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Sequential syntactic knowledge supports item but not order recall in verbal working memory

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Abstract
Previous studies have shown that psycholinguistic effects such as lexico-semantic knowledge effects mainly determine item recall in verbal working memory (WM). However, we may expect that syntactic knowledge, involving knowledge about word-level sequential aspects of language, should also impact serial-order aspects of recall in WM. Evidence for this assumption is scarce and inconsistent and has been conducted in language with deterministic syntactic rules. In languages such as French, word position is determined in a probabilistic manner: an adjective is placed before or after a noun, depending on its lexico-semantic properties. We exploited this specificity of the French language for examining the impact of syntactic positional knowledge on both item and serial order recall in verbal WM. We presented lists with adjective–noun pairs for immediate serial recall, the adjectives being in regular or irregular position relative to the nouns. We observed increased recall performance when adjectives occurred in regular position; this effect was observed for item recall but not order recall scores. We propose an integration of verbal WM and syntactic processing models to account for this finding by assuming that the impact of syntactic knowledge on serial-order WM recall is indirect and mediated via syntax-dependent item-retrieval processes.

Keywords Verbal working memory · Long-term memory · Syntactic knowledge · Serial order

Introduction

There is ample evidence for interactions between long-term memory (LTM) knowledge and verbal working memory (WM), such as the presence of different psycholinguistic effects in verbal WM tasks. Serial recall performance has been shown to be higher for nonwords with high versus low phonotactic frequency phoneme combinations, indicating that sublexical phonological knowledge supports verbal WM (Coady & Aslin, 2004; Coady et al., 2010; Gathercole et al., 1999; Majerus et al., 2004; Munson et al., 2005; Zamuner et al., 2004). Similarly, serial recall performance is increased for words relative to nonwords (Besner & Davelaar, 1982; Brener, 1940; Hulme et al., 1991; Jefferies et al., 2006a, b) and for high-frequency words relative to low-frequency words, implying that verbal WM is supported by lexico-semantic knowledge (Hulme et al., 1997; Kowialiewski & Majerus, 2020; Majerus & Van der Linden, 2003; Poirier & Saint-Aubin, 1996; Watkins & Watkins, 1977). Contributions from semantic levels of knowledge have also been shown, as illustrated by the presence of word imageability, semantic relatedness, or sentence superiority effects in verbal WM (Brener, 1940; Cattell, 1886; Jefferies et al., 2004; Poirier & Saint-Aubin, 1996; Savill et al., 2015, 2018). The present study examines the impact of syntactic knowledge on verbal WM, a less frequently studied linguistic variable but of strong interest as it may not only support WM for item information, as most of the effects listed so far do, but also WM for serial order information.

Regarding interactions between WM and long-term language knowledge, a distinction of major theoretical interest is between item-level and serial-order aspects of information held in WM. While not all theoretical models make this distinction (e.g., Baddeley & Hitch, 1974; Baddeley et al., 1998; Botvinick & Plaut, 2006), many other WM models assume that item-level representations are supported by the language system (or are identical to temporary activation of long-term language representations). The representation of serial order information (i.e., the order of the items

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within a list of words), on the other hand, is considered to be supported by specific, nonlinguistic processes such as temporal, spatial or other types of contextual positional codes (e.g., Brown et al., 2000; Burgess & Hitch, 1999, 2006; Hartley et al., 2016; Henson, 1998; Majerus, 2009, 2013). The item/order distinction is supported by a number of empirical findings, showing that item recall and serial order recall can be differentially impacted in WM impaired populations in the context of brain injury or neurodevelopmental disorder (Attout & Majerus, 2015; Hachmann et al., 2020; Majerus et al., 2015; Perez et al., 2012; Romani et al., 2015). Neuroimaging studies have also shown that item-level representations in verbal WM are supported by cortices in language processing areas while serial order-level representations are supported by nonlinguistic cortices in intraparietal and/or inferior parietal areas (Cristoforetti et al., 2022; Kowialiewski et al., 2021; Majerus et al., 2010; Marshuetz et al., 2000; but see Papagno & Trojano, 2018). Critically, regarding phonological, lexico-semantic and semantic psycholinguistic effects in verbal WM, phonological and lexico-semantic knowledge have been consistently shown to support item recall but not order recall (Gathercole et al., 2001; Hulme et al., 1991, 1997; Majerus & D'Argembeau, 2011; Nairne & Kelley, 2004; Poirier & Saint-Aubin, 1996; Saint-Aubin & Poirier, 1999a, b, 2000; Walker & Hulme, 1999). If there is any impact on order recall, it is usually characterized by a detrimental impact. Increased rates of order errors have been observed for semantically related words as compared to semantically unrelated words (Kowialiewski et al., 2021; Poirier et al., 2015), as well as for word list versus nonword list recall (e.g., Jefferies et al., 2006a, b). This reverse impact of linguistic knowledge on serial order recall has been interpreted as reflecting between-item lexico-semantic co-activation effects interfering with the maintenance of initial word order in the memory list (Kowialiewski et al., 2021, 2022). In sum, there is ample evidence for an impact of linguistic knowledge on the retention of item rather than serial order information in verbal WM, in line with many current models of verbal WM. At the same time, these findings might appear counterintuitive given that a core property of the language system is the processing of sequential information, such as the sequential arrangements of phonemes in a word or of words in a sentence. Hence, we may also expect that specific aspects of language knowledge impact serial order maintenance, and not only maintenance of items (Majerus, 2019). This assumption is in line with "fully emergent" models of verbal WM, which consider that the verbal WM and the language system are interconnected and interact dynamically (Acheson & MacDonald, 2009; Buchsbaum & D'Esposito, 2019; Cowan, 1993; Hasson et al., 2015; MacDonald, 2016; Postle, 2006; Schwering & MacDonald, 2020). According to this approach, language is the representational substrate for WM. Based on these models, we should expect syntactic knowledge to also support verbal WM at both item and serial order levels. Indeed, contrary to other WM models suggesting that the role of language in WM is primarily limited to item-level representations in LTM (e.g., Burgess & Hitch, 1999), linguistic models of verbal WM consider that all aspects are supported by linguistic representations, including the temporary representation of serial order information (e.g., Schwering & MacDonald, 2020). In support of this assumption, some studies have shown that the ability to reproduce verbal sequences such as arbitrary digit sequences (e.g., digit span tasks) can be predicted by the natural frequency of occurrence of digit sequences in the natural language (Jones & Macken, 2018). Similarly, better serial order reconstruction performance has been observed for word sequences presented in an order consistent with syntactic knowledge (Jones & Farrell, 2018), and better recall has been observed for grammatical versus ungrammatical sequences ("sentence superiority effect"; e.g., Cattell, 1886; Massol et al., 2021; Snell & Grainger, 2017), suggesting that memory for order can also be supported by linguistic knowledge, although it may be difficult to distinguish syntactic from semantic effects particularly for the latter studies.

Of particular theoretical interest here is the impact of syntactic knowledge on verbal WM. Syntactic knowledge concerns the way words can be combined within a verbal segment as a function of their grammatical function. For example, in many languages such as English and German, adjectives precede nouns rather than the reverse. These syntactic rules determine, by definition, sequential regularities between words. It follows that this sequential type of linguistic knowledge may support more specifically also the maintenance of serial order aspects of memoranda in verbal WM. Current evidence for the impact of syntactic knowledge on serial order recall in WM remains sparse and ambiguous. It has been shown that lists of words were overall better recalled when they formed a meaningful sentence (Brener, 1940; Jefferies et al., 2004), but sequences of words were also better remembered when they followed familiar syntactic rules, regardless of semantic consistency. Epstein (1961) showed that nonsense sequences of syllables led to higher recall performance if they were presented with regular English syntactical structure and morphology (e.g., "meeving gups keebed gompily") than without (e.g., "meev gup keeb gomp"). Marks and Miller (1964) found that when syntactic rules were disrupted in semantically anomalous sentences, the most disrupted sequences led to the poorest recall performance. Perham et al. (2009) showed better recall performance for adjective–noun pairs when presented in canonical order for English syntax, that is, when the adjective preceded the noun rather than the reverse. More recently, Schweppe et al. (2022) compared, for German language material, recall performance for canonical versus

non-canonical adjective–noun pairs, by further manipulating the inflection of the adjectives, German being a highly inflected language. They observed an advantage for recall of adjective–noun lists when the pairs were presented in canonical order (adjective before noun), but only when the adjectives were also correctly inflected. This study was also one of the first making an explicit distinction between item and serial order recall measures. Interestingly, Schweppe et al. observed an advantage of canonical adjective–noun order on item recall but not on order recall measures. One other study used a serial order reconstruction task for investigating the impact of syntactic knowledge on verbal WM (Jones & Farrell, 2018). This study, for English language stimuli, showed better serial order reconstruction performance for semantically meaningless but syntactically legal versus illegal word sequences, with reproduction errors further tending to make sequences more syntactic ("syntactic bias"). Serial order reconstruction is typically interpreted as a measure of order memory given that item information is fully available at recall and only order information has to be reconstructed. At the same time, the results of this study are difficult to interpret in terms of a specific impact of syntactic knowledge on the retention of serial order information in WM given that there was no specific measure of item WM performance. Even if recall performance in a serial order reconstruction task is only based on order judgments and items are provided at recall, participants must still remember that a given item was in the list in order to be able to retrieve its serial position. While the items are presented during encoding, participants must internally maintain the information about each item and its position in the list. This internal representation of items in their original order allows participants to accurately place them in the correct serial order during reconstruction. Therefore, although the task involves making order judgements based on the provided items, nevertheless intervenes during encoding and maintenance. If a participant does not remember anymore that a given item was in the list, even if provided at recall, it will be very difficult to retrieve its serial position. It is therefore important to measure both order and item aspects as directly as possible.

In sum, a number of studies appear to show an influence of syntactic knowledge on verbal WM performance but the locus of this effect in terms of item versus serial order aspects of WM is far from being understood. As mentioned earlier, given the sequential nature of syntactic knowledge, an impact on serial order recall performance should be expected. Most studies conducted so far on syntactic knowledge effects did not explicitly distinguish between item and order aspects of WM. Jones et al. (2006) observed an impact on a serial order reconstruction task but with no direct control of item WM aspects. The only study directly controlling for item and serial order WM aspects by Schweppe et al. (2022) observed an impact of syntactic knowledge on item recall performance only. Critically, a potential limitation of the study by Schweppe et al. is the fact that the German language, like English language, specifies adjective–noun order in a fully deterministic manner: adjectives always precede the noun. Given these very strict syntactic rules, non-canonical adjective–noun order may seem so unnatural to a German-speaking participant that it hinders efficient memorization and recall of the items, as well as the intervention of syntactic knowledge about the position of words within the list. Therefore, instead of making order errors, the participant may rather make omission item errors, as observed by the Schweppe et al. study. Note that this result should indeed be specific for adjective–noun sequences as compared with pure noun sequences. In languages such as German and French, a direct and exclusive succession of nouns will not be recognized as a syntactic structure and should therefore not activate specific syntactic knowledge about the ordering of the nouns that would interfere with or facilitate their memorization (i.e., in a given list of nouns, there are no syntactic rules that would determine that Noun A should always precede Noun B). On the opposite, for adjective–noun pairs, the syntactic rules specifying that an adjective always precedes a noun (in deterministic languages such as German) will become activated and will detect a major linguistic violation when a non-canonical, noun–adjective pair is presented. A related problem caused by this situation is that word order and syntactic legality are confounded: For adjective noun pairs, the legal order will always imply adjective anteposition relative to the noun, making it impossible to fully cross syntactic legality and adjective position.

The present study

Given the inconsistency and limitations of the few previous studies examining the role of syntactic knowledge effects on serial order aspects of WM, the present study reexamined the impact of adjective–noun syntactic knowledge on item and serial order recall in verbal WM for a language providing more flexibility in terms of adjective–noun order and legality. We used the French language as both adjective anteposition (i.e., adjective–noun order) and postposition (i.e., noun–adjective order) can be considered as syntactically legal. More specifically, in French, size-related adjectives, monosyllabic adjectives, and high-frequency adjectives usually precede the noun (e.g., petit chien [*small dog*], beau manteau [*beautiful coat*], dernier jour [*last day*]) while colour-related adjectives, shape-related adjectives, substance-related adjectives, polysyllabic adjectives, morphologically constructed adjectives and low frequency adjectives typically follow the noun (e.g., manteau orange [*orange coat*], chien dangereux [*dangerous dog*], homme impoli [*rude man*], travailleur besogneux [*hardworking*

man]; Abeillé & Godard, 1999; Thuilier, 2012, 2013; Thuilier et al., 2010a, b; Wilmet, 1980). At the same time, many other types of adjectives are correct in both positions. In fact, the positional pairing of adjectives and nouns is based on probabilistic regularities rather than deterministic rules in French. It follows that syntactic effects in verbal WM for French language stimuli should reflect these complex, context-dependent positional regularities.

We exploited this property of the French language to create adjective–noun lists that fully cross syntactic legality (or rather, regularity, in the present case) and adjective position relative to the noun (anteposition vs postposition), leading to four list types (regular adjective–noun anteposition, irregular adjective–noun anteposition; regular noun–adjective postposition; irregular noun–adjective postposition). Like in the study by Schweppe et al. (2022), the lists were presented for immediate serial recall, allowing for the determination of both item and order recall/error measures. Given that in the study by Schweppe et al., the expression of the syntactic effect was subject to the type of inflection (correct/incorrect) of the adjectives, we also manipulated inflection. French, like German, marks gender and plural via the inflections added to the adjective (e.g., masculine: garçon [*boy*] marrant [*funny*], feminine: fille [*girl*] marrante [*funny*]; plural: garçons [*boys*] marrants [*funny*], filles [*girls*] marrantes [*funny*]). Inflection was manipulated in two different experimental groups, a first group receiving the four before-mentioned list types with correct inflection (e.g., masculine: piment [*pepper*] élégant [*elegant*]; feminine: tasse [*cup*] agressive [*aggressive*]), and a second group receiving the four list types with incorrect inflection (e.g., masculine: piment [*pepper*] élégante [*elegant*], tasse [*cup*] agressif [*agressive*]). We hypothesized that syntactically regular list types should lead to higher recall performance relative to irregular list types, independently of type of adjective position, and this not only for item but also for order measures. Furthermore, we expected a syntactic regularity effect also for incorrectly inflected adjectives lists albeit smaller than for correctly inflected adjectives lists.

