1] This effect is assumed to result from confusion between memory traces that had similar phonological representations, and it is accordingly considered as an index of the phonological encoding of the memory items. This is supported by the fact that when the phonological processes also responsible for subvocal rehearsal are impeded by a concurrent articulatory suppression, PSE disappears for visually presented items (Baddeley, 2007). Contrasting with the large number of studies that have investigated the effect in immediate serial recall, studies about PSE in the context of working memory are scarce, and only few studies have manipulated phonological similarity in complex span tasks. These tasks, which are frequently used to assess working memory capacity, are quite similar to the simple span tasks with sequential presentation of words and recall at the end of each list. However, in complex span tasks, a concurrent task is introduced after the presentation of each word, participants maintaining the list of words while performing this secondary

[1] We do not discuss in this article one specific type of phonological similarity that is the lists of words sharing the same rhyme (e.g., *coin*, *joint*, *point*). In contrast to the detrimental effect of phonological similarity, the performance in immediate recall is better with rhyming words lists. The fact that all the words of a list belong to the same category (e.g., the words ending by "*oin*") seems to give a cue that facilitates their retrieval from memory (e.g., Fallon, Groves, & Tehan, 1999).

activity. For example, in the operation span task (Turner & Engle, 1989), participants verify equations such as "8/4 + 1 = 6" after the presentation of each word. Although these complex span tasks have some similarities to simple span tasks, they reflect the dual function of processing (i.e., concurrent task) and storage (i.e., maintenance of words), which is the specificity of working memory.

Predictions concerning the occurrence of a PSE in complex span task depend on the theoretical conception of what is working memory. For example, those models that integrate specific structures or processes for verbal short-term storage into a larger structure such as Baddeley's (2007, 2012) theory or the extended TBRS model (Camos et al., 2009) would expect PSE in complex span tasks as it is observed in immediate serial recall. On the contrary, alternative models may expect a PSE in simple span but not in the complex span tasks. We know, for example, that performance in complex span tasks is a better predictor of fluid intelligence or high-level cognition than simple spans (e.g., Conway, Kane, & Engle, 2003; Daneman & Carpenter, 1980; Engle, Tuholski, Laughlin, & Conway, 1999) suggesting that complex spans rely on different mechanisms from those involved in simple spans. This is well reflected in Unsworth and Engle's (2007) model, which distinguishes between a primary memory that can hold simultaneously only four items and a secondary memory. When more than four items need to be maintained or when distractors are processed after each item in complex span paradigm, attention will be distracted, and representations of memory items will be moved to secondary memory from which they would be recovered at recall. Thus, according to this model, the mechanisms underpinning performance in complex and simple span tasks differ, the former depending on the retrieval from secondary memory and the latter from the maintenance in primary memory, at least for part of the memory lists. Within this theoretical framework, it could be imagined that PSE would emerge only in simple span, and not in complex span tasks. To summarize, as Lobley, Baddeley, and Gathercole (2005) noted, understanding the role of the specific subsystems of working memory in complex span performance is of particular interest, because their contribution has been described by some as negligible (e.g., Just & Carpenter, 1992; Shah & Miyake, 1996), whereas others give them a potentially important role (Baddeley, 2007; Engle, Kane, et al., 1999; Kane & Engle, 2000; Towse, Hitch, & Hutton, 1998, 2000).

In fact, the four studies that have investigated PSE in complex span tasks led to rather divergent results (Camos et al., 2011; Lobley et al., 2005; Macnamara, Moore, & Conway, 2011; Tehan, Hendry, & Kocinski, 2001). Lobley et al. (2005) were able to reproduce the detrimental effect of phonological similarity in a complex span paradigm. Participants heard sentences for which they had to remember the last word while judging the grammaticality (Experiment 1) or the veracity of the sentences (Experiments 2 and 3). When the last words of each sentence shared central phoneme (e.g., *job, strong, hot*), recall performance was weaker than when the words had different central phonemes (e.g., *fast, rule, speech*). Lobley et al. also observed that when participants were asked to complete each sentence, and not simply to judge them, PSE was greater (0.45 vs. 0.04 of difference in span in Experiment 2). This increase in PSE may depend on the increase in attentional demand of the secondary task because completing sentences is more demanding than reading them. In accordance with this suggestion, there was also a trend for a larger PSE when sentences were more complex in the grammaticality judgement span task (0.65 vs. 0.26 of difference in span in Experiment 1). Similarly, Camos et al. (2011, Experiment 1) observed a detrimental effect of similar-word lists when the concurrent task was attention demanding like a choice reaction time (CRT) task, but PSE disappeared when the attentional demand of the task was low, such as a simple reaction time (SRT) task. To summarize, these studies reported a detrimental effect of similar-word lists on recall with a modulation of PSE according to the attentional demand of the concurrent task, PSE being stronger under higher attentional load. However, other studies failed to observe PSE or even reported a facilitating effect of similar-word lists.

Macnamara et al. (2011, Experiment 3) observed no effect of phonological similarity in a reading span task in which participants read aloud sentences and maintained unrelated words. More surprisingly, Tehan et al. (2001) observed better recall performance in similar lists when participants had to verify complex operations (Experiment 2A), but this effect disappeared when they had to read aloud the digits of the same operations (Experiment 2B). Although it is difficult to understand the facilitation effect as it was observed only in one experiment, in both studies PSE did not occur when the concurrent task required participants to speak aloud during retention. Finally, although the two tasks in Tehan et al. (2001) varied in attentional demand (verifying operations vs. just reading digits), a possible effect of attentional demand of the concurrent task on PSE could not be assessed, because this factor covaried with articulatory suppression during retention, the verification of operation being silent (pressing keys) while reading digits was aloud.

To summarize, results on PSE in complex span tasks are quite inconsistent, but the analysis of concurrent tasks used in these four studies sheds light on what could cause variations in PSE. First, when the concurrent task is performed aloud, such as reading sentences in Macnamara et al. (2011) or reading digits in Tehan et al. (2001, Experiment 2B), phonological similarity of the memory items had no effect on recall. This lack of effect could be reminiscent of what is observed in immediate recall tests in which articulatory suppression makes PSE disappear when items are visually presented. This disappearance is usually explained by the fact that concurrent articulation would impede phonological encoding of visual stimuli, which is assumed to be the source of PSE. However, in the studies using complex span tasks reported above, there is no doubt that memory items were phonologically encoded, because they were either auditorily presented (Lobley et al., 2005) or visually presented but read aloud (Camos et al., 2011; Macnamara et al., 2011; Tehan et al., 2001). This suggests that the disappearance of PSE in complex span tasks involving concurrent articulation cannot be ascribed to a lack of phonological encoding of memory items. Nonetheless, encoding and maintenance are more distinguishable processes in complex than in simple span tasks. In complex span tasks, the processing episodes between memory items result in protracted delay between encoding and recall, which makes necessary the use of specific processes to maintain memory traces in an active state (Camos et al., 2009, 2011). The reported findings suggest that the PSE in complex span tasks would depend on availability of phonological processes during maintenance.

Second, PSE seems to emerge or increase with the attentional demand of the secondary task. For example, in Lobley et al. (2005), PSE was stronger when participants had to complete rather than simply read sentences, the former process being probably more demanding. Similarly, in Camos et al. (2011), there was no PSE when the distracting activity was a SRT task, but the effect appeared with a more demanding CRT task.

It is worth noting that the two factors on which PSE occurrence in complex span tasks seems to depend (i.e., attentional demand and articulatory requirement of the concurrent task) point towards the two systems of maintenance hypothesized by the TBRS model: Attentional demand impedes refreshing whereas articulatory suppression blocks subvocal rehearsal. The hypothesis of two independent mechanisms of maintenance leads to the prediction that PSE should occur when the phonological-specific system is available for maintenance and should consequently disappear when concurrent articulation hinders its use. By contrast, impeding attentional refreshing with a demanding concurrent task should lead to poorer verbal recall but should leave PSE unaffected as long as the phonological system remains available. We tested these hypotheses by manipulating the articulatory suppression and attentional demand induced by the secondary task of complex span tasks in which participants had to maintain lists of six similar or dissimilar words. The two first experiments investigated the occurrence of PSE in complex span tasks in which the processing component induced either a concurrent attentional load (Experiment 1) or a concurrent articulation (Experiment 2). In the last experiment (Experiment 3), these two factors were orthogonally manipulated. In Experiment 1, the concurrent attentional demand was created by a silent judgement location task in which participants were to judge the location of a square presented on the bottom or top of the screen by pressing designated keys. This visuospatial task with manual responses was intended to minimize sources of potential representation-based interferences. It should be noted that in most studies reported above, the concurrent task involved verbal items. Either participants heard, read, or completed sentences, or they read or solved arithmetic operations. Although Lobley et al. (2005, Experiment 3) have shown that the nature of the responses to the secondary task (oral or by pressing key) does not affect PSE, it remains that verbal distractors (e.g., reading sentences) could interfere with verbal memoranda (words) and obscure the effects of the two factors of interest here.

In Experiment 2, concurrent articulation was induced by asking participants to repeat "oui" (yes) while maintaining the same lists of words as those in Experiment 1. The articulation of this monosyllabic word would impede phonological mechanism during maintenance, but it does not require much attention (Naveh-Benjamin & Jonides, 1984). In Experiment 3, we manipulated orthogonally the attentional demand of the secondary task and the presence of a concurrent articulation during maintenance.