Methods

Participants

Sixty participants per inflection group were recruited (see Scoring and Analysis Procedure section for justification of sample size) via the University of Liège web platform, and via advertisements on social networks. Data from seven participants had to be excluded due to technical problems in data collection, four in the correct-inflection group, and three in the incorrect-inflection group. Participants were between 18 and 35 years old ($M = 22.628$, $SD = 2.876$); 56 participants were female. All participants were native French speakers, right-handed, and with normal hearing. They reported no history of learning, neuropsychological or neurological disorder, and no current drug use (e.g., cannabis) or alcohol abuse. The study was approved by the ethics committee of the Faculty of Medicine of the University of Liège. Participants were informed that no financial compensation was provided. All participants gave informed consent to participate in the study.

Materials

To select the adjective–noun pairings and to determine the preferred position of the adjectives relative to the noun, a group of 13 French-speaking young adults from the University of Liège not taking part in the main experiment was recruited prior to the study for an online syntactic preference judgment task. They were presented 120 noun–adjective/adjective–noun pairs and they had to determine whether they were in correct, correct but unusual, or incorrect syntactic order. The adjectives and nouns used were similar to the French equivalents of the stimuli used by Schweppe et al. (2022) with the addition of adjectives regularly found in anteposition, postposition, or both, according to French linguistics (Abeillé & Godard, 1999; Grevisse & Goose, 1993; Thuilier, 2013). Based on the judgments obtained from the syntactic preference judgment task, we selected the 36 anteposition/postposition adjectives that received the most consistent ratings for the "correct order" and "incorrect order" response categories (at least 60% agreement). These 36 adjectives where then associated with a set of 36 male and 36 female nouns.

Semantic plausibility was minimized as far as possible within pairs by avoiding direct and obvious semantic associations between the adjectives and the nouns (such as "great job"). Semantic plausibility of the adjective–noun pairs was assessed by a further independent group of 10 French-speaking, young adult participants and was rated as absent for 67.36% of the pairs by the majority of participants (i.e., at least 60%) and 27.78% of pairs were rated as semantically plausible due to the very general meaning of specific adjectives (e.g., moteur blanc [*white engine*]; petite symétrie [*small symmetry*]). We ensured that this type of pairs occurred equally often in the different list conditions. Phonological similarity was further minimized within pairs by ensuring that nouns did not have the same onset as or rhyme as the adjective (e.g., discarding pairs such as "éléphant–élégant").

The final stimulus set consisted of 48 lists with three adjective–noun pairs in each list. Four list conditions were determined: regular adjective anteposition, irregular adjective anteposition, regular adjective postposition, and irregular adjective postposition (12 lists per condition). Each adjective was used once in each of the four list conditions,

and was paired to either a masculine or a female noun. The same masculine/female adjective–noun pairings were used once in regular/irregular adjective anteposition list conditions and once in regular/irregular adjective postposition list conditions, thereby ensuring that the same adjectives and adjective–noun pairings were used across the four list conditions.

Two group conditions were defined: one in which the lists contained only correctly inflected adjectives, and a second one in which the lists contained only incorrectly inflected adjectives. A given list contained exclusively masculine or female adjective–noun pairs in order to avoid distinctiveness effects within the list that might arise when mixing grammatical gender type. In addition, we created two parallel versions (A and B) of the set of materials, containing the same lists but presented in a different pseudorandom order.

The auditory modality was used to focus most directly on serial order processing and associated syntactic processes. Spoken language necessarily involves sequential processing and furthermore reflects the modality in which basic syntactic structures were initially learned during the language learning process. The stimuli were recorded by a French-native female speaker adopting a neutral voice. Each item was recorded separately, and then combined to form adjective–noun/noun–adjective pairs. The full stimulus lists are presented in Appendix Tables 14, 15, 16 and 17.

Procedure

The experiment was conducted online via OpenSesame software (https://osdoc.cogsci.nl/) implemented in the Jatos web interface (https://www.jatos.org/). Instructions were given by the experimenter via a video conferencing platform. All participants were asked to turn on their cameras for the duration of the experiment to ensure that they did not take any notes. Participants were randomly assigned to one group (correct or incorrect inflection) and one version of the task (A or B). Participants were instructed to listen carefully to each of the 48 six word lists, and to orally recall the words (adjectives and nouns) immediately in the same order. If the participants could not remember a word at a particular position of the list, they had to say "oublié" (*forgotten*) for that position. Before the presentation of the 48 experimental lists, the participants completed two practice trials with feedback to ensure that they had correctly understood the task instructions. To avoid any ambiguity about the specific adjective–noun pairs within each list, the interstimulus interval within each pair was smaller (350 ms) than the interstimulus interval between pairs (1,000 ms). There was no time limit for the participant to respond and all responses were recorded for later transcription and scoring. The experiment lasted about 20 minutes per participant.

Scoring and analysis procedure

Three scores were calculated over all items (with no distinction of nouns or adjectives): overall accuracy (i.e., the proportion of correct items in correct position), item recall score (i.e., the proportion of correct items regardless of their position), and order recall score (i.e., the number of items recalled in correct serial position divided by the item recall score), by pooling over all trials for a given condition. We also conducted error analyses by focusing specifically on adjective inflection recall errors and adjective order recall errors. Adjective inflection errors were defined as incorrectly inflected adjectives being recalled with correct inflection (i.e., corrections) or as correctly inflected adjectives recalled with incorrect inflection (i.e., inflection errors) and adjective order recall errors were defined as an adjective in an irregular position being recalled in a regular position (i.e., regularization) or as an adjective from a regular position being recalled in an irregular position (i.e., swaps between two adjacent positions). Adjective inflection errors and adjective order recall errors scores were expressed in proportions (specific adjective error type divided by the sum of the two adjective error types). Given that adjectives and nouns are presented in pairs, an adjective order recall error should also imply the same for the corresponding noun if produced (see Table 20 in Appendix for the analysis of noun order recall errors). In order to avoid redundancy in the analyses, we focused only on adjectives. For the sake of completeness, we additionally conducted analyses on adjective omission errors (adjective for which the participant said "oublié" [*forgotten*] or adjective not recalled) and noun omission errors (nouns for which the participant said "oublié" or noun not recalled), the latter being reported in the Appendix.

The data were analyzed using a Bayesian statistical framework. Bayesian statistics have the advantage, relative to frequentist statistics, of determining the strength of the evidence both against and in favour of the null hypothesis in order to identify which effect is associated with the strongest evidence (Clark et al., 2018; Kruschke, 2010; Lee & Wagenmakers, 2013; Nuijten et al., 2015; Wagenmakers et al., 2018). Bayesian statistics also allow multiple statistical tests to be carried out without increasing Type I error risk (Clark et al., 2018). The Bayes factor (BF) is the likelihood ratio of a given model, the best-fitting model being the one with the highest BF. BF_{01} indicates evidence in favour of the null hypothesis, while BF_{10} indicates evidence in favour of the alternative hypothesis. Although there are no fixed thresholds for BF values, we used the following categories for describing strength of evidence: a BF of at least 1 is considered to indicate anecdotal evidence, a BF of at least 3 is considered to indicate moderate evidence, a BF of at least 10 is considered to provide strong evidence, a BF of at least 30 is considered to provide very strong evidence, and a BF

of at least 100 is considered to indicate decisive evidence (Jeffreys, 1998).

Regarding statistical power, the Bayesian statistical framework is based on collecting evidence in favour or against an effect of interest and this evidence is incremental and evolves as a function of collected data (Schönbrodt & Wagenmakers, 2018). In contrast to frequentist statistical frameworks, inference taken from obtained data is also independent of the data collection plan (Berger & Wolpert, 1988; Dienes, 2011; Wagenmakers et al., 2018). It is, however, possible to conduct an indicative design analysis in order to determine the sensitivity of a given Bayesian statistical design: This design analysis estimates the probability of obtaining a specific BF value for a specific effect as a function of simulated sample sizes and an a priori estimation of the effect size (Schönbrodt & Wagenmakers, 2018). We used Monte Carlo simulations and the Bayesian Factor Design Analysis package (Schönbrodt, 2016) implemented in R (Version 3.6.2) using the default Cauchy prior distribution parameters, also available (http://shinyapps.org/apps/BFDA/) to assess the sensitivity of our statistical design to provide evidence for an effect of syntactic regularity/irregularity and position on overall accuracy (i.e., the proportion of correct items in correct position). This analysis showed that if the effect of interest exists, the minimal sample size needed for reaching a specific level of evidence (BF_{10}>10) in favour of the effect in 100% of simulated samples was $N = 40$. If the effect of interest does not exist, the minimal sample size needed for reaching a specific level of evidence (BF_{01}>10) in favour of the absence of an effect in 100% of simulated samples was $N = 65$. For this sensitivity analysis, we assumed a medium effect size of Cohen's d = 0.5 based on the study by Schweppe et al. (2022).

Results

A first 2 (inflection: correct/incorrect) × 2 (position: adjective ante-/postposition) × 2 (regularity: regular/irregular position) Bayesian mixed analysis of variance (ANOVA) was performed on the overall accuracy score, using the JASP statistical package with default prior settings (Version 0.16.3.0; JASP Team, 2022). The model associated with the strongest evidence included the regularity and inflection factors. This model was 3.13 times more likely than the model with the next-largest BF value and including Inflection only (regularity: $\eta_p^2 = 0.07$; inflection: $\eta_p^2 = 0.059$; evidence for the absence of a Regularity × Inflection interaction: $BF_{01} = 3.135$; see Tables 1 and 2). As expected, overall accuracy was higher for lists with adjectives in regular syntactic position or when correctly inflected (see Fig. 1).

Next, we ran the same analysis on the item recall score. Again, the strongest model included the Regularity and Inflection factors. This model was 2.45 times more likely than the following model including all three factors (Regularity, Inflection, Position) and the interaction between Regularity and Position (Regularity: $\eta^2_p = 0.093$; Inflection: $\eta^2_p = 0.08$; evidence for absence of interaction effect: $BF_{01} = 5.618$) (see Tables 3 and 4). As expected, item recall performance was higher for lists with adjectives in regular position or when correctly inflected (see Fig. 2).

We then ran the critical analysis on the order recall score. All factors were associated with anecdotal to moderate evidence for an *absence* of an effect (regularity: $BF_{01} = 5.613$, $\eta_p^2 = 0.006$; position: $BF_{01} = 7.088$, $\eta_p^2 = 0.002$; inflection: $BF_{01} = 1.344$, $\eta_p^2 = 0.018$; see Fig. 3, Tables 5 and 6). In contrast to the results for the overall accuracy and item recall scores, and contrary to our expectations, syntactically regular list types did not lead to higher recall performance relative to irregular list types for order recall.

Error analysis

To examine the impact of regularity and inflection on item and order recall performance in a more fine-grained manner, we determined adjective inflection recall errors and adjective order recall errors. For inflection, errors could be an incorrectly inflected adjective becoming correctly inflected (i.e., corrections) or a correctly inflected adjective becoming an incorrectly inflected adjective (i.e., inflection errors). For order, errors could be irregular positioned adjectives being produced in a regular position (i.e., regularization) or regular positioned adjectives being produced in an irregular position (i.e., swaps between two adjacent positions). We may expect that incorrectly inflected adjectives lead to errors that involve recall of the correct inflection. Likewise, for adjectives in an irregular, nonpreferred position relative to a noun, they may be erroneously recalled in their preferred serial position relative to a noun. For the sake of completeness, we also determined adjective omission errors and noun omission errors (see Appendix for the latter). As a reminder, adjective inflection recall errors, adjective order recall and omission errors scores were expressed in proportions. Adjective inflection recall errors and adjective omission errors were divided by the sum of relevant item errors (i.e., the sum of total adjective inflection recall errors and total adjective omission errors). Adjective order recall errors were divided by the sum of order errors (i.e., the sum of the total adjective order recall errors and the sum of the total item recall score minus the overall accuracy score). Given that an adjective order recall error should also imply the same for the corresponding noun if produced, we focused only on adjectives in order to avoid redundancy in the analyses. For information purposes, the same analysis on nouns, also taking into account nouns recalled individually but in irregular position, led to similar results (see Appendix).