EXPERIMENT 1

The aim of Experiment 1 was to test the occurrence of PSE in a complex span task in which the concurrent task induced attentional demand. For this purpose, participants were asked to judge the location of squares on screen by pressing keys on keyboard. This secondary task had the advantage of not involving verbal distractors that could cause interference with the words to maintain. Between each word, participants judged the location of six squares presented successively. Although the analysis of the literature suggests that PSE in complex span tasks is related to the attentional demand of the concurrent task, our theory predicts a PSE in complex span tasks that should remain unaffected by variation of the attentional demand of the secondary task. For this purpose, we created two levels of attentional demand by varying the pace at which the squares were displayed on screen, either at a slow rate of 1,500 ms per square or at a rapid rate of 750 ms per square. Increasing the pace of the concurrent task has been shown to increase the attentional demand of the task, resulting in poorer recall performance (for a review, Barrouillet et al., 2011). The same lists of six words as those in the pretest were used (see Appendices A and B). Recall performance was assessed in three different scores—that is, in terms of *correct position*, *correct item,* or *correct order*. Indeed, two of the four previous studies that tested the PSE in complex span tasks analysed these three scores and observed some variations in results depending on scores. Tehan et al. (2001) observed a PSE in Experiment 2A, but only on the *correct position* and *correct item* scores. By contrast, Macnamara et al. (2011) observed no PSE for the three scores.

Method

Participants

Twenty-three undergraduate students at the Université de Bourgogne (France) participated in the experiment in exchange for additional course credit. The 20 women and 3 men were all native French speakers and were aged from 17 to 22 years ($M = 19.0$, $SD = 1.13$).

Material and procedure

Previous studies on PSE were mainly done in English, and, to our knowledge, the only lists of phonologically similar words created in French were those used by Fournet, Juphard, Monnier, and Roulin (2003). However, the similar word lists in Fournet et al. (2003) were rhyming words. Thus, we built our own lists of words that shared the same central phoneme as that in Baddeley's (1966) original study.

Lists of six words to memorize were built from an initial corpus of 914 singular nouns extracted from the database of French words *Lexique 3* (New, Pallier, Ferrand, & Matos, 2001). The words were all monosyllabic with a CVC (consonant–vowel–consonant) phonological structure. The lists of similar words were constructed by selecting words with the same central phoneme, but different initial and final phonemes (e.g., *boule, coupe, four, goutte, pouce, douche*). Twenty lists were constructed and then divided into two sets of 10 lists (S1 and S2). We took care that the lists with the same central phoneme were not all in the same set (e.g., among the five lists containing words with the central phoneme [a], three were randomly assigned to set S1, and the other two were assigned to S2). From each set of similar lists, S1 and S2, two sets of dissimilar word lists, D1 and D2, were created. All lists of D1 were built by rearranging the words of the entire S1 as to minimize the number of phonemes shared within a list. Lists of D2 were formed in the same way from the words of S2 (see Appendix A). Thus, words in a list shared on average 0.90 phonemes for D1 and 0.93 for D2 versus 5.60 and 5.67 for S1 and S2, respectively. The words were also distributed in the lists while keeping the average frequency of words (i.e., the frequency of occurrence according to the corpus of books in *Lexique 3*) between 25 and 37 for each list. Finally, because the similar and dissimilar lists were composed of the same words, they did not differ on average in the characteristics of words such as length, concreteness, or imageability. In a pretest, we verified that these lists of words revealed a PSE in simple span task (see Appendix B).

These word lists were introduced as material to be maintained in a complex span paradigm. Participants were seated approximately 60 cm from the computer screen, in which stimuli were presented with Psyscope (Cohen et al., 1993). A trial began with the presentation of a fixation cross centred on screen (Figure 1). After 500 ms, the first word of a list was presented in red in the centre of the screen for 1,000 ms. After a delay of 500 ms, six squares of 18-mm side appeared successively on screen. The squares appeared randomly and with equal probability 15 mm above or below the centre of the screen. Participants were instructed to press a right key when the square appeared at the bottom of the screen and a left key when the square appeared at the top. For the slow pace, each square was presented for 1,000 ms, followed by a period of 500 ms before the onset of the next square, while for the fast pace, each square was presented for 500 ms, followed by a period of 250 ms. Each trial was preceded by an indication of the rate of appearance of the squares (i.e., “slow” or “fast”). After the presentation of six squares, a second word was presented, and so on. The words of a list were presented in random order, different for each participant. The list sets, S1, S2, D1, and D2, were counterbalanced between the two paces. Half of the participants saw lists of S1 and D2 with the slow pace and lists of S2 and D1 with the fast

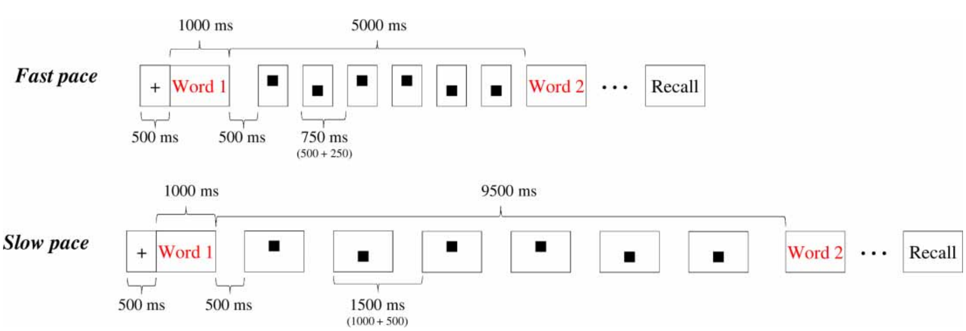

Figure 1. *The complex span paradigm involving the location judgement with fast and slow paces for Experiment 1. To view this figure in colour, please visit the online version of this Journal.*

pace, and vice versa for the other half of the participants. Therefore, each word was seen twice by a single participant in the experiment, once in a similar list and once in a dissimilar list, but never twice in the same pace. Once all the words from a list were presented, the word "Rappel" appeared on screen for 1,000 ms, indicating to participants to recall words aloud in serial order. The experimenter noted the order in which participants recalled words.

Recall was rated in three different ways by computing (a) the total percentage of words recalled in correct position (*correct position*), (b) the total percentage of words recalled regardless of position (*correct word*), and (c) the total percentage of correctly recalled positions (*correct order*) obtained by dividing the percentage of correct position by the percentage of correct word as proposed by Fallon et al. (1999). In addition, the percentages of correct responses and response times (RTs) for the location judgement task were registered to verify that participants correctly performed the concurrent task. A response was considered incorrect when participants pressed the wrong key or did not press any key. Only RTs for correct locations were considered for analysis.

A training phase of 36 stimuli to judge for each rate allowed participants to familiarize themselves with the location judgement task. Then, participants received a test trial for each rate for which the words to be remembered were replaced by first names. The experiment lasted approximately one hour.

Results

Due to a technical failure for two participants, the analyses of the percentages of correct response and RTs for the location judgement task were performed only on 21 participants. However, the recall scores of the entire sample were analysed.

To verify that participants paid enough attention to the location judgement task, analyses of variance (ANOVAs) were performed on the percentages of correct response and RTs for the location judgement task, with the pace of the task (fast vs. slow) and the type of list (similar vs. dissimilar) as within-subject factors. They revealed a single significant effect, the pace effect. While high enough to ensure that participants did their best on the location judgement task, the percentage of correct localizations was significantly higher in slow (94%, $SD = 4\%$) than in fast pace (91%, $SD = 6\%$), $F(1, 20) = 15.93$, $p < .001$, $\eta_p^2 = .44$, and RTs were on average longer in slow (380 ms, $SD = 31$ ms) than in fast pace (353 ms, $SD = 27$ ms), $F(1, 20) = 33.25$, $p < .001$, $\eta_p^2 = .62$. By contrast, memorizing similar or dissimilar words had no effect either on the percentage of correct location, $F < 1$, or on RTs, $F(1, 20) = 1.25$, $p = .277$, $\eta_p^2 = .06$.

More interestingly, ANOVAs were performed on each recall score—that is, *correct position*, *correct word*, and *correct order*—with pace (rapid vs. slow) and type of lists (similar vs. dissimilar) as within-subject factors. Whatever the score, the analysis revealed a similar pattern with a pace effect, an effect of the type of lists, but no interaction.