Table 1 Results of the 2 × 2 × 2 Bayesian ANOVA for the overall accuracy score

Model comparison					
Models	P(M)	P(M|data)	BF_M	BF_{10}	error %
Null model (incl. subject and random slopes)	0.053	0.026	0.481	1.000	
Regularity + Inflection	0.053	0.356	9.966	13.689	3.326
Inflection	0.053	0.114	2.310	4.369	12.182
Regularity + Inflection + Regularity × Inflection	0.053	0.109	2.192	4.170	2.844
Regularity	0.053	0.087	1.709	3.332	72.372
Position + Regularity + Inflection	0.053	0.085	1.663	3.248	1.334
Position + Regularity + Inflection + Position × Regularity	0.053	0.080	1.575	3.090	7.346
Position + Inflection	0.053	0.035	0.655	1.349	8.328
Position + Regularity + Inflection + Regularity × Inflection	0.053	0.029	0.543	1.125	39.541
Position + Regularity	0.053	0.024	0.441	0.918	4.070
Position + Regularity + Inflection + Position × Inflection	0.053	0.015	0.274	0.576	5.184
Position + Regularity + Inflection + Position × Regularity + Regularity × Inflection	0.053	0.008	0.144	0.305	3.346
Position + Regularity + Position × Regularity	0.053	0.008	0.139	0.295	3.171
Position + Regularity + Inflection + Position × Regularity + Position × Inflection	0.053	0.006	0.114	0.242	5.100
Position	0.053	0.005	0.099	0.211	1.042
Position + Inflection + Position × Inflection	0.053	0.005	0.091	0.193	6.395
Position + Regularity + Inflection + Position × Inflection + Regularity × Inflection	0.053	0.004	0.080	0.169	6.204
Position + Regularity + Inflection + Position × Regularity + Position × Inflection + Regularity × Inflection	0.053	0.002	0.032	0.069	5.539
Position + Regularity + Inflection + Position × Regularity + Position × Inflection + Regularity × Inflection + Position × Regularity × Inflection	0.053	0.002	0.030	0.064	48.367

P|M represents the prior model probabilities, *P(M|data)* represents the posterior model probabilities, and BF_M shows the change in model odds from prior to posterior. The BF_{10} column lists the Bayes factors for each model against the null model, and the *error %* column indicates the percentage of error associated with each model comparison

Table 2 Descriptive statistics of the 2 × 2 × 2 Bayesian ANOVA for the overall accuracy score

Position	Regularity	Inflection	Mean	*SE*	*N*
Ante	Regular	Correct	0.713	0.152	56
		Incorrect	0.621	0.168	57
	Irregular	Correct	0.676	0.160	56
		Incorrect	0.609	0.156	57
Post	Regular	Correct	0.688	0.156	56
		Incorrect	0.616	0.156	57
	Irregular	Correct	0.678	0.157	56
		Incorrect	0.609	0.179	57

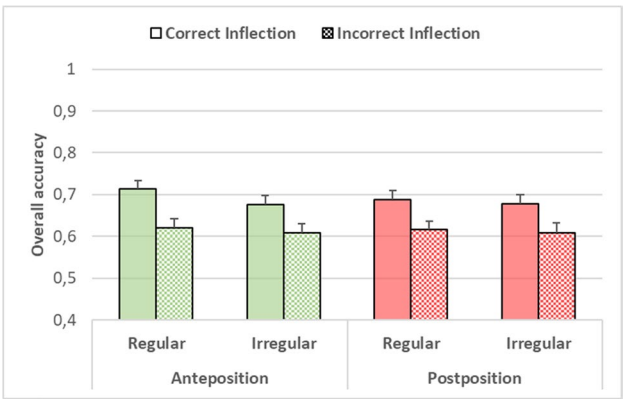

Fig. 1 Overall accuracy in terms of position, regularity, and inflection

Regarding adjective inflection recall errors, a 2 × 2 × 2 Bayesian three-way ANOVA showed that the data were best explained by a model including inflection, error type, the interaction between regularity and position, as well as the interaction between inflection error type and position (inflection error type: $\eta_p^2 = 0.248$; Regularity × Position: $\eta_p^2 = 0.068$; Inflection Error Type × Position: $\eta_p^2 = 0.087$; see Tables 7 and 8). This analysis suggests that adjective inflection recall errors involved "corrections" more often than "inflection errors." This situation tended to be more frequent when the adjective was also in postposition, while fewer corrections were observed when the adjective was in anteposition. Given that in French, adjectives occur more frequently in postposition than anteposition (e.g., Benzitoun, 2014; Henkel, 2016; Thuilier et al., 2010a, b), and given that correct adjective inflection is determined by the associated noun,

Table 3 Results of the 2 × 2 × 2 Bayesian ANOVA for the item recall score

Model Comparison					
Models	P(M)	P(M|data)	BF_M	BF_{10}	error %
Null model (incl. subject and random slopes)	0.053	0.005	0.096	1.000	
Regularity + Inflection	0.053	0.416	12.801	78.262	2.662
Position + Regularity + Inflection + Position × Regularity	0.053	0.169	3.667	31.874	6.526
Inflection	0.053	0.090	1.782	16.964	6.781
Position + Regularity + Inflection	0.053	0.072	1.401	13.601	2.544
Regularity + Inflection + Regularity × Inflection	0.053	0.071	1.369	13.307	5.973
Position + Regularity + Inflection + Position × Regularity + Position × Inflection	0.053	0.035	0.657	6.636	5.890
Regularity	0.053	0.034	0.627	6.340	1.087
Position + Regularity + Inflection + Position × Regularity + Regularity × Inflection	0.053	0.029	0.544	5.521	4.578
Position + Regularity + Inflection + Position × Inflection	0.053	0.018	0.326	3.348	17.788
Position + Regularity + Inflection + Regularity × Inflection	0.053	0.016	0.288	2.966	5.220
Position + Regularity + Position × Regularity	0.053	0.012	0.226	2.330	1.925
Position + Inflection	0.053	0.012	0.225	2.324	2.162
Position + Regularity	0.053	0.006	0.117	1.219	2.257
Position + Regularity + Inflection + Position × Regularity + Position × Inflection + Regularity × Inflection	0.053	0.006	0.108	1.120	13.242
Position + Regularity + Inflection + Position × Inflection + Regularity × Inflection	0.053	0.003	0.055	0.574	11.420
Position + Inflection + Position × Inflection	0.053	0.003	0.045	0.471	3.314
Position + Regularity + Inflection + Position × Regularity + Position × Inflection + Regularity × Inflection + Position × Regularity × Inflection	0.053	0.001	0.025	0.259	8.775
Position	0.053	0.001	0.019	0.194	3.711

Table 4 Descriptive statistics of the 2 × 2 × 2 Bayesian ANOVA for the item recall score

Position	Regularity	Inflection	Mean	*SE*	*N*
Ante	Regular	Correct	0.800	0.099	56
		Incorrect	0.728	0.125	57
	Irregular	Correct	0.771	0.105	56
		Incorrect	0.708	0.128	57
Post	Regular	Correct	0.780	0.112	56
		Incorrect	0.718	0.115	57
	Irregular	Correct	0.776	0.114	56
		Incorrect	0.714	0.143	57

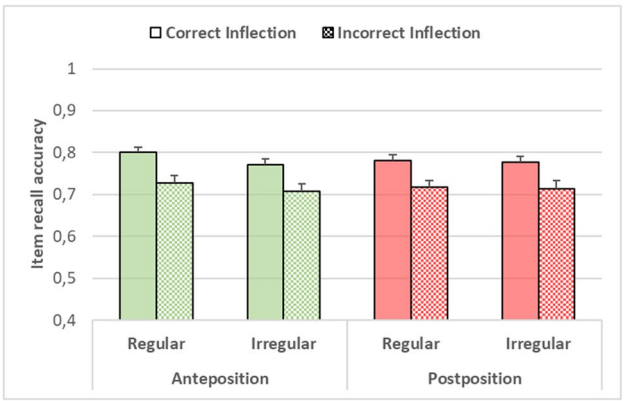

Fig. 2 Item recall accuracy in terms of position, regularity, and inflection

we may indeed expect more adjective inflection corrections to occur when the adjective follows a noun. Finally, the interaction between regularity and position suggests that more inflection recall errors overall are produced when adjectives are in regular postposition and in irregular anteposition. As can be seen in Fig. 4, the observation of an increased proportion of adjective inflection recall errors when in regular postposition was mainly due to an increase of the proportion of "corrections" (i.e., the pattern of results we already discussed). On the other hand, the relative increase of adjective inflection recall errors in irregular anteposition concerned both types of errors and was less expected. However, since French adjectives occur more frequently in postposition than anteposition, an adjective (expected to occur in postposition) appearing in an irregular anteposition could be particularly disruptive regarding the processing of the adjectives as a syntactically coherent item, leading to particularly poor encoding of the associated inflection. It should be noted that adjective inflection recall errors accounted for only a small proportion of the relevant item errors (mean proportion =

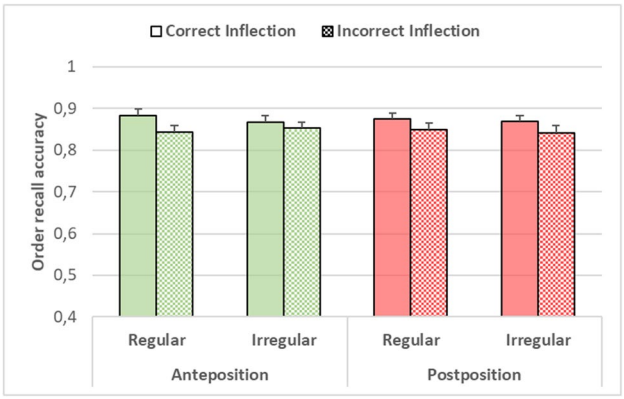

Fig. 3 Order recall accuracy in terms of position, regularity, and inflection

0.119, *SE* = 0.012), with adjective omission errors being predominant (mean proportion = 0.784, *SE* = 0.022).

Next, regarding adjective omission errors, the data were best explained by a model including regularity and inflection factors, as well as the interaction between regularity and inflection. This model was however only 2.85 times more likely than the model including regularity and inflection factors only, and hence the interaction needs to be interpreted with caution (regularity: $\eta_p^2 = 0.092$; inflection: $\eta_p^2 = 0.484$; Regularity × Inflection: $\eta_p^2 = 0.071$; see Tables 9 and 10). As expected, more adjective omission errors were observed when the adjective was in an irregular syntactic position but also when correctly inflected (see Fig. 5). Correct inflection is likely to reinforce the expectation of the participant that the adjective and the noun are linked, and this expectation is then contradicted when the noun and adjective are presented in irregular syntactic order, leading to an increase of omission errors. The same principle could also tentatively explain the increase of omission errors overall when adjectives are correctly vs. incorrectly inflected by assuming that the expected association is contradicted by the mainly implausible semantic links between the adjectives and the nouns.

Finally, regarding adjective order recall errors, all factors were again associated with moderate evidence for an *absence* of an effect, in line with the main analyses on order recall performance (regularity: $BF_{01} = 7.92$, $\eta_p^2 = 0.0002$; position: $BF_{01} = 6.971$, $\eta_p^2 = 0.0002$; inflection: $BF_{01} = 3.936$, $\eta_p^2 = 0.023$; see Fig. 6, Tables 11 and 12). Once again, contrary to our expectations, adjectives in an irregular position were not recalled more frequently in a regular position than were adjectives in a regular position recalled more frequently in an irregular position. It should be noted that a further analysis showed that most of the adjective order recall errors involved permutations

Table 5 Results of the 2 × 2 × 2 Bayesian ANOVA for the order recall score

Model Comparison					
Models	P(M)	P(M|data)	BF_M	BF_{01}	error %
Null model (incl. subject and random slopes)	0.053	0.412	12.601	1.000	
Position + Regularity + Position × Regularity	0.053	0.306	7.950	1.344	2.002
Inflection	0.053	0.073	1.425	5.613	2.862
Position	0.053	0.058	1.110	7.088	1.610
Regularity	0.053	0.055	1.041	7.530	2.606
Position + Regularity + Inflection + Position × Regularity	0.053	0.043	0.812	9.537	2.379
Position + Inflection	0.053	0.018	0.321	23.466	9.658
Regularity + Inflection	0.053	0.012	0.216	34.792	12.259
Position + Regularity + Inflection + Position × Regularity + Position × Inflection	0.053	0.008	0.140	53.215	3.193
Position + Regularity + Inflection + Position × Regularity + Regularity × Inflection	0.053	0.007	0.135	55.434	2.510
Position + Regularity	0.053	0.002	0.041	180.724	2.875
Position + Inflection + Position × Inflection	0.053	0.002	0.031	238.713	6.700
Regularity + Inflection + Regularity × Inflection	0.053	0.002	0.030	250.669	18.561
Position + Regularity + Inflection	0.053	0.001	0.021	351.919	4.559
Position + Regularity + Inflection + Position × Regularity + Position × Inflection + Regularity × Inflection	0.053	4.759^{e-4}	0.009	865.320	12.756
Position + Regularity + Inflection + Position × Regularity + Position × Inflection + Regularity × Inflection + Position × Regularity × Inflection	0.053	3.497^{e-4}	0.006	1177.368	4.370
Position + Regularity + Inflection + Regularity × Inflection	0.053	2.380^{e-4}	0.004	1729.904	7.017
Position + Regularity + Inflection + Position × Inflection	0.053	6.832^{e-5}	0.001	6026.958	10.083
Position + Regularity + Inflection + Position × Inflection + Regularity × Inflection	0.053	5.098^{e-5}	9.177^{e-4}	8076.757	37.939

Table 6 Descriptive statistics of the 2 × 2 × 2 Bayesian ANOVA for the order recall score

Position	Regularity	Inflection	Mean	*SE*	*N*
Ante	Regular	Correct	0.883	0.110	56
		Incorrect	0.843	0.116	57
	Irregular	Correct	0.867	0.115	56
		Incorrect	0.853	0.099	57
Post	Regular	Correct	0.875	0.100	56
		Incorrect	0.849	0.120	57
	Irregular	Correct	0.868	0.112	56
		Incorrect	0.842	0.121	57

between two adjacent positions (87.7%), while a minority of errors involved swaps between two adjectives (e.g., swaps between adjective on Position 1 and adjective on Position 3) (11.26%).

Partial pairs recall

Further analyses were conducted on recall of partial pairs by reporting the mean number of pairs for which the first item was recalled, but not the second, and vice versa. The position factor was not included in this analysis for reducing model complexity given the addition of the item factor, with Item 1 representing pairs with only the first item recalled, and Item 2 representing pairs with only the second item recalled. A 2 × 2 × 2 Bayesian three-way ANOVA showed that the data were best explained by a model including the interaction between regularity and item (Regularity × Item: $\eta p^2 = 0.391$; see Table 13). While more second items were indeed recalled for pairs in regular position, likely reflecting a baseline recency effect for the second item of the final pairs, the opposite was observed for pairs in irregular position, with more first items recalled for pairs in irregular position (see Fig. 7). The importance of this result will be discussed in the Discussion section. For information purposes, the same analysis was performed on adjectives and nouns separately (see Appendix).