For the *correct position* scores, dissimilar words were better recalled (66%, $SD = 17\%$) than similar words (53%, $SD = 18\%$), $F(1, 22) = 29.37$, $p = .001$, $\eta_p^2 = .57$. More words were also recalled in the correct position in slow (64%, $SD = 18\%$) than in fast pace (55%, $SD = 17\%$), $F(1, 22) = 25.05$, $p < .001$, $\eta_p^2 = .53$. The interaction between type of lists and pace was not significant, $F < 1$ (Figure 2). The pattern of results was the same for the *correct word* scores, with dissimilar lists (80%,

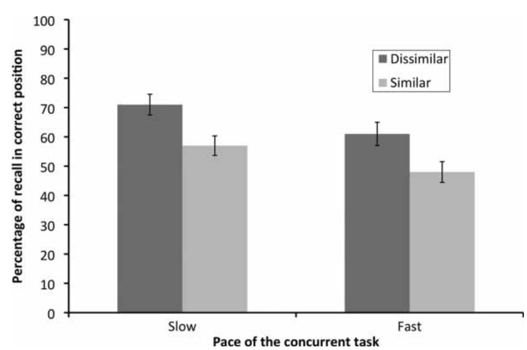

Figure 2. *Mean percentages of recall in the correct position according to the pace of concurrent task (slow vs. fast) and the type of list (similar vs. dissimilar) in Experiment 1.*

$SD = 10\%$) better recalled than similar lists (73%, $SD = 12\%$), $F(1, 22) = 15.11$, $p < .001$, $\eta_p^2 = .41$, more words recalled in slow (81%, $SD = 10\%$) than in fast pace (73%, $SD = 12\%$), $F(1, 22) = 40.32$, $p < .001$, $\eta_p^2 = .65$, and no interaction, $F <$ 1. Finally, a similar pattern was obtained with the *correct order* score: The order of recall was better for dissimilar words (82%, $SD = 13\%$ vs. 71%, $SD = 16\%$), $F(1, 22) = 32.83$, $p < .001$, $\eta_p^2 = .60$, and in slow pace (78%, $SD = 14\%$, vs. 74 %, $SD = 15\%$), $F(1, 22) = 6.06$, $p < .05$, $\eta_p^2 = .22$. Finally, the PSE also did not interact with the pace of the concurrent task, $F < 1$.

Discussion

The purpose of Experiment 1 was to assess the PSE in complex span tasks, because the results found in the literature are too divergent to draw any firm conclusion about the existence of such an effect. An analysis of existing studies showed that they all introduced verbal tasks as a secondary task in complex span tasks, which could create representational interference with the words to be maintained. Moreover, the PSE in two studies seemed amplified when attentional demand of the secondary task was increased. Experiment 1 gave us the opportunity to test the PSE when verbal interference sources were reduced because the secondary task required processing of visuospatial stimuli (i.e., squares shown at the top or bottom of the screen) by giving a motor response (i.e., pressing keys). In addition, we were able to assess the impact on the PSE of the attentional demand of the secondary task by manipulating its pace.

The results are clear and consistent whatever the type of scores used in the analysis. First, we observed a detrimental PSE on recall in a complex span task. As had been observed by Lobley et al. (2005), lists of similar words were recalled less than lists of dissimilar words. This result goes against the results of Macnamara et al. (2011) and Tehan et al. (2001). It should also be noted that the PSE in Experiment 1 was similar in size (13% in *correct position*) to the effect observed in the immediate serial recall task (12%) in the pretest where the same word lists were used. Moreover, Experiment 1 replicated an effect that has been observed many times (e.g., Barrouillet et al., 2004; Barrouillet, Bernardin, Portrat, Vergauwe, & Camos, 2007). Indeed, increasing the pace of the secondary task reduced performance. Reducing from 1,500 to 750 ms the time available to do a location judgement reduced the time during which attention can be diverted from the secondary task and dedicated to the maintenance of memory traces, for example by attentional refreshing. With less time for maintenance, memory traces are of lower quality at the time of recall, resulting in a drop in performance. Although the increased pace of the secondary task reduced recall performance, it did not affect the PSE as shown by the absence of interaction. Thus, contrary to what could be observed in Lobley et al. (2005), increasing attentional demand of the secondary task does not increase the size of the PSE. These findings are also at odds with Camos et al. (2011) in which the type of concurrent task (SRT vs. CRT) interacted with PSE. However, whereas the two tasks greatly differed in attentional demand in Camos et al. (2011), the present study only modulated the attentional demand of the same task. The observed lack of interaction could result from an insufficient variation in attentional demand between the two conditions. In Experiment 3, we compared two greatly contrasted conditions in terms of attention requirements.

EXPERIMENT 2

The aim of the second experiment was to verify that concurrent articulation makes PSE disappear in complex span task as our theory predicts. Participants had to maintain the same lists of similar or dissimilar words as those in Experiment 1, but the concurrent task was here the recurrent articulation of a single monosyllabic word. Such a concurrent articulation would impede articulatory mechanism during maintenance, but leave it available during encoding.

Method

Participants

Twenty-seven undergraduate students at the University of Bourgogne (France) participated in the experiment in exchange for additional course credit. The 25 women and 2 men were all native French speakers and were aged from 17 to 25 years ($M = 19.6$ years, $SD = 1.71$). None of them had participated in the pretest or in Experiment 1.

Material and procedure

The same word lists as those used in Experiment 1 were used in this experiment, and participants saw all the 40 lists in a random order, half being similar word lists and half dissimilar word lists. The procedure was similar to the fast pace condition in Experiment 1. However, in the 5,000-ms delay between words, participants repeated "oui" (yes) at a constant pace. To ensure that participants kept saying "oui" regularly and at the same pace in all trials, a black square was repeatedly presented for 250 ms in the centre of screen with a stimulus onset asynchrony (SOA) of 500 ms. As a consequence, participants repeated "oui" 10 times after each word.

Results

ANOVAs were conducted on the three recall scores (*position correct*, *correct word*, and *correct order*) with the type of lists as within-subject factor. Among the three scores, PSE was drastically reduced compared with the pretest and Experiment 1, to the point of being nonsignificant for the *correct position* (dissimilar: 61%, $SD = 18\%$, vs. similar: 58%, $SD = 19\%$), $F(1, 26) = 2.22$, $p = .148$, $\eta_p^2 = .08$, and the *correct word* (72% for both types of list) scores, $F < 1$, although it remained significant for *correct order* score (81% vs. 78%), $F(1, 26) = 4.99$, $p < .05$, $\eta_p^2 = .16$.

Discussion

The introduction of a mere articulation as a concurrent task in a complex span task was enough to dramatically reduce PSE. Although participants probably encoded the memory items phonologically, impeding articulation during maintenance made PSE disappear. Usually, such articulatory suppression is thought to impede the subvocal rehearsal in charge of maintaining verbal items in the short term. This suggests that the occurrence of PSE in complex span tasks relies on the use of subvocal rehearsal to maintain memory items. At a first sight, this could be considered at odds with the literature in which PSE is an index of the phonological nature of the memory traces and not of the implication of an articulatory mechanism of maintenance (Baddeley, 2007). We address this issue in our general discussion and show how this could be easily reconciled within Baddeley's conception of a phonological loop.

EXPERIMENT 3

In this last experiment, we orthogonally manipulated the two factors explored in the previous experiments. As previously, participants maintained lists of similar or dissimilar words in a complex span task in which the nature of the concurrent task was varied. As we discussed, the lack of interaction between PSE and the concurrent task in Experiment 1 may result from an insufficient difference in attentional demand between the two conditions of concurrent task. Thus, we chose to maximize this difference in the present experiment. After the presentation of a memory item, participants were presented either with the same location judgement task as that in Experiment 1 or with an unfilled delay of the same duration as that of the location task. Moreover, we manipulated the level of articulatory suppression by asking participants either to remain quiet or to concurrently repeat the word "oui" in the interitem intervals. To ensure that the amount of articulatory suppression remained similar between individuals and across trials and conditions, participants heard beeps in a headphone, which primed saying "oui". Although this manipulation probably required more attention than simply repeating "oui" at self-pace, this supplementary attentional demand should be rather small in comparison with the induced difference in attentional demand between the unfilled delay and the location judgement task.

Method

Participants

Twenty-nine undergraduate students at the University of Bourgogne (France) participated in the experiment in exchange for additional course credit. The 25 women and 4 men were all native French speakers and were aged from 17 to 23 years ($M = 19.1$ years, $SD = 1.28$). None of them had participated in the pretests or in Experiments 1 and 2.

Material and procedure

Because we needed more lists of words for Experiment 3, we constructed a new pool of word lists that were pretested in an immediate recall task (see Appendix C). It gave us the opportunity to replicate the previous findings with new material, thus minimizing the risk that our results depend on these specific lists. Lists of six words were constructed from a corpus of 275 monosyllabic words extracted from the database of French words *Lexique 3* (New et al., 2001). The words had a CVC phonological structure and three to six letters. These new lists were constructed in the same way as in the previous experiments, except that the sets S1, S2, D1, and D2 contained 16 lists (see Appendix D). The words of a list shared on average 0.83 and 1.06 phonemes for D1 and D2, respectively, and 6.4 and 5.81 for S1 and S2, respectively. The words were also distributed in the lists so that the average frequency of words within a list was between 17 and 36 (frequency of occurrence in the corpus of books in *Lexique* 3). However, the frequencies of the words were more widely distributed, between 3.51 and 95.27, because only a limited number of words corresponding to our selection criteria had a frequency close to 30. Half the participants saw the lists S1 and D2, while the other half of participants saw the lists S2 and D1. A procedure similar to that in the previous experiments was designed for Experiment 3, with a delay of 6,000 ms between words. This delay was filled differently according to four conditions (Figure 3).

In the unfilled delay (D) condition, the screen remained blank, and participants had nothing to do. In the articulatory suppression (AS) condition, a sequence of 12 tones (32 bit, 44,100 Hz) was presented in a headset. Each tone lasted 10 ms and was followed by a silence of 490 ms. The first beep appeared 500 ms after a word. Participants were instructed to say “oui” (yes) each time they heard a beep. In the location judgement task condition (T), a sequence of six squares of 18-mm side was presented on the screen. Each square appeared for 667 ms, followed by a blank screen for 333 ms for a total of 1,000 ms per square. The squares appeared randomly with equal probability either 15 mm above or 15 mm below the centre of the screen. The first square appeared immediately after a word. Participants were instructed to judge the location of the squares by pressing keys as in Experiment 1, a right key when the square appeared at the bottom of the screen and a left key when the square appeared at the top. In a last condition (TAS), the location judgement task was carried out simultaneously with articulatory suppression. Thus, participants were asked to say “oui” each time they heard a beep, while judging the location of the squares on the screen by pressing keys. At the end of the 6,000-ms delay, a second word was presented for 1,000 ms, followed again by a delay, and so on. The words of a list were presented in random order. Recalled words were typewritten as in the pretest.

Each of the four conditions included eight trials, four with similar-word lists and four with dissimilar-word lists. The word lists were drawn randomly from the new pool of lists. The order of the eight trials was randomized with no more than two lists of the same type following each other. The four conditions were presented per block, and the order of blocks was random. At the beginning of each block, participants were familiarized with the procedure. They performed one trial in the D and AS conditions, two in the T condition to familiarize themselves with the location judgement task, and four in the TAS because it required the simultaneous location judgement and articulatory

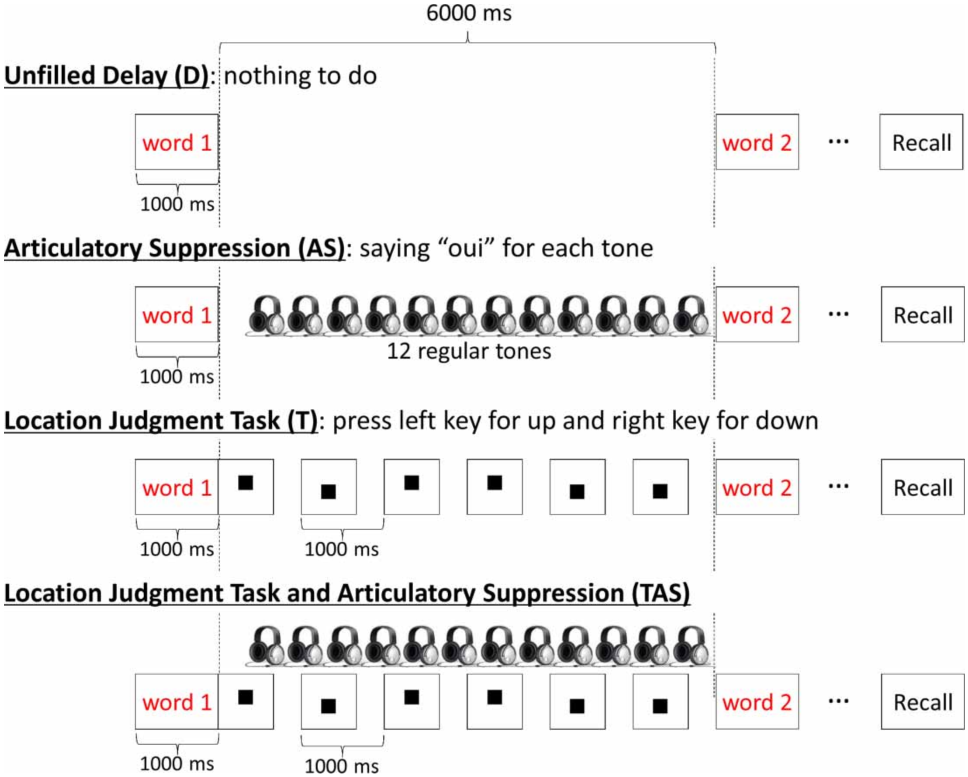

Figure 3. *The four conditions used in Experiment 3. To view this figure in colour, please visit the online version of this Journal.*

suppression. For these training trials, the memory items were first names to avoid any interference with the words used in the test phase, as in previous experiments. The experiment lasted approximately one hour.

The percentages of correct localizations and RTs for the location judgement task were recorded to monitor that participants performed the task correctly as well as the amount of articulatory suppression (i.e., the number of "oui" responses produced).

Results

The data of all participants were considered for analysis since their percentages of correct location judgement were above 70% in the dual-task conditions (i.e., T and TAS conditions). We performed ANOVAs with repeated measures on the percentages of correct judgement and on RTs with similarity (similar vs. dissimilar) and articulatory suppression (no suppression = T vs. with suppression = TAS) as within-subject factors. These analyses revealed no effect of similarity, no articulatory suppression effect, and no interaction between similarity and articulatory suppression (ps $> .15$). The judgements were as correct in T as in TAS conditions (86%, $SD = 7\%$, and 85%, $SD = 8\%$, respectively), and the RTs did not differ between these two conditions (419 ms, $SD = 49$ ms, and 425 ms, $SD = 47$ ms).

Regarding recall scores, ANOVAs were performed with similarity (similar vs. dissimilar), attentional demand (low: D and AS vs. high: TAS and T), and articulatory suppression (without: D and T vs. with: AS and TAS) as within-subject factors. For the *correct position* scores, the PSE observed in the pretest was replicated. Similar words (54%, $SD = 16\%$) were less recalled than dissimilar words (61%, $SD = 17\%$), $F(1, 28) = 15.36$, $p < .01$, $\eta_p^2 = .35$. The recall was also affected by the introduction of an attentional demand through the location judgement task (50%, $SD = 17\%$ vs. 65%, $SD = 16\%$ for conditions with and without judgement task, respectively), $F(1, 28) = 81.46$, $p < .001$, $\eta_p^2 = .74$. Finally, recall was lower under articulatory suppression (50%, $SD = 18\%$ vs. 65%, $SD = 16\%$ for conditions with and without concurrent articulation, respectively), $F(1, 28) = 42.62$, $p < .001$, $\eta_p^2 = .60$.

More importantly, concerning PSE, the main findings of the two previous experiments were replicated. First, the observed PSE was not affected by the attentional demand of the secondary task, as testified by the nonsignificant interaction between similarity and attentional demand, $F < 1$. By contrast, PSE depended on the presence of a concurrent articulation with a significant interaction between similarity and articulatory suppression, $F(1, 28) = 17.93$, $p < .001$, $\eta_p^2 = .39$. No other interaction was significant. Planned comparisons showed a PSE in both silent conditions, $F(1, 28) = 18.89$, $p < .001$, $\eta_p^2 = .40$, for the silent unfilled delay condition, $F(1, 28) = 18.79$, $p < .001$, $\eta_p^2 = .40$, and for the silent location judgement task condition. By contrast, PSE disappeared in both conditions with articulatory suppression, performed either alone, $F(1, 28) = 1.74$, $p = .198$, $\eta_p^2 = .06$, or with the concurrent judgement task, $F < 1$ (Figure 4).

The pattern of results was similar for the two other scores. For the *correct word* score, the main effects of similarity, concurrent task, and articulatory suppression were significant, $F(1, 28) = 13.03$, $p < .01$, $\eta_p^2 = .32$, $F(1, 28) = 87.32$, $p < .001$, $\eta_p^2 = .76$, and $F(1, 28) = 48.06$, $p < .001$, $\eta_p^2 = .63$, respectively. The interaction between similarity and articulatory suppression was the only significant interaction, $F(1, 28) = 12.87$, $p < .01$, $\eta_p^2 = .31$, PSE being significant under D and T conditions, $F(1, 28) = 22.64$, $p < .001$, $\eta_p^2 = .45$, and $F(1, 28) = 11.16$, $p < .01$, $\eta_p^2 = .29$, but not under AS and TAS, $F(1, 28) = 1.08$, $p = .309$, $\eta_p^2 = .04$ and $F < 1$, respectively. Finally, for the *correct order* score, the similarity and concurrent task effects were significant, $F(1, 28) = 7.88$, $p < .001$, $\eta_p^2 = .22$, and $F(1, 28) = 22.84$, $p < .001$, $\eta_p^2 = .45$, respectively, but not the effect of articulatory suppression,

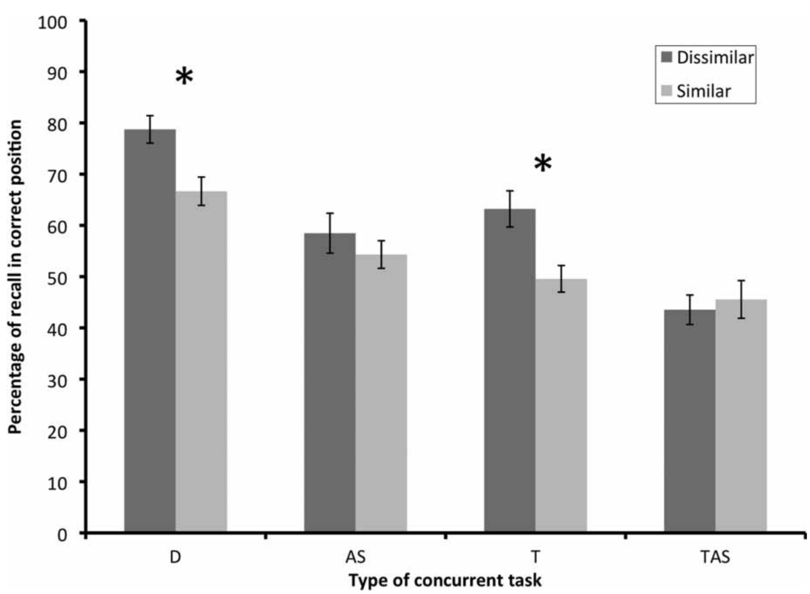

Figure 4. *Mean percentages of recall in the correct position according to the four conditions and the type of list (similar vs. dissimilar) in Experiment 3. Asterisks refer to significant phonological similarity effect (PSE). D = unfilled delay. AS = articulatory suppression. T = location judgement task. TAS = location judgement task simultaneously with articulatory suppression.*

$F(1, 28) = 2.19$, $p = .150$, $\eta_p^2 = .07$. However, and as in the previous analyses, the similarity interacted with the articulatory suppression, $F(1, 28) = 5.94$, $p < .05$, $\eta_p^2 = .18$, with the same pattern as that previously described: PSE was significant under D and T conditions, $F(1, 28) = 4.88$, $p < .05$, $\eta_p^2 = .40$, and $F(1, 28) = 9.70$, $p < .01$, $\eta_p^2 = .40$, but not under AS and TAS, Fs < 1, respectively. No other interaction was significant.