Table 7 Results of the 2 × 2 × 2 Bayesian ANOVA for adjective inflection recall errors

Model Comparison					
Models	P(M)	P(Mldata)	BF_M	BF_{10}	error %
Null model (incl. Position, Regularity, subject, and random slopes)[a]	0.091	7.362^{e-9}	7.362^{e-8}	1.000	
Inflection Error Type + Inflection Error Type × Position + Position × Regularity	0.091	0.672	20.486	9.127^{e+7}	5.186
Inflection Error Type + Inflection Error Type × Position + Inflection Error Type × Regularity + Position × Regularity	0.091	0.145	1.696	1.970^{e+7}	3.809
Inflection Error Type + Position × Regularity	0.091	0.088	0.968	1.199^{e+7}	3.778
Inflection Error Type + Inflection Error Type × Position + Inflection Error Type × Regularity + Position × Regularity + Inflection Error Type × Position × Regularity	0.091	0.042	0.438	5.698^{e+6}	4.442
Inflection Error Type + Inflection Error Type × Position	0.091	0.024	0.241	3.193^{e+6}	3.638
Inflection Error Type + Inflection Error Type × Regularity + Position × Regularity	0.091	0.019	0.199	2.648^{e+6}	5.320
Inflection Error Type + Inflection Error Type × Position + Inflection Error Type × Regularity	0.091	0.005	0.055	746115.825	4.841
Inflection Error Type	0.091	0.003	0.033	447193.202	3.052
Inflection Error Type + Inflection Error Type × Regularity	0.091	9.860^{e-4}	0.010	133924.942	16.915
Position × Regularity	0.091	1.827^{e-7}	1.827^{e-6}	24.820	3.669

[a]The main effects of regularity and position were not robust ($\eta_p^2 = 0.027$ and $\eta_p^2 = 0.003$, respectively), and hence, these factors were added to the null model for correct interpretation of the model including the interactions

Table 8 Descriptive statistics of the 2 × 2 × 2 Bayesian ANOVA for adjective inflection recall errors

Position	Regularity	Inflection	Error type	Mean	*SE*	*N*
Ante	Regular	Correct	Inflection errors	0.013	0.034	56
		Incorrect	Corrections	0.027	0.033	57
	Irregular	Correct	Inflection errors	0.024	0.061	56
		Incorrect	Corrections	0.051	0.055	57
Post	Regular	Correct	Inflection errors	0.011	0.022	56
		Incorrect	Corrections	0.055	0.059	57
	Irregular	Correct	Inflection errors	0.006	0.016	56
		Incorrect	Corrections	0.050	0.048	57

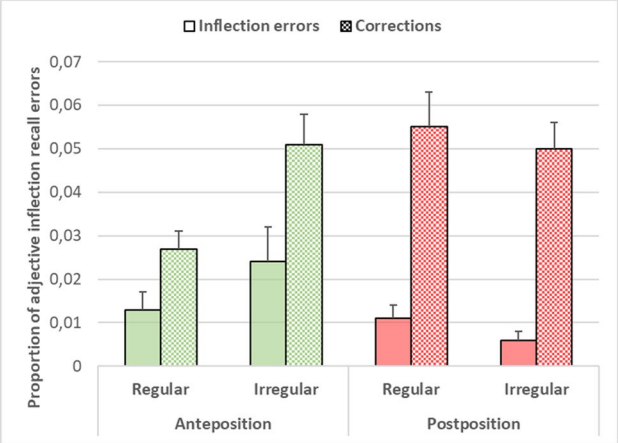

Fig. 4 Proportion of adjective inflection recall errors, in terms of position, regularity, and inflection

Discussion

The results of the present study are striking as they reproduce the null findings of the Schweppe et al. (2022) study regarding the impact of adjective–noun syntactic knowledge specifically on serial-order aspects of verbal WM, while, critically, using a language that allows for both adjective anteposition and postposition. Schweppe et al. used German language stimuli only allowing for adjective anteposition, resulting in illegal adjective postposition stimuli sounding extremely unfamiliar and preventing efficient encoding and retrieval in verbal WM. The present study shows that a null effect of adjective–noun syntactic knowledge on serial-order WM is not specific to the German language and also characterizes syntactically much more flexible languages such as French. On the other hand, our results showed a robust impact of adjective–noun associative knowledge on item recall, as also observed by Schweppe et al.

From a broad theoretical perspective, these results appear to add further evidence for the role of linguistic knowledge in verbal WM. In line with a number of language-based accounts of verbal WM (Acheson & MacDonald, 2009; Jones et al., 2006; Majerus, 2009, 2013; Martin & Saffran, 1992; Martin et al., 1994; Poirier et al., 2015), the present results support the idea that verbal WM performance is determined to a large extent by access to long-term linguistic structures that correspond to the stimuli to be memorized. While many studies have shown that phonological, lexical, and semantic levels of long-term linguistic knowledge support verbal WM, fewer studies have specifically studied the impact of syntactic knowledge. The present study adds new evidence to the limited number of studies that have specifically investigated the impact of syntactic linguistic

Table 9 Results of the 2 × 2 × 2 Bayesian ANOVA for adjective omission errors

Model Comparison					
Models	P(M)	P(M|data)	BF_M	BF_{10}	error %
Null model (incl. subject and random slopes)	0.053	1.085^{e-14}	1.953^{e-13}	1.000	
Regularity + Inflection + Regularity × Inflection	0.053	0.576	24.500	5.312^{e+13}	2.655
Regularity + Inflection	0.053	0.202	4.569	1.865^{e+13}	2.928
Position + Regularity + Inflection + Regularity × Inflection	0.053	0.086	1.696	7.937^{e+12}	2.705
Inflection	0.053	0.038	0.706	3.477^{e+12}	1.460
Position + Regularity + Inflection	0.053	0.028	0.526	2.618^{e+12}	3.519
Position + Regularity + Inflection + Position × Inflection + Regularity × Inflection	0.053	0.028	0.510	2.539^{e+12}	5.494
Position + Regularity + Inflection + Position × Regularity + Regularity × Inflection	0.053	0.014	0.249	1.257^{e+12}	7.532
Position + Regularity + Inflection + Position × Inflection	0.053	0.010	0.175	8.861^{e+11}	9.638
Position + Inflection	0.053	0.006	0.101	5.152^{e+11}	2.310
Position + Regularity + Inflection + Position × Regularity	0.053	0.005	0.082	4.193^{e+11}	10.392
Position + Regularity + Inflection + Position × Regularity + Position × Inflection + Regularity × Inflection	0.053	0.004	0.076	3.861^{e+11}	11.600
Position + Inflection + Position × Inflection	0.053	0.002	0.029	1.497^{e+11}	2.643
Position + Regularity + Inflection + Position × Regularity + Position × Inflection	0.053	0.001	0.022	1.112^{e+11}	2.829
Position + Regularity + Inflection + Position × Regularity + Position × Inflection + Regularity × Inflection + Position × Regularity × Inflection	0.053	8.610^{e-4}	0.016	7.934^{e+10}	7.385
Regularity	0.053	4.272^{e-14}	7.690^{e-13}	3.937	1.715
Position + Regularity	0.053	6.325^{e-15}	1.138^{e-13}	0.583	4.083
Position	0.053	1.539^{e-15}	2.771^{e-14}	0.142	3.302
Position + Regularity + Position × Regularity	0.053	8.498^{e-16}	1.530^{e-14}	0.078	2.307

Table 10 Descriptive statistics of the 2 × 2 × 2 Bayesian ANOVA for adjective omission errors

Position	Regularity	Inflection	Mean	*SE*	*N*
Ante	Regular	Correct	0.216	0.094	56
		Incorrect	0.150	0.068	57
	Irregular	Correct	0.265	0.134	56
		Incorrect	0.150	0.075	57
Post	Regular	Correct	0.212	0.093	56
		Incorrect	0.159	0.083	57
	Irregular	Correct	0.253	0.095	56
		Incorrect	0.166	0.092	57

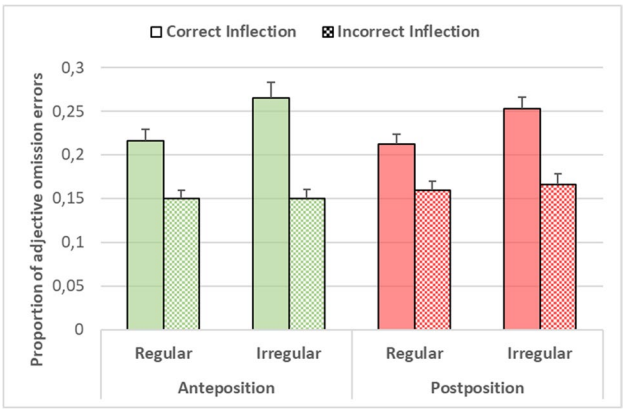

Fig. 5 Proportion of adjective omission errors, in terms of position, regularity, and inflection

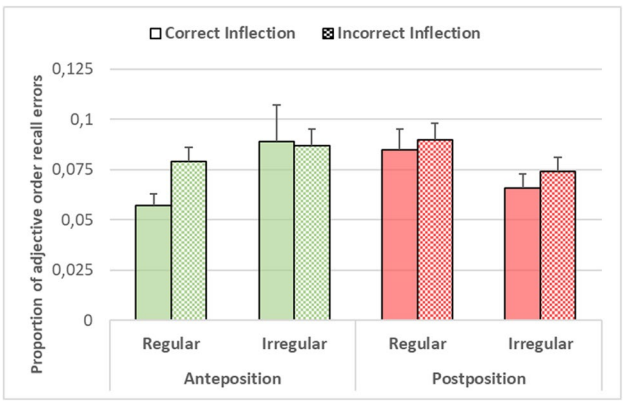

Fig. 6 Proportion of adjective order recall errors, in terms of position, regularity, and inflection

knowledge on verbal WM by showing that syntactic knowledge about adjective–noun associations supports at least item aspects of verbal WM.

Linguistic knowledge effects in verbal WM are interpreted as reflecting the intervention of language representations that support and reconstruct decaying WM traces (e.g., Hulme et al., 1991; Schweickert, 1993) and/or that directly provide the representational basis for information held in WM (Acheson & MacDonald, 2009; Kowialiewski & Majerus, 2020; Kowialiewski et al., 2021; Majerus, 2009; Martin & Saffran, 1992). This support is considered to act at the level of the phonological, lexical, and semantic features of individual memoranda (Majerus, 2009; Martin & Saffran, 1992), and the fact that most linguistic effects exert an impact on item recall in WM tasks is in line with this assumption. However, as already discussed earlier, fully emergent linguistic accounts of WM (e.g., Schwering & MacDonald, 2020) consider that any type of knowledge that defines language processing should also define WM processing, given that language is the representational substrate for WM. Following these accounts, we should also expect that knowledge about linguistic sequential structures should support sequence-level aspects of verbal WM, and more specifically, the maintenance of serial order information in WM. It is therefore interesting to observe that sequential knowledge about adjective–noun order, although having a strong impact at the item level, does not appear to support the maintenance of order information.

How can we then explain this apparent paradoxical finding of sequential linguistic knowledge supporting item-level but not sequence-level aspects of WM? We argue that our results support an *indirect* effect of syntactic knowledge on serial order WM, by assuming dependency rather than independency of item and serial order levels of representation in WM, and by assuming that retrieval of item information is conditioned by sequential regularities, in line with recurrent network models of verbal WM that assume unified item-order representations (Botvinick & Plaut, 2006), full linguistic models of verbal WM (Schwering & MacDonald, 2020) as well as psycholinguistic models of syntactic processing. At the same time, our findings allow to exclude a *direct* effect of syntactic adjective–noun order on serial order WM and an associated full independency of item and serial order recall (as assumed for example by contextual, positional models of serial order WM; Burgess & Hitch, 1999, 2006) by showing that sequential knowledge does not directly lead to an increase in serial-order recall performance or serial-order errors, independently of its effect in item-level encoding and retrieval. In other words, the results of the present study suggest that illegal adjective–noun orderings prevent the retrieval of associated item information rather than directly leading to order errors. This could be explained by a chaining-type representation of item and serial order representation: an adjective (noun) stored in WM cues the associated noun (adjective), but only if the chain corresponds to its corresponding long-term sequential representation (i.e., if the specific adjective [noun] precedes the specific noun [adjective] in natural language chains). If the

Table 11 Results of the 2 × 2 × 2 Bayesian ANOVA for adjective order recall errors

Model Comparison					
Models	P(M)	P(M|data)	BF_M	BF_{01}	error %
Null model (incl. subject and random slopes)	0.053	0.461	15.408	1.000	
Position + Regularity + Position × Regularity	0.053	0.180	3.950	2.563	5.103
Inflection	0.053	0.117	2.389	3.936	1.184
Position	0.053	0.066	1.275	6.971	4.770
Regularity	0.053	0.058	1.113	7.920	1.285
Position + Regularity + Inflection + Position × Regularity	0.053	0.044	0.819	10.596	4.008
Position + Inflection	0.053	0.016	0.295	28.587	2.040
Regularity + Inflection	0.053	0.015	0.266	31.715	1.482
Position + Regularity + Inflection + Position × Regularity + Position × Inflection	0.053	0.013	0.245	34.339	40.318
Position + Regularity	0.053	0.009	0.171	48.926	3.156
Position + Regularity + Inflection + Position × Regularity + Regularity × Inflection	0.053	0.008	0.143	58.707	1.838
Position + Inflection + Position × Inflection	0.053	0.004	0.070	118.934	5.394
Regularity + Inflection + Regularity × Inflection	0.053	0.003	0.051	164.010	5.065
Position + Regularity + Inflection	0.053	0.002	0.035	238.249	2.085
Position + Regularity + Inflection + Position × Regularity + Position × Inflection + Regularity × Inflection	0.053	0.002	0.035	240.972	9.427
Position + Regularity + Inflection + Position × Regularity + Position × Inflection + Regularity × Inflection + Position × Regularity × Inflection	0.053	7.694^{e-4}	0.014	599.419	17.231
Position + Regularity + Inflection + Position × Inflection	0.053	4.405^{e-4}	0.008	1047.069	3.716
Position + Regularity + Inflection + Regularity × Inflection	0.053	3.620^{e-4}	0.007	1274.222	3.723
Position + Regularity + Inflection + Position × Inflection + Regularity × Inflection	0.053	2.433^{e-4}	0.004	1895.844	66.106

same adjective–noun pair is presented in reversed, irregular order, the noun (adjective), presented first, will not cue the following adjective (noun) as this adjective (noun) is usually not produced after the noun (adjective). Hence, irregular order of adjective–noun pairs will prevent efficient encoding, maintenance and retrieval of item information. This interpretation is in line with chaining models of serial order recall (at least with those assuming unidirectional chaining such as Ebbinghaus, 1885; Lindsay & Logan, 2021): when a string of words to be recalled does not correspond to the usual succession of the words, successive items cannot be retrieved as inter-item associative chains are disrupted. A similar interpretation of our findings can be made based on the additional error analyses we carried out. We observed an increase of item omission errors when adjectives (and also postpositioned nouns) occur in irregular positions and, most critically, an increase of partial pairs with the first adjective (noun) recalled but not the second noun (adjective) for irregularly ordered adjective–noun pairs. In case of irregularity of adjective–noun order, the first item of a given pair may be retrieved but it will not provide a cue for the following word, leading to an increased proportion of partial pairs with only the first item recalled. Notably, similar results are observed from the separate analyses of partial pairs involving either nouns or adjectives, supporting the existence of a general chaining mechanism and of a disruptive effect of irregular syntactic position on cuing. In sum, any deviation from expected syntactic position should disrupt cuing. The results of T. Jones and Farrell (2018) using a serial-order reconstruction task could be explained in a similar manner: The advantage observed in serial order reconstruction for syntactically legal word sequences could actually stem from a better ability to maintain items and to cue successive items during retrieval based on a better match between the syntactic nature of items and their associated position in the syntactic frame.

A similar explanation of the results can be derived from psycholinguistic models of syntactic processing (Garrett,

Table 12 Descriptive statistics of the 2 × 2 × 2 Bayesian ANOVA for adjective order recall errors

Position	Regularity	Inflection	Mean	*SE*	*N*
Ante	Regular	Correct	0.057	0.044	56
		Incorrect	0.079	0.055	57
	Irregular	Correct	0.085	0.077	56
		Incorrect	0.090	0.058	57
Post	Regular	Correct	0.089	0.134	56
		Incorrect	0.087	0.057	57
	Irregular	Correct	0.066	0.051	56
		Incorrect	0.074	0.052	57

Table 13 Results of the 2 × 2 × 2 Bayesian ANOVA for partial pairs recall

Model Comparison					
Models	P(M)	P(M|data)	BF_M	BF_{10}	error %
Null model (incl. Item, Regularity, Inflection, subject, and random slopes)[a]	0.111	$6.060e^{-17}$	4.848^{e-16}	1.000	
Item × Regularity	0.111	0.567	10.459	9.350^{e+15}	3.549
Item × Regularity + Item × Inflection	0.111	0.236	2.476	3.900^{e+15}	3.519
Item × Regularity + Regularity × Inflection	0.111	0.126	1.154	2.080^{e+15}	7.672
Item × Regularity + Item × Inflection + Regularity × Inflection	0.111	0.057	0.482	9.386^{e+14}	8.699
Item × Regularity + Item × Inflection + Regularity × Inflection + Item × Regularity × Inflection	0.111	0.014	0.115	2.330^{e+14}	5.584
Item × Inflection	0.111	2.434^{e-17}	1.947^{e-16}	0.402	4.160
Regularity × Inflection	0.111	1.223^{e-17}	9.784^{e-17}	0.202	4.651
Item × Inflection + Regularity × Inflection	0.111	4.706^{e-18}	3.765^{e-17}	0.078	6.494

[a]The main effects of regularity, item, and inflection were not robust ($\eta_p^2 = 0.09$; $\eta_p^2 = 0.002$; $\eta_p^2 = 0.022$, respectively), and hence, these factors were added to the null model for correct interpretation of the model including the interactions

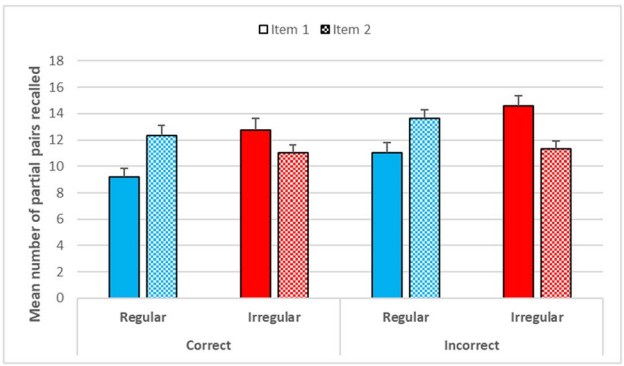

Fig. 7 Mean number of partial pairs, in terms of regularity, item, and inflection

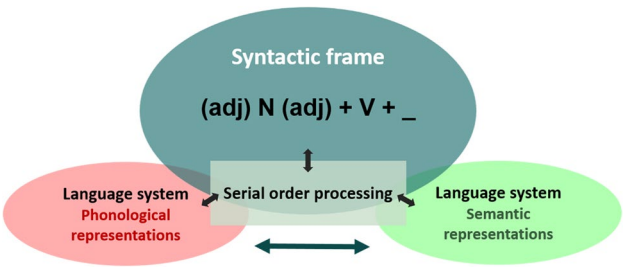

Fig. 8 Macroscopic proposal for an integrated WM and language processing architecture that includes syntactic levels of processing, in which item and serial order are linked via interitem associative sequential knowledge

1988; Levelt, 1999). In these models, syntactic order is encoded via a syntactic frame structure, which defines the position in which each constituent of a sentence should be located, depending on its syntactic and lexical nature. Once the syntactic frame has been defined, the syntactic slots are filled with the phonological (item) content of the selected words. For the memory lists used in the present study, the syntactic frame to be constructed would be Adj N + Adj N + Adj N or N Adj + N Adj + N Adj, depending on the type of WM list. More specifically, when a list has to be recalled, either the Adj N + Adj N + Adj N or the N Adj + N Adj + N Adj frame created during memory list encoding will be activated, and the syntactic slots have to be completed with their respective phonological content. The slots will not be filled if the adjective (noun) to be placed in a specific slot does not correspond to the types of adjectives (nouns) that are usually allocated to the ante/post position of this slot, relative to the noun (adjective). Adjective inflection recall errors on the other hand can freely occur as type of inflections is determined by the noun to which adjectives are associated rather than by syntactic position. Note, however, that this psycholinguistic account alone cannot explain our results. While it is compatible with the increased omission errors for irregular adjective–noun order lists, it would not predict an increase of partial pairs with the first but not the second item recalled. It would instead predict an increase of recall omission of both first and second items. Our results rather support an account where item and serial order are linked via inter-item associative sequential knowledge, in addition to syntactic parsing and frame prediction processes (see Fig. 8).

A potential limitation of the present study is that the specific outcome of results might have been facilitated by the redundant and predictable nature of the WM list. However, as already stated above, while this situation may have led to increased omission errors for irregular lists due to the predictability of the resulting syntactic frame, this situation alone cannot explain the increased partial pairs with only the first item recalled. In any case, it remains to be shown

Table 14 Materials used in Group 1 (correct inflection), Version A; IRREG/REG = irregular or regular position; ANTE/POST = anteposition or postposition of the adjective

List	Condition	Gender	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6
1	IRREG + ANTE	masc	familier	muguet	naïf	soda	sec	coussin
2	REG + ANTE	fem	importante	bière	nouvelle	paupière	joyeuse	casserole
3	REG + POST	fem	vipère	brillante	myrtille	jalouse	vanille	glissante
4	IRREG + POST	fem	serrure	élégante	texture	grande	résine	seconde
5	IRREG + ANTE	fem	sèche	écharpe	bruyante	lavande	familière	amande
6	REG + ANTE	masc	gros	pseudonyme	petit	laiton	vieux	pentagone
7	REG + POST	masc	moteur	blanc	soda	naïf	orteil	agressif
8	IRREG + POST	masc	titane	grand	carnaval	léger	béret	joyeux
9	IRREG + ANTE	masc	discret	poivron	gluant	poignet	gourmand	balcon
10	IRREG + POST	masc	pentagone	vieux	nombril	puissant	laiton	petit
11	IRREG + ANTE	fem	maladroite	poitrine	creuse	chorale	brumeuse	gazelle
12	IRREG + ANTE	fem	agressive	tasse	discrète	fourchette	brillante	vipère
13	IRREG + POST	fem	agence	légère	vésicule	dernière	virgule	belle
14	REG + ANTE	masc	puissant	nombril	bref	whisky	élégant	piment
15	REG + POST	masc	tiroir	compétent	coussin	sec	poignet	gluant
16	REG + ANTE	masc	premier	terroir	léger	carnaval	précieux	fleuve
17	REG + POST	masc	jasmin	méfiant	poivron	discret	champagne	glissant
18	REG + ANTE	masc	grand	titane	dernier	thorax	important	béton
19	IRREG + POST	fem	nectarine	brève	salamandre	première	bouilloire	longue
20	REG + POST	fem	batterie	blanche	cannelle	compétente	patate	naïve
21	REG + ANTE	masc	long	acier	nouveau	trapèze	mauvais	vestibule
22	IRREG + ANTE	masc	brillant	palmier	ringard	saumon	méfiant	jasmin
23	REG + POST	fem	oreille	gourmande	écharpe	sèche	poitrine	maladroite
24	IRREG + POST	fem	vessie	précieuse	symétrie	petite	pommette	vieille
25	REG + POST	masc	terroir	premier	piment	élégant	whisky	bref
26	IRREG + ANTE	masc	blanc	moteur	agressif	orteil	bruyant	bonnet
27	IRREG + POST	fem	casserole	joyeuse	urgence	mauvaise	banane	puissante
28	REG + POST	fem	chorale	creuse	amande	familière	limace	ringarde
29	REG + ANTE	fem	grande	texture	élégante	serrure	puissante	banane
30	IRREG + POST	masc	vecteur	beau	pseudonyme	gros	béton	important
31	REG + POST	fem	lavande	bruyante	tasse	agressive	gazelle	brumeuse
32	REG + ANTE	fem	mauvaise	urgence	vieille	pommette	première	salamandre
33	IRREG + ANTE	fem	naïve	patate	blanche	batterie	compétente	cannelle
34	REG + POST	masc	pull	jaloux	balcon	gourmand	muguet	familier
35	REG + ANTE	masc	joyeux	béret	beau	vecteur	second	silicone
36	IRREG + POST	masc	fleuve	précieux	thorax	dernier	vestibule	mauvais
37	IRREG + POST	masc	silicone	second	acier	long	trapèze	nouveau
38	REG + POST	masc	menton	brumeux	bonnet	bruyant	saumon	ringard
39	REG + ANTE	fem	grosse	religion	dernière	vésicule	belle	virgule
40	IRREG + ANTE	fem	jalouse	myrtille	gourmande	oreille	glissante	vanille
41	IRREG + POST	masc	palmier	brillant	miroir	maladroit	tissu	creux
42	IRREG + ANTE	fem	gluante	fourmi	ringarde	limace	méfiante	tisane
43	IRREG + POST	fem	bière	importante	paupière	nouvelle	religion	grosse
44	REG + ANTE	fem	petite	symétrie	longue	bouilloire	précieuse	vessie
45	IRREG + ANTE	masc	compétent	tiroir	jaloux	pull	brumeux	menton
46	REG + ANTE	fem	seconde	résine	légère	agence	brève	nectarine
47	REG + POST	fem	tisane	méfiante	fourchette	discrète	fourmi	gluante
48	IRREG + ANTE	masc	glissant	champagne	creux	tissu	maladroit	miroir

Table 15 Materials used in Group 1 (correct inflection), Version B; IRREG/REG = irregular or regular position; ANTE/POST = anteposition or postposition of the adjective

List	Condition	Gender	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6
1	IRREG + POST	masc	terroir	premier	piment	élégant	whisky	bref
2	IRREG + ANTE	fem	agressive	tasse	discrète	fourchette	brillante	vipère
3	REG + ANTE	masc	gros	pseudonyme	petit	laiton	vieux	pentagone
4	REG + POST	masc	menton	brumeux	bonnet	bruyant	saumon	ringard
5	IRREG + POST	masc	titane	grand	carnaval	léger	béret	joyeux
6	IRREG + POST	masc	fleuve	précieux	thorax	dernier	vestibule	mauvais
7	IRREG + ANTE	fem	jalouse	myrtille	gourmande	oreille	glissante	vanille
8	REG + POST	masc	palmier	brillant	miroir	maladroit	tissu	creux
9	REG + ANTE	masc	puissant	nombril	bref	whisky	élégant	piment
10	REG + POST	fem	tisane	méfiante	fourchette	discrète	fourmi	gluante
11	REG + ANTE	fem	mauvaise	urgence	vieille	pommette	première	salamandre
12	IRREG + ANTE	masc	familier	muguet	naïf	soda	sec	coussin
13	REG + POST	fem	chorale	creuse	amande	familière	limace	ringarde
14	REG + ANTE	masc	long	acier	nouveau	trapèze	mauvais	vestibule
15	REG + ANTE	fem	grosse	religion	dernière	vésicule	belle	virgule
16	REG + POST	masc	moteur	blanc	soda	naïf	orteil	agressif
17	REG + ANTE	fem	grande	texture	élégante	serrure	puissante	banane
18	REG + POST	masc	pull	jaloux	balcon	gourmand	muguet	familier
19	REG + ANTE	fem	petite	symétrie	longue	bouilloire	précieuse	vessie
20	REG + POST	fem	oreille	gourmande	écharpe	sèche	poitrine	maladroite
21	REG + ANTE	masc	joyeux	béret	beau	vecteur	second	silicone
22	REG + POST	fem	lavande	bruyante	tasse	agressive	gazelle	brumeuse
23	REG + POST	masc	jasmin	méfiant	poivron	discret	champagne	glissant
24	REG + ANTE	masc	premier	terroir	léger	carnaval	précieux	fleuve
25	IRREG + ANTE	masc	compétent	tiroir	jaloux	pull	brumeux	menton
26	IRREG + POST	masc	vecteur	beau	pseudonyme	gros	béton	important
27	IRREG + POST	fem	casserole	joyeuse	urgence	mauvaise	banane	puissante
28	IRREG + ANTE	masc	blanc	moteur	agressif	orteil	bruyant	bonnet
29	IRREG + ANTE	fem	maladroite	poitrine	creuse	chorale	brumeuse	gazelle
30	IRREG + POST	fem	nectarine	brève	salamandre	première	bouilloire	longue
31	IRREG + POST	fem	serrure	élégante	texture	grande	résine	seconde
32	REG + POST	fem	batterie	blanche	cannelle	compétente	patate	naïve
33	REG + ANTE	fem	importante	bière	nouvelle	paupière	joyeuse	casserole
34	IRREG + POST	masc	pentagone	vieux	nombril	puissant	laiton	petit
35	IRREG + ANTE	masc	glissant	champagne	creux	tissu	maladroit	miroir
36	IRREG + ANTE	fem	gluante	fourmi	ringarde	limace	méfiante	tisane
37	IRREG + POST	fem	agence	légère	vésicule	dernière	virgule	belle
38	IRREG + ANTE	fem	naïve	patate	blanche	batterie	compétente	cannelle
39	IRREG + POST	masc	silicone	second	acier	long	trapèze	nouveau
40	IRREG + ANTE	fem	sèche	écharpe	bruyante	lavande	familière	amande
41	IRREG + ANTE	masc	brillant	palmier	ringard	saumon	méfiant	jasmin
42	REG + ANTE	masc	grand	titane	dernier	thorax	important	béton
43	IRREG + POST	fem	vessie	précieuse	symétrie	petite	pommette	vieille
44	IRREG + ANTE	masc	discret	poivron	gluant	poignet	gourmand	balcon
45	REG + POST	fem	vipère	brillante	myrtille	jalouse	vanille	glissante
46	IRREG + POST	fem	bière	importante	paupière	nouvelle	religion	grosse
47	REG + POST	masc	tiroir	compétent	coussin	sec	poignet	gluant
48	REG + ANTE	fem	seconde	résine	légère	agence	brève	nectarine