Discussion

This last experiment had two aims. First, it aimed at evaluating the impact on PSE of the two factors of interest—the articulatory and attentional demands of the concurrent task—by varying them orthogonally. Second, because Experiment 1 failed to reveal an interaction between PSE and the variation in attentional demand, contrary to what previous findings led to expect (Camos et al., 2011; Lobley et al., 2005), we generated a stronger contrast in attentional demand between conditions by introducing in a complex span paradigm either a demanding judgement task or an unfilled delay.

The results replicated the main findings of the two previous experiments while using a different set of word lists. The PSE observed in complex span task disappeared under concurrent articulation, but remained unaffected by the attentional demand of the intervening task. Moreover, the absence of interaction between PSE and attentional demand observed in Experiment 1 was replicated here, although we dramatically contrasted the two conditions. This discards the suggestion that the absence of interaction was due to insufficient manipulation of the attentional demand in Experiment 1 and speaks in favour of an absence of implication of attentional mechanisms in the emergence of PSE in complex span tasks. Finally, only this experiment could assess the potential interactive effects of articulatory suppression and attentional demand on PSE, and it failed to report any significant three-way interaction. We discuss these findings below.

GENERAL DISCUSSION

Recently, we suggested that the maintenance of verbal information in working memory is sustained by two distinct systems: One is specifically dedicated to the maintenance of phonological representations through verbal rehearsal while the other would maintain multimodal representations through attentional refreshing (Barrouillet & Camos, 2010; Camos et al., 2009). This theoretical framework predicts that phonologically related phenomena should occur when the domain-specific system is involved in maintenance, but should disappear when concurrent articulation hinders its use. By contrast, impeding maintenance in the domain-general system by a concurrent attentional demand should impair recall performance without affecting phonologically related phenomena. The aim of the present study was to test this prediction by investigating the occurrence of PSE in complex span tasks and how this effect is affected by the articulatory suppression and the attentional demand induced by the secondary task. Four main findings emerged from this study.

First, as we predicted and confirming previous studies like Lobley et al. (2005) and Camos et al. (2011), we observed a PSE in complex span tasks, recall performance being better for phonologically dissimilar than similar word lists. This effect is often observed in immediate serial recall test, but the literature brought a mixed picture in the complex span paradigm, with two out of the four studies failing to report PSE in complex span tasks (Macnamara et al., 2011; Tehan et al., 2001). However, and this is our second main finding, the introduction of a concurrent articulation during retention made PSE disappear. Such an effect of articulatory suppression explains why PSE was not reported when participants read aloud digits in Tehan et al. (2001) or sentences in Macnamara et al. (2011). In line with our theory, this suggests that the emergence of PSE depends on the maintenance of memory traces in verbal-specific system through rehearsal. As we already mentioned, this conclusion could be considered at odds with the main conception of the phonological loop, the subsystem dedicated to verbal information in Baddeley's (1986, 2007) theory.

In immediate serial recall, the auditory presentation of the memory items or their visual presentation with their conversion by subvocalization both lead to a phonological representation of the memory items, and thus to the PSE (Baddeley, 2007). When subvocalization is impeded by articulatory suppression, the visually presented words would not gain access to the phonological store, and the PSE does not appear. By contrast, auditorily presented words automatically gain access to the phonological store, and even under articulatory suppression, PSE occurs (Baddeley, Lewis, & Vallar, 1984). The effect is thus usually taken as evidence of the phonological nature of the store rather than of the nature of the rehearsal process. Thus, in immediate serial recall, recall of information is liable to PSE when phonologically encoded. By contrast, in complex span tasks, PSE seems to depend on the availability of verbal rehearsal. This finding could be reconciled with Baddeley's conception by assuming that the constraints induced by the secondary task on maintenance mechanisms have an impact on the nature of memory traces. Because there are two mechanisms of maintenance for verbal information in working memory, the format of representation underpinning recall depends on the type of mechanism available. Even if memory items are initially phonologically encoded, concurrent articulation prevents the maintenance of this form of representation during the protracted delays of retention that characterize complex span tasks. In this case, information would be maintained in a multimodal format within the still-available domain-general system, a format that would make memory traces immune to PSE.

Accordingly, and in line with our predictions, variation in the attentional demand of the concurrent task did not modulate PSE, contrary to what was observed by Lobley et al. (2005) and Camos et al. (2011). PSE remained unchanged even under a drastic manipulation in Experiment 3, and even though the overall level of recall was reduced when the concurrent task was more demanding, as it was expected. The increased PSE observed by Lobley et al. (2005) when participants were asked to complete sentences rather than to read them for veracity judgement (0.45 vs. 0.04 of difference in span, respectively) would then not come from an increase in attentional demand of the secondary task. Instead, it could result from a strong use of knowledge stored in long-term memory when sentences have to be completed. This suggestion remains to be tested, and a precise account on how an increasing use of long-term knowledge would magnify PSE needs to be proposed. Nevertheless, such an explanation cannot account for Camos et al.'s (2011) findings, because they used tasks that poorly relied on long-term knowledge. Their more demanding task was similar to the location judgement task used here, and they also observed PSE. By contrast, Camos et al. (2011) did not observed PSE with a concurrent SRT task. The authors suggested that the absence of PSE resulted from the abandonment of the subvocal rehearsal for attentional refreshing that does not involve phonological representations and makes recall immune to PSE. This interpretation was corroborated by the fact that participants instructed to use attentional refreshing did not exhibit PSE. This impact of strategy use is reminiscent to Campoy and Baddeley (2008) and Hanley and Bakopoulou (2003) who observed the same disappearance of PSE when instructing participants to use semantic encoding in immediate serial recall. This kind of interpretation is compatible with the idea that PSE depends on the nature of maintenance mechanisms.

Finally, the present study documented that attentional demand and articulatory suppression did not have interactive effect on PSE. Each of these factors is known to affect specifically one mechanism of maintenance: attentional refreshing and subvocal rehearsal, respectively. It is thus not so surprising that they did not interact, if we admit that the two maintenance mechanisms are independent, as suggested by Camos et al. (2009) and Baddeley (2012).

Overall, the present results support our predictions and the hypothesis that variations in PSE in complex span tasks depend on the availability of a verbal rehearsal mechanism for maintaining phonological representations of the memoranda. However, an alternative account would be that concurrent articulation produces interfering verbal material instead of blocking rehearsal, such interference driving the observed effects. In an immediate serial recall task, Gupta and MacWhinney (1995) showed that part of the concurrent articulation effect is due to interference created by the speech. Though representation-based interference probably plays some role in forgetting, the extant literature about the interference between distractors and memory items in complex span tasks suggests that the dramatic effects produced by concurrent articulation in our experiments cannot be accounted for by a representation-based interference hypothesis, whatever the mechanism of interference invoked. Among the most frequently hypothesized sources of interference are the response competition created by the similarity between distractors and targets, the distortion of memory traces by superposition of distributed representations, and the feature overwriting (Oberauer, 2009). As far as response competition is concerned, converging empirical evidence indicates that the degree of phonological similarity between targets and distractors in complex span tasks has no effect on recall performance (e.g., Oberauer, 2009; Oberauer, Lange, & Engle, 2004). The superposition of distributed representations predicts the opposite of the response competition account, dissimilar distractors having the more detrimental effect. Within this account, forgetting depends on the novelty or dissimilarity of the distractors with the current content of short-term memory, novel items receiving larger encoding weight and producing stronger interference, whereas repeated items would result in negligible encoding weight (Lewandowsky, Geiger, & Oberauer, 2008). Recall that participants were asked to repeatedly utter the French word “oui” [wi] between two successive memory items. It could be argued that repeating the same word after each memory item would rapidly have no effect at all. However, as proposed by Oberauer, Lewandowsky, Farrell, Jarrold, and Greaves (2012), the association of “oui” to distinct position markers has the result that its first occurrence after each memory item reacquires novelty. This makes possible the occurrence of a novelty-gated interference. Nonetheless, it has been demonstrated that, within carefully controlled experimental settings, novelty has no effect per se (Plancher & Barrouillet, 2013), weakening the hypothesis of forgetting through novelty encoding.