Table 16 Materials used in Group 2 (incorrect inflection), Version A; IRREG/REG = irregular or regular position; ANTE/POST = anteposition or postposition of the adjective

List	Condition	Gender	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6
1	IRREG + ANTE	masc	sec	écharpe	familier	amande	glissant	vanille
2	REG + POST	fem	chorale	creux	cannelle	compétent	patate	naïf
3	REG + ANTE	fem	première	terroir	légère	carnaval	précieuse	fleuve
4	IRREG + ANTE	masc	gluant	fourmi	discret	fourchette	méfiant	tisane
5	IRREG + POST	masc	silicone	seconde	acier	longue	béret	joyeuse
6	REG + POST	masc	palmier	brillante	miroir	maladroite	tissu	creuse
7	REG + ANTE	masc	gros	religion	long	bouilloire	premier	salamandre
8	IRREG + ANTE	fem	familière	muguet	naïve	soda	jalouse	pull
9	IRREG + POST	masc	piment	élégante	vecteur	belle	trapèze	nouvelle
10	REG + POST	masc	saumon	ringarde	balcon	gourmande	menton	brumeuse
11	IRREG + ANTE	masc	maladroit	poitrine	blanc	batterie	brumeux	gazelle
12	REG + POST	masc	pull	jalouse	soda	naïve	muguet	familière
13	IRREG + POST	fem	serrure	élégant	texture	grand	résine	second
14	REG + ANTE	masc	petit	symétrie	vieux	pommette	précieux	vessie
15	IRREG + ANTE	fem	glissante	champagne	gluante	poignet	méfiante	jasmin
16	IRREG + POST	fem	nectarine	bref	salamandre	premier	virgule	beau
17	IRREG + POST	masc	fleuve	précieuse	thorax	dernière	vestibule	mauvaise
18	IRREG + ANTE	masc	naïf	patate	compétent	cannelle	creux	chorale
19	IRREG + ANTE	masc	jaloux	myrtille	gourmand	oreille	bruyant	lavande
20	REG + ANTE	fem	longue	acier	grosse	pseudonyme	élégante	piment
21	REG + POST	fem	tisane	méfiant	fourchette	discret	fourmi	gluant
22	IRREG + POST	masc	terroir	première	whisky	brève	béton	importante
23	IRREG + ANTE	fem	brillante	palmier	ringarde	saumon	gourmande	balcon
24	REG + ANTE	fem	importante	béton	petite	laiton	belle	vecteur
25	REG + POST	fem	vipère	brillant	myrtille	jaloux	vanille	glissant
26	REG + POST	masc	orteil	agressive	bonnet	bruyante	moteur	blanche
27	REG + ANTE	fem	joyeuse	béret	mauvaise	vestibule	grande	titane
28	REG + POST	masc	tiroir	compétente	coussin	sèche	poignet	gluante
29	IRREG + ANTE	masc	agressif	tasse	ringard	limace	brillant	vipère
30	IRREG + POST	fem	bière	important	paupière	nouveau	religion	gros
31	IRREG + ANTE	fem	discrète	poivron	creuse	tissu	compétente	tiroir
32	IRREG + POST	fem	vessie	précieux	symétrie	petit	bouilloire	long
33	REG + ANTE	masc	important	bière	joyeux	casserole	dernier	vésicule
34	REG + POST	fem	lavande	bruyant	tasse	agressif	gazelle	brumeux
35	REG + ANTE	masc	mauvais	urgence	léger	agence	beau	virgule
36	IRREG + POST	masc	pentagone	vieille	nombril	puissante	pseudonyme	grosse
37	REG + POST	fem	batterie	blanc	limace	ringard	amande	familier
38	REG + ANTE	masc	nouveau	paupière	élégant	serrure	grand	texture
39	REG + POST	fem	oreille	gourmand	écharpe	sec	poitrine	maladroit
40	REG + ANTE	fem	vieille	pentagone	dernière	thorax	nouvelle	trapèze
41	REG + ANTE	fem	puissante	nombril	brève	whisky	seconde	silicone
42	IRREG + POST	masc	titane	grande	carnaval	légère	laiton	petite
43	REG + POST	masc	jasmin	méfiante	poivron	discrète	champagne	glissante
44	IRREG + ANTE	fem	blanche	moteur	agressive	orteil	bruyante	bonnet
45	IRREG + POST	fem	agence	léger	vésicule	dernier	pommette	vieux
46	IRREG + ANTE	fem	maladroite	miroir	sèche	coussin	brumeuse	menton
47	IRREG + POST	fem	casserole	joyeux	urgence	mauvais	banane	puissant
48	REG + ANTE	masc	second	résine	puissant	banane	bref	nectarine

Table 17 Materials used in Group 2 (incorrect inflection), Version B; IRREG/REG = irregular or regular position; ANTE/POST = anteposition or postposition of the adjective

List	Condition	Gender	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6
1	REG + POST	fem	lavande	bruyant	tasse	agressif	gazelle	brumeux
2	IRREG + POST	masc	pentagone	vieille	nombril	puissante	pseudonyme	grosse
3	REG + ANTE	masc	mauvais	urgence	léger	agence	beau	virgule
4	REG + POST	fem	oreille	gourmand	écharpe	sec	poitrine	maladroit
5	REG + ANTE	masc	nouveau	paupière	élégant	serrure	grand	texture
6	IRREG + ANTE	masc	naïf	patate	compétent	cannelle	creux	chorale
7	IRREG + POST	fem	agence	léger	vésicule	dernier	pommette	vieux
8	REG + ANTE	masc	second	résine	puissant	banane	bref	nectarine
9	REG + POST	masc	orteil	agressive	bonnet	bruyante	moteur	blanche
10	REG + POST	masc	saumon	ringarde	balcon	gourmande	menton	brumeuse
11	REG + ANTE	fem	longue	acier	grosse	pseudonyme	élégante	piment
12	IRREG + ANTE	masc	sec	écharpe	familier	amande	glissant	vanille
13	REG + POST	fem	chorale	creux	cannelle	compétent	patate	naïf
14	IRREG + POST	fem	casserole	joyeux	urgence	mauvais	banane	puissant
15	IRREG + ANTE	masc	maladroit	poitrine	blanc	batterie	brumeux	gazelle
16	IRREG + POST	masc	piment	élégante	vecteur	belle	trapèze	nouvelle
17	IRREG + POST	masc	titane	grande	carnaval	légère	laiton	petite
18	IRREG + ANTE	fem	brillante	palmier	ringarde	saumon	gourmande	balcon
19	REG + ANTE	fem	puissante	nombril	brève	whisky	seconde	silicone
20	REG + POST	fem	tisane	méfiant	fourchette	discret	fourmi	gluant
21	IRREG + ANTE	fem	maladroite	miroir	sèche	coussin	brumeuse	menton
22	IRREG + POST	masc	fleuve	précieuse	thorax	dernière	vestibule	mauvaise
23	REG + POST	fem	batterie	blanc	limace	ringard	amande	familier
24	IRREG + ANTE	masc	jaloux	myrtille	gourmand	oreille	bruyant	lavande
25	IRREG + POST	fem	nectarine	bref	salamandre	premier	virgule	beau
26	IRREG + ANTE	masc	gluant	fourmi	discret	fourchette	méfiant	tisane
27	REG + POST	masc	palmier	brillante	miroir	maladroite	tissu	creuse
28	REG + ANTE	fem	joyeuse	béret	mauvaise	vestibule	grande	titane
29	IRREG + POST	fem	vessie	précieux	symétrie	petit	bouilloire	long
30	REG + POST	masc	pull	jalouse	soda	naïve	muguet	familière
31	REG + ANTE	fem	vieille	pentagone	dernière	thorax	nouvelle	trapèze
32	IRREG + ANTE	fem	glissante	champagne	gluante	poignet	méfiante	jasmin
33	IRREG + POST	fem	serrure	élégant	texture	grand	résine	second
34	REG + ANTE	fem	importante	béton	petite	laiton	belle	vecteur
35	IRREG + ANTE	fem	blanche	moteur	agressive	orteil	bruyante	bonnet
36	IRREG + POST	masc	terroir	première	whisky	brève	béton	importante
37	REG + POST	masc	jasmin	méfiante	poivron	discrète	champagne	glissante
38	REG + ANTE	masc	important	bière	joyeux	casserole	dernier	vésicule
39	IRREG + ANTE	fem	familière	muguet	naïve	soda	jalouse	pull
40	REG + POST	masc	tiroir	compétente	coussin	sèche	poignet	gluante
41	REG + ANTE	masc	gros	religion	long	bouilloire	premier	salamandre
42	REG + ANTE	masc	petit	symétrie	vieux	pommette	précieux	vessie
43	REG + POST	fem	vipère	brillant	myrtille	jaloux	vanille	glissant
44	IRREG + POST	masc	silicone	seconde	acier	longue	béret	joyeuse
45	IRREG + ANTE	fem	discrète	poivron	creuse	tissu	compétente	tiroir
46	IRREG + POST	fem	bière	important	paupière	nouveau	religion	gros
47	REG + ANTE	fem	première	terroir	légère	carnaval	précieuse	fleuve
48	IRREG + ANTE	masc	agressif	tasse	ringard	limace	brillant	vipère

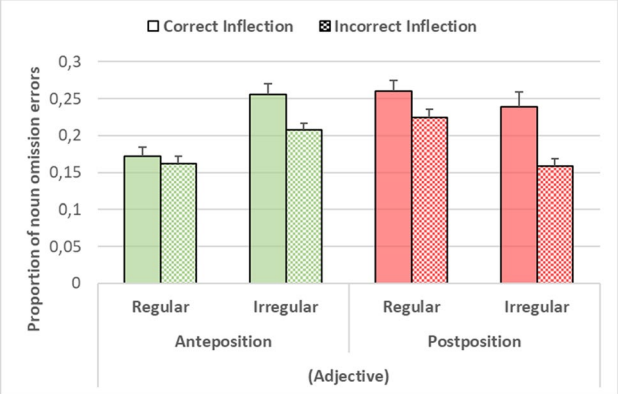

Fig. 9 Proportion of noun omission errors, in terms of position, regularity, and inflection

whether increased serial order errors could be observed in WM lists where adjective–noun order is less predictable, by presenting lists mixing adjective–noun and noun–adjective pairs and without any interval separating the pairs, by inserting a delay between the lists and recall to reduce the impact of phonological sequential representation, or by instructing participants to use a free recall strategy. Also, a stronger and more direct effect on serial order may be observed when manipulating noun-verb order (boy eats bread vs. boy bread eats) rather than noun–adjective order given that verbs are an obligatory constituent of natural sentences unlike adjectives. The results of increased serial order WM for syntactically legal sequences in the study by T. Jones and Farrell (2018) could indeed be driven by the inclusion of verbs in their memory lists.

Finally, Schweppe et al. (2022) observed an impact of syntactic order regularity on item WM recall only when the adjectives were correctly inflected. Interestingly, a similar interaction between regularity and inflection emerged in the context of our analysis of adjective omission errors, with a higher proportion of omission errors when adjectives were both in an irregular syntactic position and correctly inflected. Correct inflection may indeed reinforce the expectation that the adjective and noun are related, and presenting them in an irregular syntactic order may lead to increased omission errors. However, this interaction was not robust and needs to be interpreted with caution. In addition, syntactic order and inflection exerted two independent effects in most analyses, suggesting that, for the French language stimuli used in this study, they stemmed from different sources. Schweppe et al. considered that there is an overlap between syntactic constraints on word order and morpho-syntactic constraints such as adjective inflection. This may indeed be the case for languages with highly deterministic morpho-syntactic structures: As soon as one constraint is violated, WM recall performance sharply drops as the entire sequence is perceived as highly ungrammatical and may not receive further (syntactic) linguistic support anymore. For languages with probabilistic morpho-syntactic structures such as French, morphological (inflections) and syntactic constraints appear to interact in a more flexible manner and the irregularity of one of the constraints does not automatically invalidate the other constraint. This is also supported by the complex interactions with syntactic order that were observed for inflection recall errors in this study. However, it should be noted that the sample size had been determined for the main effect of regularity (order), not the interaction between order and inflection. Despite a rather large sample size ($N = 113$), our interpretation therefore still needs to be considered with caution.

In this study, inflection of the adjective reflects morpho-phonological knowledge associated to items and not positional (syntactic) knowledge about items in the list. One may wonder why the impact of adjective inflection was much more important than the impact of adjective order. Inflectional effects are probably stronger because they are deterministic: Every adjective needs to be correctly inflected and there is only one possible correct inflection. Adjective–noun order effects on the other hand, as already mentioned, are, in the French language, probabilistic: An adjective can be found in both anteposition and post-position, and these flexible rules may also explain the lesser impact of adjective–noun order.

To conclude, the present study provides evidence for the impact of syntactic order knowledge on verbal WM performance and calls for a deep integration of language processing and WM architectures, by including syntactic levels of processing in addition to the phonological, lexical and semantic processing levels considered by most WM architectures. Although additional clarification is needed regarding the interactions between syntactic sequential knowledge structures and order recall in WM, the present results provide further evidence for an indirect effect of syntactic knowledge on serial order WM by predicting successive item cues based on interitem associative and sequential knowledge.

Appendix

Complementary analysis: Noun omission errors

Regarding noun omission errors, the most parsimonious model with the strongest evidence included the inflection factor, and the interaction between position and regularity (inflection: $\eta_p^2 = 0.043$; Position × Regularity: $\eta_p^2 = 0.067$; see Tables 18 and 19). Like for adjective omission errors,

Table 18 Results of the 2 × 2 × 2 Bayesian ANOVA for noun omission errors

Model Comparison					
Models	P(M)	P(M|data)	BF_M	BF_{10}	error %
Null model (incl. Position, Regularity, subject, and random slopes)[a]	0.091	8.056^{e-13}	8.056^{e-12}	1.000	
Inflection + Inflection × Regularity + Position × Regularity	0.091	0.410	6.951	5.090^{e+11}	5.693
Inflection + Position × Regularity	0.091	0.279	3.873	3.466^{e+11}	3.965
Inflection + Inflection × Position + Inflection × Regularity + Position × Regularity	0.091	0.161	1.915	1.995^{e+11}	4.072
Inflection + Inflection × Position + Position × Regularity	0.091	0.118	1.339	1.466^{e+11}	3.945
Inflection + Inflection × Position + Inflection × Regularity + Position × Regularity + Inflection × Position × Regularity	0.091	0.032	0.329	3.948^{e+10}	4.215
Position × Regularity	0.091	7.153^{e-5}	7.153^{e-4}	8.878^{e+7}	2.676
Inflection + Inflection × Regularity	0.091	1.199^{e-9}	1.199^{e-8}	1488.444	2.898
Inflection	0.091	1.105^{e-9}	1.105^{e-8}	1371.233	4.403
Inflection + Inflection × Position + Inflection × Regularity	0.091	7.046^{e-10}	7.046^{e-9}	874.608	28.393
Inflection + Inflection × Position	0.091	3.903^{e-10}	3.903^{e-9}	484.486	3.952

[a]The main effect of regularity was not robust ($\eta_p^2 = 0.011$), and hence, this factor was added to the null model for correct interpretation of the model including the interactions

noun omission errors were more frequent in the correct adjective inflection condition. The Position × Regularity interaction furthermore showed that noun omission errors were more frequent when occurring in irregular postposition like for associated adjectives in irregular anteposition, but also when occurring in regular anteposition (see Fig. 9). The latter finding may again be the result of the semantically mainly implausible noun–adjective associations, the noun occurring in the expected position relative to the adjective; this syntactic association will then be contradicted by the semantic incongruency between the two elements, increasing the probability of the nouns not being efficiently maintained and recalled.

Table 19 Descriptive statistics of the 2 × 2 × 2 Bayesian ANOVA for noun omission errors

Position	Regularity	Inflection	Mean	*SE*	*N*
Ante	Regular	Correct	0.172	0.012	56
		Incorrect	0.162	0.010	57
	Irregular	Correct	0.256	0.014	56
		Incorrect	0.208	0.009	57
Post	Regular	Correct	0.260	0.015	56
		Incorrect	0.225	0.011	57
	Irregular	Correct	0.239	0.020	56
		Incorrect	0.159	0.010	57

Complementary analysis: Separate partial pairs recall analysis for adjectives and nouns

Additional analyses were conducted on recall of partial pairs, by focussing specifically on either adjectives or nouns as item reference. For the analysis on adjectives as item reference, the conditions were defined as follows: Item 1 in regular position (regular anteposition), Item 1 in irregular position (irregular anteposition), Item 2 in regular position (regular postposition), and Item 2 in irregular position (irregular postposition). A 2 × 2 × 2 Bayesian three-way ANOVA showed that the data were best explained by a model including the interaction between regularity and item (Regularity × Item: $\eta_p^2 = 0.239$; see Table 21). In line with the results of partial pairs analysis, more second items were recalled for pairs in regular position, while the opposite was observed for pairs in irregular position, with more first items recalled for pairs in irregular position (see Fig. 10).

Regarding partial pairs analysis on nouns as item reference, the conditions were defined as Item 1 in regular position (regular postposition), Item 1 in irregular position (irregular postposition), Item 2 in regular position (regular anteposition), and Item 2 in irregular position (irregular anteposition). The model with strongest evidence included regularity, and, critically, the interaction

Table 20 Results of the 2 × 2 × 2 Bayesian ANOVA for noun order recall errors (evidence for the alternative hypothesis)

Model Comparison					
Models	P(M)	P(M|data)	BF_M	BF_{10}	error %
Null model (incl. Position, Regularity, Inflection, subject, and random slopes)[a]	0.111	0.008	0.061	1.000	
Position × Regularity + Position × Inflection + Regularity × Inflection + Position × Regularity × Inflection	0.111	0.634	13.854	83.111	4.878
Position × Regularity	0.111	0.103	0.918	13.502	7.056
Position × Regularity + Position × Inflection	0.111	0.102	0.906	13.337	13.307
Position × Regularity + Regularity × Inflection	0.111	0.071	0.613	9.334	6.043
Position × Regularity + Position × Inflection + Regularity × Inflection	0.111	0.067	0.575	8.786	8.684
Position × Inflection	0.111	0.006	0.052	0.846	3.887
Regularity × Inflection	0.111	0.005	0.039	0.640	4.181
Position × Inflection + Regularity × Inflection	0.111	0.004	0.034	0.547	4.451

[a]The main effects of regularity, position, and inflection were not robust ($\eta_p^2 = 0.002$; $\eta_p^2 = 0.000$; $\eta_p^2 = 0.051$, respectively), and hence, these factors were added to the null model for correct interpretation of the model including the interactions

Table 21 Results of the 2 × 2 × 2 Bayesian ANOVA for partial pairs recall of adjectives

Model Comparison					
Models	P(M)	P(M|data)	BF_M	BF_{10}	error %
Null model (incl. Item, Regularity, Inflection, subject, and random slopes)[a]	0.111	$2.544e^{-8}$	$2.035e^{-7}$	1.000	
Item × Regularity	0.111	0.453	6.635	$1.782e^{+7}$	3.122
Item × Regularity + Item × Inflection	0.111	0.350	4.314	$1.377e^{+7}$	4.610
Item × Regularity + Item × Inflection + Regularity × Inflection	0.111	0.099	0.877	$3.885e^{+6}$	42.878
Item × Regularity + Regularity × Inflection	0.111	0.087	0.759	$3.407e^{+6}$	9.081
Item × Regularity + Item × Inflection + Regularity × Inflection + Item × Regularity × Inflection	0.111	0.011	0.087	423023.348	3.984
Item × Inflection	0.111	$1.761e^{-8}$	$1.409e^{-7}$	0.692	4.040
Regularity × Inflection	0.111	$4.568e^{-9}$	$3.654e^{-8}$	0.180	5.841
Item × Inflection + Regularity × Inflection	0.111	$2.898e^{-9}$	$2.318e^{-8}$	0.114	4.562

[a]The main effects of regularity, item, and inflection were not robust ($\eta_p^2 = 0.001$; $\eta_p^2 = 0.005$; $\eta_p^2 = 0.014$, respectively), and hence, these factors were added to the null model for correct interpretation of the model including the interactions

Table 22 Results of the 2 × 2 × 2 Bayesian ANOVA for partial pairs recall of nouns

Model Comparison					
Models	P(M)	P(M|data)	BF_M	BF_{10}	error %
Null model (incl. Item, Inflection, subject, and random slopes)[a]	0.091	2.310^{e-13}	2.310^{e-12}	1.000	
Regularity + Regularity × Item	0.091	0.664	19.777	2.875^{e+12}	8.251
Regularity + Regularity × Item + Regularity × Inflection	0.091	0.155	1.837	6.717^{e+11}	9.978
Regularity + Regularity × Item + Item × Inflection	0.091	0.123	1.401	5.319^{e+11}	8.915
Regularity + Regularity × Item + Regularity × Inflection + Item × Inflection	0.091	0.045	0.476	1.966^{e+11}	34.329
Regularity + Regularity × Item + Regularity × Inflection + Item × Inflection + Regularity × Item × Inflection	0.091	0.012	0.125	5.337^{e+10}	13.269
Regularity	0.091	4.637^{e-12}	4.637^{e-11}	20.069	8.328
Regularity + Regularity × Inflection	0.091	9.231^{e-13}	9.231^{e-12}	3.995	8.384
Regularity + Item × Inflection	0.091	8.211^{e-13}	8.211^{e-12}	3.554	8.348
Regularity + Regularity × Inflection + Item × Inflection	0.091	1.702^{e-13}	1.702^{e-12}	0.737	8.541
Item × Inflection	0.091	3.899^{e-14}	3.899^{e-13}	0.169	8.318

[a]The main effects of item and inflection were not robust ($\eta_p^2 = 0.024$; $\eta_p^2 = 0.024$, respectively), and hence, these factors were added to the null model for correct interpretation of the model including the interactions

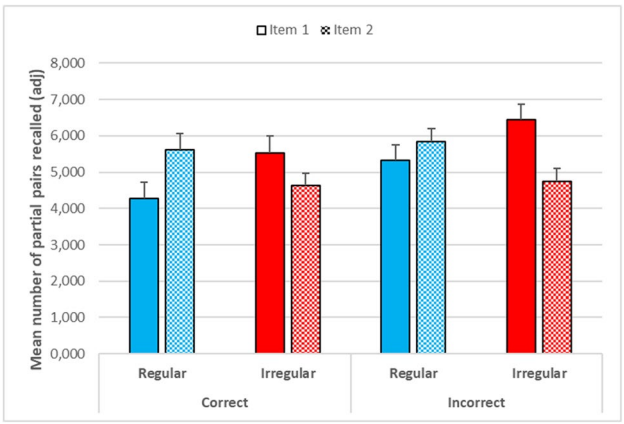

Fig. 10 Mean number of partial pairs (adjectives only), in terms of regularity, item, and inflection

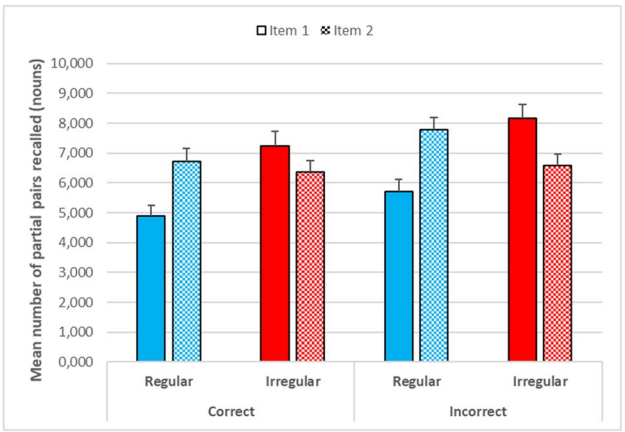

Fig. 11 Mean number of partial pairs (nouns only), in terms of regularity, item, and inflection

between item and regularity factors (regularity: $\eta_p^2 = 0.126$; Item × Regularity: $\eta_p^2 = 0.301$; see Table 22). Once again, more second items were recalled for pairs in regular position, while the opposite was observed for pairs in irregular position, with more first items recalled for pairs in irregular position (see Fig. 11).

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Data availability The experiment was not preregistered, but the datasets and analyses generated during the current study are available in a repository at the following address: https://osf.io/3tua6/

Declarations

Ethics approval The study was approved by the ethics committee of the Faculty of Medicine of the University of Liège.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Consent for publication Not applicable.

Conflicts of interest The authors declare no conflict of interest in connection with this work.

References

Abeillé, A., & Godard, D. (1999). La position de l'adjectif épithète en français: le poids des mots [The position of the adjective epithet in French: The weight of the words]. *Recherches Linguistiques de Vincennes, 28*, 9–32. https://doi.org/10.4000/rlv.1211

Acheson, D. J., & MacDonald, M. C. (2009). Verbal working memory and language production: Common approaches to the serial ordering of verbal information. *Psychological Bulletin, 135*(1), 50. https://doi.org/10.1037/a0014411

Attout, L., & Majerus, S. (2015). Working memory deficits in developmental dyscalculia: The importance of serial order. *Child Neuropsychology, 21*(4), 432–450. https://doi.org/10.1080/09297049.2014.922170

Baddeley, A. D., & Hitch, G. J. (1974). Working Memory. In G. A. Bower (Ed.), *Recent advances in learning and motivation* (Vol. 8, pp. 47–89). New York: Academic Press.

Baddeley, A., Gathercole, S., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review, 105*(1), 158. https://doi.org/10.1037/0033-295x.105.1.158

Benzitoun, C. (2014). La place de l'adjectif épithète en français: ce que nous apprennent les corpus oraux [The place of the adjective epithet in French: What the oral corpora teach us]. *Actes du 4ème Congrès Mondial de Linguistique Française, CMLF2014* (pp. 2333–2348).

Berger, J. O., & Wolpert, R. L. (1988). *The likelihood principle* (2nd ed.). Institute of Mathematical Statistic.

Besner, & Davelaar. (1982). Basic processes in reading: Two phonological codes. *Canadian Journal of Psychology/Revue canadienne de psychologie, 36*(4), 701.

Botvinick, M. M., & Plaut, D. C. (2006). Short-term memory for serial order: A recurrent neural network model. *Psychological Review, 113*(2), 201–233. https://doi.org/10.1037/0033-295X.113.2.201

Brener, R. (1940). An experimental investigation of memory span. *Journal of Experimental Psychology, 26*(5), 467–482. https://doi.org/10.1037/h0061096

Brown, G. D. A., Preece, T., & Hulme, C. (2000). Oscillator-based memory for serial order. *Psychological Review, 107*(1), 127–181. https://doi.org/10.1037/0033-295X.107.1.127

Buchsbaum, B. R., & D'Esposito, M. (2019). A sensorimotor view of verbal working memory. *Cortex, 112*, 134–148. https://doi.org/10.1016/j.cortex.2018.11.010

Burgess, N., & Hitch, G. J. (1999). Memory for serial order: A network model of the phonological loop and its timing. *Psychological Review, 106*(3), 551–581. https://doi.org/10.1037/0033-295X.106.3.551

Burgess, N., & Hitch, G. J. (2006). A revised model of short-term memory and long-term learning of verbal sequences. *Journal of Memory and Language, 55*(4), 627–652. https://doi.org/10.1016/j.jml.2006.08.005

Cattell, J. M. (1886). The time it takes to see and name objects. *Mind, 11*, 63–65. https://doi.org/10.1093/mind/os-xi.41.63

Clark, K. M., Hardman, K. O., Schachtman, T. R., Saults, J. S., Glass, B. A., & Cowan, N. (2018). Tone series and the nature of working memory capacity development. *Developmental Psychology, 54*(4), 663–676. https://doi.org/10.1037/dev0000466

Coady, J. A., & Aslin, R. N. (2004). Young children's sensitivity to probabilistic phonotactics in the developing lexicon. *Journal of Experimental Child Psychology, 89*(3), 183–213. https://doi.org/10.1016/j.jecp.2004.07.004

Coady, J., Evans, J. L., & Kluender, K. R. (2010). Role of phonotactic frequency in nonword repetition by children with specific language impairments. *International Journal of Language & Communication Disorders, 45*(4), 494–509. https://doi.org/10.3109/13682820903222783

Cowan, N. (1993). Activation, attention, and short-term memory. *Memory & Cognition, 21*, 162–167. https://doi.org/10.3758/bf03202728

Cristoforetti, G., Majerus, S., Sahan, M. I., van Dijck, J. P., & Fias, W. (2022). Neural patterns in parietal cortex and hippocampus distinguish retrieval of start versus end positions in working memory. *Journal of Cognitive Neuroscience, 34*(7), 1230–1245. https://doi.org/10.1162/jocn_a_01860

Dienes, Z. (2011). Bayesian versus orthodox statistics: Which side are you on? *Perspectives on Psychological Science, 6*(3), 274–90. https://doi.org/10.1177/1745691611406920

Ebbinghaus, H. (1885). *Über das gedächtnis: untersuchungen zur experimentellen psychologie* [About memory: Studies in experimental psychology]. Duncker & Humblot.