It remains possible that the two constituent phonemes of “oui” involve a sufficient overlap with the phonemes of the memory items to overwrite them and induce forgetting (Nairne, 1990; Oberauer & Kliegl, 2006). It should be noted that in such models (e.g., Nairne, 1990) an attentional parameter can weight a particular type of feature. This could account for the differential effect of our concurrent tasks on PSE. A visuospatial intervening task could orient attention towards phonological features of the memory items, inducing a PSE, whereas a concurrent articulation could lead to favouring of nonphonological features, making PSE disappear. Thus, it could be argued that feature overwriting modulated by an attentional parameter could account for the present results. However, empirical manipulations of the potential amount of feature overwriting created by the feature overlap between memory items and distractors proved disappointing. An analysis of the extant literature and a comparison of the reported findings with our results clearly indicate that the present results, and especially the effect of concurrent articulation, cannot be totally accounted for by feature-overwriting interference. Oberauer (2009) studied the effects of such overwriting by comparing two levels of overlap between memoranda and distractors in a complex span task in which participants had to maintain lists of four words while reading four distractors after each memory item. In a low phoneme overlap condition, targets and distractors did not share any phoneme, whereas in the high overlap condition, all the phonemes of the memory items were repeated among distractor words. This sharp contrast from 0% to 100% of the phonemes in memory items that were repeated in distractors resulted in a small difference in recall performance (from 57.7 to 52.0% correct) that failed to reach significance in a further experiment. Could the same mechanism of overlap produce the decrease in recall that concurrent articulation involves in our experiments? Consider, for example, Experiment 3, in which recall performance for dissimilar lists dropped from 78.7% to 58.5% under concurrent articulation, with a mean proportion of phonemes in the memory items repeated in the distractors (i.e., the word "oui") that did not exceed 4%. It is clear that the dramatic decrease in recall produced by concurrent articulation cannot result from feature overlap.

Thus, none of the main representation-based interference mechanisms that have been described in the literature can account for the effect of concurrent articulation observed in our experiments. Moreover, suggesting that the effect of a concurrent articulation relies on the interference of the produced material restricts this effect to an irrelevant speech effect. In an immediate serial recall task, Hanley and Bakopoulou (2003) have already shown that PSE is not affected by irrelevant speech when mechanisms of maintenance are controlled for. Consequently, the idea that concurrent articulation has its effect by impeding verbal rehearsal to counteract forgetting remains the more plausible explanation.

CONCLUSION

To conclude, the present study brings further evidence in favour of our model in which verbal working memory involves two distinct and independent systems that differ in the nature of the stored representations and the processes of their maintenance. Our results point toward the hypothesis that one of these systems maintains phonological representations through verbal rehearsal, whereas the other holds multimodal memory traces through attentional refreshing. PSE would occur when the former system is available and disappears when it is hindered by concurrent articulation, resolving apparent discrepancies in the results reported in the literature. Our results suggest that both domain-general and domain-specific systems contribute to verbal maintenance at short term, thus constraining working memory theorizing.

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APPENDIX A

Word lists used for similar and dissimilar conditions in the pretest, Experiment 1, and Experiment 2

Similar word lists SI						*Similar word lists S2*					
Words	*Phonetic symbols*	*Frequency*	*Words*	*Phonetic symbols*	*Frequency*	*Words*	*Phonetic symbols*	*Frequency*	*Words*	*Phonetic symbols*	*Frequency*
faute	fOt	81,08	selle	sEI	16,08	danse	d@s	29,19	bête	bEt	63,18
taupe	tOp	2,84	rêve	REv	80,20	banque	b@k	25,54	fesse	fEs	6,42
paume	pOm	22,57	méche	mES	19,12	gang	g@g	3,04	maire	mER	13,11
zone	zOn	34,39	gêne	ZEn	26,96	fente	f@t	10,54	laine	lEn	34,86
dose	dOz	9,32	thése	tEz	7,77	lampe	l@p	70,88	chaise	SEz	86,35
sauce	sOs	11,76	paire	pER	26,89	manche	m@S	35,41	pelle	pEI	11,35
	6,00	**26,99**		*5,33*	**29,50**		*5,00*	**29,10**		*5,33*	**35,88**
bague	bag	16,08	rive	Riv	35,14	vase	vaz	26,76	bise	biz	8,11
gare	gaR	78,58	cire	siR	15,41	tache	taS	33,92	pipe	pip	25,74
dalle	dal	13,38	mine	min	48,18	cave	kav	42,09	fiche	fiS	7,57
vache	vaS	26,08	gîte	Zit	5,81	rage	RaZ	44,12	guide	gid	16,69
nappe	nap	18,18	vide	vid	75,74	patte	pat	21,28	rire	RiR	112,57
page	paZ	55,88	tic	tik	4,86	lac	lak	32,84	digue	dig	7,97
	5,67	**34,70**		*6,00*	**30,86**		*6,00*	**33,50**		*5,67*	**29,78**
châale	Sal	9,32	roche	RoS	14,12	chasse	Sas	53,38	port	poR	64,86
rame	Ram	5,74	colle	kol	7,43	bâche	baS	10,07	botte	bot	8,51
canne	kan	26,62	mode	mod	46,96	gaffe	gaf	17,57	somme	som	72,70
tasse	tas	25,07	tort	toR	51,55	date	dat	36,62	vol	vol	41,22
vague	vag	38,18	bosse	bos	6,82	lame	lam	25,81	rock	Rok	19,59
bar	baR	52,57	pote	pot	22,97	cap	kap	15,68	code	kod	13,58
	5,33	**26,25**		*5,67*	**24,98**		*5,33*	**26,52**		*5,67*	**36,74**
panne	pan	10,81	bonne	bon	43,99	chute	Syt	35,27	bol	bol	20,07
race	Ras	28,72	folle	fol	14,05	tube	tyb	11,35	poche	poS	101,82
case	kaz	9,46	note	not	39,32	ruse	Ryz	13,31	gomme	gom	9,26
dame	dam	106,15	coq	kok	15,68	cure	kyR	8,18	loge	loZ	18,11
bac	bak	13,99	gosse	gos	34,12	lune	lyn	63,24	choc	Sok	37,57
phare	faR	10,68	pomme	pom	46,08	nuque	nyk	48,51	fosse	fos	10,74
	5,67	**29,97**		*5,33*	**32,21**		*6,33*	**29,98**		*5,67*	**32,93**
bec	bEk	23,31	four	fuR	25,07	chéque	SEk	6,01	foule	ful	101,62
fer	fER	106,28	douche	duS	20,27	pêche	pES	26,76	court	kuR	7,30
messe	mEs	32,70	goutte	gut	30,34	théme	tEm	10,54	touffe	tuf	6,69
gel	ZEI	6,22	coupe	kup	33,58	scéne	sEn	95,27	mousse	mus	23,04
séve	sEv	7,03	boule	bul	38,31	guêpe	gEp	2,84	bouc	buk	8,92
veine	vEn	15,27	pouce	pus	29,86	zéle	zEI	10,61	soupe	sup	35,74
	5,67	**31,80**		*5,33*	**29,57**		*5,67*	**25,34**		*6,00*	**30,55**

Dissimilar word lists D1						*Dissimilar word lists D2*					
Words	*Phonetic symbols*	*Frequency*	*Words*	*Phonetic symbols*	*Frequency*	*Words*	*Phonetic symbols*	*Frequency*	*Words*	*Phonetic symbols*	*Frequency*
dame	dam	106,15	race	Ras	28,72	chasse	Sas	53,38	lac	lak	32,84
thése	tEz	7,77	séve	sEv	7,03	guide	gid	16,69	pêche	pES	26,76
coq	kok	15,68	note	not	39,32	zéle	zEI	10,61	théme	tEm	10,54
sauce	sOs	11,76	vide	vid	75,74	bouc	buk	8,92	vol	vol	41,22
goutte	gut	30,34	four	fuR	25,07	lampe	l@p	70,88	soupe	sup	35,74
panne	pan	10,81	colle	kol	7,43	vase	vaz	26,76	danse	d@s	29,19
	0,67	**30,42**		*1,33*	**30,55**		*1,00*	**31,21**		*1,33*	**29,38**
gare	gaR	78,58	canne	kan	26,62	rage	RaZ	44,12	port	poR	64,86
veine	vEn	15,27	paire	pER	26,89	fesse	fEs	6,42	laine	lEn	34,86
pote	pot	22,97	mode	mod	46,96	poche	poS	101,82	choc	Sok	37,57

(*Continued overleaf*)

Appendix A. Conntinued.

Dissimilar word lists D1						*Dissimilar word lists D2*					
Words	*Phonetic symbols*	*Frequency*	*Words*	*Phonetic symbols*	*Frequency*	*Words*	*Phonetic symbols*	*Frequency*	*Words*	*Phonetic symbols*	*Frequency*
dose	dOz	9,32	faute	fOt	81,08	court	kuR	7,30	mousse	mus	23,04
boule	bul	38,31	tic	tik	4,86	gomme	gom	9,26	fente	f@t	10,54
rame	Ram	5,74	châle	Sal	9,32	banque	b@k	25,54	ruse	Ryz	13,31
	0,67	**28,37**		*1,00*	**32,62**		*1,00*	**32,41**		*0,67*	**30,70**
page	paZ	55,88	zone	zOn	34,39	cave	kav	42,09	lame	lam	25,81
selle	sEI	16,08	messe	mEs	32,70	chéque	SEk	6,01	bête	bEt	63,18
bonne	bon	43,99	tort	toR	51,55	bise	biz	8,11	digue	dig	7,97
rive	Riv	35,14	paume	pOm	22,57	somme	som	72,70	code	kod	13,58
douche	duS	20,27	coupe	kup	33,58	lune	lyn	63,24	nuque	nyk	48,51
phare	faR	10,68	bague	bag	16,08	gang	g@g	3,04	manche	m@S	35,41
	0,67	**30,34**		*1,00*	**31,81**		*0,33*	**32,53**		*1,00*	**32,41**
bar	baR	52,57	vache	vaS	26,08	date	dat	36,62	patte	pat	21,28
méche	mES	19,12	rêve	REv	80,20	pelle	pEI	11,35	chaise	SEz	86,35
gosse	gos	34,12	folle	fol	14,05	rire	RiR	112,57	loge	lo"Z"	18,11
taupe	tOp	2,84	mine	min	48,18	fosse	fos	10,74	touffe	tuf	6,69
dalle	dal	13,38	case	kaz	9,46	tube	tyb	11,35	cure	kyR	8,18
gêne	ZEn	26,96	bosse	bos	6,82	guêpe	gEp	2,84	bâche	baS	10,07
	0,67	**24,83**		*1,00*	**30,80**		*1,00*	**30,91**		*1,00*	**25,11**
vague	vag	38,18	nappe	nap	18,18	tache	taS	33,92	gaffe	gaf	17,57
bee	bEk	23,31	fer	fER	106,28	maire	mER	13,11	scéne	sEn	95,27
pomme	pom	46,08	roche	RoS	14,12	pipe	pip	25,74	fiche	fiS	7,57
tasse	tas	25,07	gîte	Zit	5,81	rock	Rok	19,59	bol	bol	20,07
cire	siR	15,41	pouce	pus	29,86	foule	ful	101,62	chute	Syt	35,27
gel	ZEI	6,22	bac	bak	13,99	botte	bot	8,51	cap	kap	15,68
	1,00	**25,71**		*1,00*	**31,37**		*1,00*	**33,75**		*1,00*	**31,91**

Note: For each list, the mean number of phonemes shared between words is in italics, and the mean frequency is in bold.

APPENDIX B

Pretest for Experiments 1 and 2

This pretest verified that the pool of French words we used in Experiments 1 and 2 induced a phonological similarity effect (PSE) in a simple span task.

Method

Participants

Fifteen undergraduate students at the Université de Bourgogne participated in this pretest in exchange for additional course credit. The 10 women and 5 men were all native French speakers and between 18 and 23 years of age ($M = 19.2$; $SD = 1.52$).

Material and procedure

The same lists of words as those in Experiments 1 and 2 were used in this pretest. Participants were seated approximately 60 cm from the computer screen on which words were presented with Psyscope (Cohen, MacWhinney, Flatt, & Provost, 1993). In this simple span paradigm, participants memorized and recalled the word lists aloud. The words of a list were presented successively on screen for 1,000 ms with no delay between each word. The order of lists and words within a list was random. All lists were presented to each participant. Thus, a word was seen twice, in similar and in dissimilar lists. The presentation of words was immediately followed by the signal “Rappel” asking participants to recall words aloud in serial order.

Results

Analysis of variance (ANOVA) with repeated measures was performed on the total percentage of words recalled in correct position depending on the type of lists (similar vs. dissimilar). Similar words were recalled less (33%, $SD = 9\%$) than dissimilar words (45%, $SD = 12\%$), $F(1, 14) = 39.82$, $p < .001$, $\eta_p^2 = .74$. The same pattern was observed for the *correct word* scores (similar = 50% vs. dissimilar = 55%), $F(1, 14) = 19.93$, $p < .001$, $\eta_p^2 = .59$, and the *correct order* scores (similar = 66%; dissimilar = 81%), $F(1, 14) = 34.40$, $p < .001$, $\eta_p^2 = .71$. The latter two scores are reported here for comparison with the results of Experiments 1 and 2 in which they were introduced. Thus, we replicated PSE with these lists of CVC (consonant–vowel–consonant) French words.

APPENDIX C

Pretest for Experiment 3

Method

Participants

Twenty-six psychology students from the Université de Bourgogne, 25 women and 1 man, aged 18 to 21 years of age ($M = 18.92$, $SD = 0.84$) participated. None of them had participated in previous experiments.

Material and procedure

The same word lists as those used in Experiment 3 were used in this pretest. The simple span task was the same as that in the previous pretest, except that recall was done using the keyboard. Each word was seen only once during this pretest. Once all the words from a list had been presented, the word "Rappel" (recall) appeared on screen for 1,000 ms, and participants typed the words on the keyboard in the order of presentation. When "1" appeared on screen, participants had to type the first word and press the "Enter" key, which made "2" appear on screen for recalling the second word, and so on. When participants did not remember a word, they were instructed to press the "Enter" key to advance to the next word recall. Participants were informed that it was no longer possible to go back after pressing the "Enter" key. Once the recall was completed, participants pressed the space bar to move to the next trial.

Results

We replicated with this new pool of lists the phonological similarity effect (PSE) observed

APPENDIX D

Word lists used for similar and dissimilar conditions in the pretest, and Experiment 3

Similar word lists S1						*Similar word lists S2*					
Words	*Phonetic symbols*	*Frequency*	*Words*	*Phonetic symbols*	*Frequency*	*Words*	*Phonetic symbols*	*Frequency*	*Words*	*Phonetic symbols*	*Frequency*
comte	k§t	51,42	vide	vid	75,74	rage	RaZ	44,12	fil	fil	75,95
ronde	R§d	17,97	cire	siR	15,41	patte	pat	21,28	tir	tiR	16,01
songe	s§Z	10,68	tige	tiZ	11,15	lame	lam	25,81	guise	giz	20,61
pompe	P§P	18,45	rite	Rit	8,45	gaffe	gaf	17,57	pic	pik	10,34
bombe	b§b	15,00	pif	pif	7,23	bâche	baS	10,07	biche	biS	7,30
gong	g§g	3,51	niche	niS	6,35	phase	faz	6,76	gîte	Zit	5,81
	5,00	**19,51**		*6,00*	**20,72**		*5,67*	**20,94**		*5,67*	**22,67**
lampe	l@p	70,88	digue	dig	7,97	pente	p@t	39,19	pipe	pip	25,74
change	S@Z	9,26	pile	pil	21,55	manche	m@S	35,41	guide	gid	16,69
manque	m@k	36,28	vice	vis	13,45	rampe	R@p	18,18	vigne	viN	10,61
danse	d@s	29,19	bide	bid	8,38	lance	l@s	9,32	bise	biz	8,11
tente	t@t	19,12	fiche	fiS	7,57	banque	b@k	25,54	rive	Riv	35,14
bande	b@d	52,36	mine	min	48,18	jambe	Z@b	49,93	mythe	mit	5,61
	5,67	**36,18**		*5,67*	**17,85**		*6,00*	**29,60**		*5,33*	**16,98**
gare	gaR	78,58	port	poR	64,86	masse	mas	60,54	mode	mod	46,96
cage	kaZ	34,86	gosse	gos	34,12	chatte	Sat	29,12	bonne	bon	43,99
vase	vaz	26,76	bol	bol	20,07	canne	kan	26,62	pote	pot	22,97

(*Continued overleaf*)

Appendix D. Continued.

Similar word lists S1						*Similar word lists S2*					
Words	*Phonetic symbols*	*Frequency*	*Words*	*Phonetic symbols*	*Frequency*	*Words*	*Phonetic symbols*	*Frequency*	*Words*	*Phonetic symbols*	*Frequency*
bac	bak	13,99	code	kod	13,58	bague	bag	16,08	folle	fol	14,05
panne	pan	10,81	roc	Rok	7,50	phare	faR	10,68	noce	nos	6,55
nage	naZ	6,22	somme	som	72,70	pape	pap	14,59	choc	Sok	37,57
	6,67	**28,54**		*6,00*	**35,47**		*5,33*	**26,27**		*5,67*	**28,68**
page	paZ	55,88	col	kol	51,82	chasse	Sas	53,38	pomme	pom	46,08
base	baz	31,96	note	not	39,32	lac	lak	32,84	vol	vol	41,22
vache	vaS	26,08	roche	RoS	14,12	bar re	baR	23,18	coq	kok	15,68
lard	laR	11,01	gomme	gom	9,26	dalle	dal	13,38	fort	foR	8,99
malle	mal	10,27	toque	tok	6,55	case	kaz	9,46	botte	bot	8,51
rame	Ram	5,74	bosse	bos	6,82	gamme	gam	5,74	loge	loZ	18,11
	6,33	**23,49**		*6,00*	**21,32**		*5,67*	**23,00**		*5,33*	**23,10**
race	Ras	28,72	taule	tOI	13,85	cave	kav	42,09	faute	fOt	81,08
tache	taS	33,92	zone	zOn	34,39	date	dat	36,62	dose	dOz	9,32
vague	vag	38,18	môme	mOm	37,03	bal	bal	18,31	rôle	ROI	88,51
cape	kap	10,34	rose	ROz	30,34	nappe	nap	18,18	sauce	sOs	11,76
mare	maR	9,86	fauve	fOv	7,77	tasse	tas	25,07	chauve	SOv	5,14
châle	Sal	9,32	côte	kOt	90,74	char	SaR	7,91	paume	pOm	22,57
	6,33	**21,72**		*5,67*	**35,69**		*5,67*	**24,70**		*5,67*	**36,40**
scéne	sEn	95,27	boule	bul	38,31	neige	nEZ	74,93	coupe	kup	33,58
messe	mEs	32,70	four	fuR	25,07	bête	bEt	63,18	goutte	gut	30,34
ver	vER	5,61	mousse	mus	23,04	gêne	ZEn	26,96	mouche	muS	18,72
régne	REN	12,57	couche	kuS	22,77	cerf	sER	20,27	bourg	buR	13,85
pelle	PEI	11,35	touffe	tuf	6,69	peigne	pEN	8,85	pouce	pus	29,86
chéque	SEk	6,01	voûte	vut	18,85	laisse	lEs	18,85	fougue	fug	5,07
	6,67	**27,25**		*6,00*	**22,46**		*6,67*	**35,51**		*6,00*	**21,90**
chair	SER	90,81	soupe	sup	35,74	rêve	REv	80,20	sud	syd	28,38
laine	lEn	34,86	coude	kud	33,24	chaîne	SEn	43,24	duc	dyk	14,80
sel	sEI	31,01	douche	duS	20,27	paire	pER	26,89	pull	pyl	7,03
quête	kEt	13,92	bouc	buk	8,92	méche	mES	19,12	jupe	Zyp	34,05
théme	tEm	10,54	poule	pul	16,69	thése	tEz	7,77	butte	byt	5,34
fesse	fEs	6,42	foot	fut	5,54	gel	ZEI	6,22	russe	Rys	15,54
	6,67	**31,26**		*6,33*	**20,07**		*6,00*	**30,57**		*6,00*	**17,52**
chaise	SEz	86,35	lune	lyn	63,24	fête	fEt	70,41	nuque	nyk	48,51
mec	mEk	50,41	chute	Syt	35,27	caisse	kEs	51,01	lutte	lyt	37,36
pêche	pES	26,76	cure	kyR	8,18	reine	REn	30,00	juge	ZyZ	29,80
veine	vEn	15,27	tube	tyb	11,35	bec	bEk	23,31	ruse	Ryz	13,31
zêle	zEI	10,61	bulle	byl	6,62	maire	mER	13,11	cube	kyb	5,74
dette	dEt	5,14	fugue	fyg	5,68	séve	sEv	7,03	bûche	byS	5,14
	5,67	**32,42**		*6,00*	**21,72**		*6,00*	**32,48**		*6,33*	**23,31**
Dissimilar word lists D1						*Dissimilar word lists D2*					
Words	*Phonetic symbols*	*Frequency*	*Words*	*Phonetic symbols*	*Frequency*	*Words*	*Phonetic symbols*	*Frequency*	*Words*	*Phonetic symbols*	*Frequency*
niche	niS	6,35	tige	tiZ	11,15	vigne	viN	10,61	méche	mES	19,12
port	poR	64,86	gong	g§g	3,51	ruse	Ryz	13,31	loge	loZ	18,11
boule	bul	38,31	tache	taS	33,92	reine	REn	30,00	guise	giz	20,61
chéque	SEk	6,01	four	fuR	25,07	barre	baR	23,18	patte	pat	21,28
panne	pan	10,81	bol	bol	20,07	chauve	SOv	5,14	russe	Rys	15,54
tube	tyb	11,35	pêche	pES	26,76	date	dat	36,62	faute	rot	81,08
	1,33	**22,95**		*0,67*	**20,08**		*2,00*	**19,81**		*0,33*	**29,29**
nage	naZ	6,22	soupe	sup	35,74	rôle	ROI	88,51	pomme	pom	46,08

(*Continued overleaf*)

Appendix D. Continued.

Dissimilar word lists D1						*Dissimilar word lists D2*					
Words	*Phonetic symbols*	*Frequency*	*Words*	*Phonetic symbols*	*Frequency*	*Words*	*Phonetic symbols*	*Frequency*	*Words*	*Phonetic symbols*	*Frequency*
bosse	bos	6,82	change	S@Z	9,26	neige	nEZ	74,93	pouce	pus	29,86
mec	mEk	50,41	malle	mal	10,27	pape	pap	14,59	sauce	sOs	11,76
chute	Syt	35,27	code	kod	13,58	cube	kyb	5,74	bâche	baS	10,07
ronde	R§d	17,97	côte	kOt	90,74	mythe	mit	5,61	guide	gid	16,69
couche	kuS	22,77	théme	tEm	10,54	canne	kan	26,62	gêne	ZEn	26,96
	0,67	**23,24**		*1,00*	**28,36**		*1,00*	**36,00**		*1,00*	**23,57**
zone	zOn	34,39	lampe	l@p	70,88	maire	mER	13,11	char	SaR	7,91
mare	maR	9,86	quête	kEt	13,92	tasse	tas	25,07	nappe	nap	18,18
pompe	P§P	18,45	rite	Rit	8,45	jambe	Z@b	49,93	bûche	byS	5,14
coude	kud	33,24	mousse	mus	23,04	pipe	pip	25,74	fil	fil	75,95
chair	SER	90,81	songe	s§Z	10,68	gamme	gam	5,74	thése	tEz	7,77
digue	dig	7,97	châle	Sal	9,32	bourg	buR	13,85	bonne	bon	43,99
	0,67	**32,45**		*1,00*	**22,72**		*1,33*	**22,24**		*1,33*	**26,49**
pelle	PEI	11,35	cire	siR	15,41	rive	Riv	35,14	noce	nos	6,55
toque	tok	6,55	bac	bak	13,99	duc	dyk	14,80	banque	b@k	25,54
page	paZ	55,88	messe	mEs	32,70	bête	bEt	63,18	phase	faz	6,76
bande	b@d	52,36	lune	lyn	63,24	pote	pot	22,97	rêve	REv	80,20
douche	duS	20,27	col	kol	51,82	coupe	kup	33,58	lutte	lyt	37,36
mine	min	48,18	vase	vaz	26,76	phare	faR	10,68	gaffe	gaf	17,57
	0,67	**32,43**		*1,33*	**33,99**		*1,33*	**30,06**		*0,67*	**29,00**
roche	RoS	14,12	gare	gaR	78,58	fougue	fug	5,07	dose	dOz	9,32
base	baz	31,96	bulle	byl	6,62	chasse	Sas	53,38	pull	pyl	7,03
fiche	fiS	7,57	somme	som	72,70	bal	bal	18,31	choc	Sok	37,57
scéne	sEn	95,27	foot	fut	5,54	nuque	nyk	48,51	fête	fEt	70,41
cure	kyR	8,18	môme	mOm	37,03	manche	m@S	35,41	bise	biz	8,11
tente	t@t	19,12	veine	vEn	15,27	cerf	sER	20,27	lame	lam	25,81
	0,67	**29,37**		*0,67*	**35,96**		*1,00*	**30,16**		*0,67*	**26,38**
rose	ROz	30,34	lard	laR	11,01	coq	kok	15,68	caisse	kEs	51,01
laine	lEn	34,86	fesse	fEs	6,42	tir	tiR	16,01	botte	bot	8,51
vache	vaS	26,08	voûte	vut	18,85	chatte	Sat	29,12	cave	kav	42,09
gomme	gom	9,26	pile	pil	21,55	bague	bag	16,08	pic	pik	10,34
bouc	buk	8,92	note	not	39,32	séve	sEv	7,03	lance	l@s	9,32
bide	bid	8,38	cage	kaZ	34,86	jupe	Zyp	34,05	sud	syd	28,38
	0,33	**19,64**		*1,00*	**22,00**		*0,67*	**19,66**		*2,00*	**24,94**
touffe	tuf	6,69	ver	vER	5,61	juge	ZyZ	29,80	fort	foR	8,99
régne	REN	12,57	sel	sEI	31,01	mouche	muS	18,72	masse	mas	60,54
gosse	gos	34,12	danse	d@s	29,19	folle	fol	14,05	gel	ZEI	6,22
vague	vag	38,18	comte	k§t	51,42	dalle	dal	13,38	pente	p@t	39,19
pif	pif	7,23	cape	kap	10,34	bee	bEk	23,31	biche	biS	7,30
manque	m@k	36,28	fauve	fOv	7,77	laisse	lEs	18,85	butte	byt	5,34
	0,67	**22,51**		*1,33*	**22,56**		*1,33*	**19,69**		*0,67*	**21,26**
rame	Ram	5,74	poule	pul	16,69	paire	pER	26,89	lac	lak	32,84
vice	vis	13,45	vide	vid	75,74	chaîne	SEn	43,24	goutte	gut	30,34
chaise	SEz	86,35	race	Ras	28,72	gîte	Zit	5,81	rampe	R@p	18,18
taule	toi	13,85	fugue	fyg	5,68	vol	vol	41,22	peigne	pEN	8,85
roc	Rok	7,50	dette	dEt	5,14	case	kaz	9,46	rage	RaZ	44,12
bombe	b§b	15,00	zéle	zEI	10,61	paume	pOm	22,57	mode	mod	46,96
	0,33	**23,65**		*1,00*	**23,76**		*0,67*	**24,87**		*1,00*	**30,22**

Note: For each list, the mean number of phonemes shared between words is in italics, and the mean frequency is in bold.

previously. Fewer words were recalled in the correct position in similar lists (39%, $SD = 10\%$) than in dissimilar lists (46%, $SD = 10\%$), $F(1, 25) = 21.33$, $p < .001$, $\eta_p^2 = .46$. The same was observed for the two other scores, $F(1, 25) = 5.95$, $p < .05$, $\eta_p^2 = .19$ for *correct word* (50%, $SD = 6\%$ vs. 54%, $SD = 7\%$, for similar and dissimilar lists, respectively), and $F(1, 25) = 19.97$, $p < .001$, $\eta_p^2 = .44$ for *correct order* (77%, $SD = 16\%$ vs. 85%, $SD = 14\%$, respectively) scores.