Epstein, W. (1961). The influence of syntactical structure on learning. *The American Journal of Psychology, 74*(1), 80–85.

Garrett, M. F. (1988). Processes in language production. In F. J. Newmeyer (Ed.), *Language: Psychological and biological aspects* (pp. 69–96). Cambridge University Press.

Gathercole, S. E., Frankish, C. R., Pickering, S. J., & Peaker, S. (1999). Phonotactic influences on short-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25*(1), 84. https://doi.org/10.1037/0278-7393.25.1.84

Gathercole, S. E., Pickering, S. J., Hall, M., & Peaker, S. M. (2001). Dissociable lexical and phonological influences on serial recognition and serial recall. *The Quarterly Journal of Experimental Psychology Section A, 54*(1), 1–30. https://doi.org/10.1080/027249800420000002

Grevisse, M., & Goosse, A. (1993). *Le bon usage, Grammaire française*. Duculot: Louvain-la-Neuve et Paris.

Hachmann, W. M., Cashdollar, N., Postiglione, F., & Job, R. (2020). The relationship of domain-general serial order memory and reading ability in school children with and without dyslexia. *Journal of Experimental Child Psychology, 193*, Article 104789. https://doi.org/10.1016/j.jecp.2019.104789

Hartley, T., Hurlstone, M. J., & Hitch, G. J. (2016). Effects of rhythm on memory for spoken sequences: A model and tests of its stimulus-driven mechanism. *Cognitive Psychology, 87*, 135–178. https://doi.org/10.1016/j.cogpsych.2016.05.001

Hasson, U., Chen, J., & Honey, C. J. (2015). Hierarchical process memory: Memory as an integral component of information processing. *Trends in Cognitive Sciences, 19*(6), 304–313. https://doi.org/10.1016/j.tics.2015.04.006

Henkel, D. (2016). L'antéposition de l'adjectif: quelles contreparties sémantiques? [Anteposition of the adjective: what semantic counterparts?]. In *Congrès Mondial de Linguistique Française, CMLF 2016, 27,* Article 12007. https://doi.org/10.1051/shsconf/20162712007

Henson, R. N. (1998). Short-term memory for serial order: The start-end model. *Cognitive Psychology, 36*(2), 73–137. https://doi.org/10.1006/cogp.1998.0685

Hulme, C., Maughan, S., & Brown, G. D. (1991). Memory for familiar and unfamiliar words: Evidence for a long-term memory contribution to short-term memory span. *Journal of Memory and Language, 30*(6), 685–701. https://doi.org/10.1016/0749-596X(91)90032-F

Hulme, C., Roodenrys, S., Schweickert, R., Brown, G. D., Martin, S., & Stuart, G. (1997). Word-frequency effects on short-term memory tasks: Evidence for a redintegration process in immediate serial recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23*(5), 1217. https://doi.org/10.1037/0278-7393.23.5.1217

JASP Team. (2022). JASP (Version 0.16.3.0) [Computer software]. https://jasp-stats.org/

Jefferies, E., Lambon Ralph, M. A., & Baddeley, A. D. (2004). Automatic and controlled processing in sentence recall: The role of long-term and working memory. *Journal of Memory and Language, 51*(4), 623–643. https://doi.org/10.1016/j.jml.2004.07.005

Jefferies, E., Frankish, C. R., & Lambon Ralph, M. A. (2006a). Lexical and semantic binding in verbal short-term memory. *Journal of Memory and Language, 54*(1), 81–98. https://doi.org/10.1016/j.jml.2005.08.001

Jefferies, E., Frankish, C., & Lambon Ralph, M. A. (2006b). Lexical and semantic influences on item and order memory in immediate serial recognition: Evidence from a novel task. *Quarterly Journal of Experimental Psychology, 59*(5), 949–964. https://doi.org/10.1080/02724980543000141

Jeffreys, H. (1998). *The theory of probability*. Oxford University Press.

Jones, T., & Farrell, S. (2018). Does syntax bias serial order reconstruction of verbal short-term memory? *Journal of Memory and Language, 100*, 98–122. https://doi.org/10.1016/j.jml.2018.02.001

Jones, G., & Macken, B. (2018). Long-term associative learning predicts verbal short-term memory performance. *Memory & Cognition, 46*, 216–229. https://doi.org/10.3758/s13421-017-0759-3

Jones, D. M., Hughes, R. W., & Macken, W. J. (2006). Perceptual organization masquerading as phonological storage: Further support for a perceptual-gestural view of short-term memory. *Journal of Memory and Language, 54*(2), 265–281. https://doi.org/10.1016/j.jml.2005.10.006

Kowialiewski, B., & Majerus, S. (2020). The varying nature of semantic effects in working memory. *Cognition, 202*, Article 104278. https://doi.org/10.1016/j.cognition.2020.104278

Kowialiewski, B., Gorin, S., & Majerus, S. (2021). Semantic knowledge constrains the processing of serial order information in working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 47*(12), 1958–1970. https://doi.org/10.1037/xlm0001031

Kowialiewski, B., Krasnoff, J., Mizrak, E., & Oberauer, K. (2022). The semantic relatedness effect in serial recall: Deconfounding encoding and recall order. *Journal of Memory and Language, 127*, Article 104377. https://doi.org/10.1016/j.jml.2022.104377

Kruschke, J. K. (2010). Bayesian data analysis. *Wiley Interdisciplinary Reviews: Cognitive Science, 1*(5), 658–676. https://doi.org/10.1002/wcs.72

Lee, M. D., & Wagenmakers, E.-J. (2013). *Bayesian cognitive modeling: A practical course*. Cambridge University Press.

Levelt, W. (1999). Producing spoken language. In C. Brown & P. Hagoort (Eds.), *The neurocognition of language* (pp. 83–122). Oxford University Press.

Lindsey, D. R., & Logan, G. D. (2021). Previously retrieved items contribute to memory for serial order. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 47*(9), 1403. https://doi.org/10.1037/xlm0001052

MacDonald, M. C. (2016). Speak, act, remember: The language-production basis of serial order and maintenance in verbal memory. *Current Directions in Psychological Science, 25*(1), 47–53. https://doi.org/10.1177/0963721415620776

Majerus, S. (2009). Verbal short-term memory and temporary activation of language representations: The importance of distinguishing item and order information. In A. S. C. Thorn & M. P. A. Page (Eds.), *Interactions between short-term and long-term memory in the verbal domain* (pp. 244–276). Psychology Press.

Majerus, S. (2013). Language repetition and short-term memory: an integrative framework. *Frontiers in Human Neuroscience, 7*, 357. https://doi.org/10.3389/fnhum.2013.00357

Majerus, S. (2019). Verbal working memory and the phonological buffer: The question of serial order. *Cortex, 112*, 122–133. https://doi.org/10.1016/j.cortex.2018.04.016

Majerus, S., & D'Argembeau, A. (2011). Verbal short-term memory reflects the organization of long-term memory: Further evidence from short-term memory for emotional words. *Journal of Memory and Language, 64*(2), 181–197. https://doi.org/10.1016/j.jml.2010.10.003

Majerus, S., & Van der Linden, M. (2003). Long-term memory effects on verbal short-term memory: A replication study. *British Journal of Developmental Psychology, 21*(2), 303–310. https://doi.org/10.1348/026151003765264101

Majerus, S., Van der Linden, M., Mulder, L., Meulemans, T., & Peters, F. (2004). Verbal short-term memory reflects the sublexical organization of the phonological language network: Evidence from an incidental phonotactic learning paradigm. *Journal of Memory and Language, 51*(2), 297–306. https://doi.org/10.1016/j.jml.2004.05.002

Majerus, S., D'Argembeau, A., Martinez Perez, T., Belayachi, S., Van der Linden, M., Collette, F., Salmon, E., Seurinck, R., Fias, W., & Maquet, P. (2010). The commonality of neural networks for verbal and visual short-term memory. *Journal of Cognitive Neuroscience, 22*(11), 2570–2593. https://doi.org/10.1162/jocn.2009.21378

Majerus, S., Attout, L., Artielle, M. A., & Van der Kaa, M. A. (2015). The heterogeneity of verbal short-term memory impairment in aphasia. *Neuropsychologia, 77*, 165–176. https://doi.org/10.1016/j.neuropsychologia.2015.08.010

Marks, L. E., & Miller, G. A. (1964). The role of semantic and syntactic constraints in the memorization of English sentences. *Journal of Verbal Learning and Verbal Behavior, 3*(1), 1–5. https://doi.org/10.1016/S0022-5371(64)80052-9

Marshuetz, C., Smith, E. E., Jonides, J., DeGutis, J., & Chenevert, T. L. (2000). Order information in working memory: fMRI evidence for parietal and prefrontal mechanisms. *Journal of Cognitive Neuroscience, 12*(Supplement 2), 130–144. https://doi.org/10.1162/089892900511374459

Martin, N., & Saffran, E. M. (1992). A computational account of deep dysphasia: Evidence from a single case study. *Brain and Language, 43*(2), 240–274. https://doi.org/10.1016/0093-934X(92)90130-7

Martin, R. C., Shelton, J. R., & Yaffee, L. S. (1994). Language processing and working memory: Neuropsychological evidence for separate phonological and semantic capacities. *Journal of Memory and Language, 33*(1), 83–111. https://doi.org/10.1006/jmla.1994.1005

Massol, S., Mirault, J., & Grainger, J. (2021). The contribution of semantics to the sentence superiority effect. *Scientific Reports, 11*(1), Article 20148. https://doi.org/10.1038/s41598-021-99565-6

Munson, B., Kurtz, B. A., & Windsor, J. (2005). The influence of vocabulary size, phonotactic probability, and wordlikeness on nonword repetitions of children with and without specific language impairment. *Journal of Speech, Language, and Hearing Research, 48*, 1033–1047. https://doi.org/10.1044/1092-4388(2005/072)

Nairne, J. S., & Kelley, M. R. (2004). Separating item and order information through process dissociation. *Journal of Memory and Language, 50*(2), 113–133. https://doi.org/10.1016/j.jml.2003.09.005

Nuijten, M. B., Wetzels, R., Matzke, D., Dolan, C. V., & Wagenmakers, E.-J. (2015). A default Bayesian hypothesis test for mediation. *Behavior Research Methods, 47*(1), 85–97. https://doi.org/10.3758/s13428-014-0470-2

Papagno, C., & Trojano, L. (2018). Cognitive and behavioral disorders in Parkinson's disease: An update. I: Cognitive impairments. *Neurological Sciences, 39*(2), 215–223. https://doi.org/10.1007/s10072-017-3154-8

Perez, T. M., Majerus, S., Mahot, A., & Poncelet, M. (2012). Evidence for a specific impairment of serial order short-term memory in dyslexic children. *Dyslexia, 18*(2), 94–109. https://doi.org/10.1002/dys.1438

Perham, N., Marsh, J. E., & Jones, D. M. (2009). Short article: Syntax and serial recall: How language supports short-term memory for order. *Quarterly Journal of Experimental Psychology, 62*(7), 1285–1293. https://doi.org/10.1080/17470210802635599

Poirier, M., & Saint-Aubin, J. (1996). Immediate serial recall, word frequency, item identity and item position. *Canadian Journal of Experimental Psychology/Revue Canadienne de Psychologie Expérimentale, 50*(4), 408. https://doi.org/10.1037/1196-1961.50.4.408

Poirier, M., Saint-Aubin, J., Mair, A., Tehan, G., & Tolan, A. (2015). Order recall in verbal short-term memory: The role of semantic networks. *Memory & Cognition, 43*(3), 489–499. https://doi.org/10.3758/s13421-014-0470-6

Postle, B. R. (2006). Working memory as an emergent property of the mind and brain. *Neuroscience, 139*(1), 23–38. https://doi.org/10.1016/j.neuroscience.2005.06.005

Romani, C., Tsouknida, E., & Olson, A. (2015). Encoding order and developmental dyslexia: A family of skills predicting different orthographic components. *The Quarterly Journal of Experimental Psychology, 68*, 99–128. https://doi.org/10.1080/17470218.2014.938666

Saint-Aubin, J., & Poirier, M. (1999a). The influence of long-term memory factors on immediate serial recall: An item and order analysis. *International Journal of Psychology, 34*(5/6), 347–352. https://doi.org/10.1080/002075999399675

Saint-Aubin, J., & Poirier, M. (1999b). Semantic similarity and immediate serial recall: Is there a detrimental effect on order information? *The Quarterly Journal of Experimental Psychology: Section A, 52*(2), 367–394. https://doi.org/10.1080/713755814

Saint-Aubin, J., & Poirier, M. (2000). Immediate serial recall of words and nonwords: Tests of the retrieval-based hypothesis. *Psychonomic Bulletin & Review, 7*(2), 332–340. https://doi.org/10.3758/BF03212990

Savill, N., Metcalfe, T., Ellis, A. W., & Jefferies, E. (2015). Semantic categorisation of a word supports its phonological integrity in verbal short-term memory. *Journal of Memory and Language, 84*, 128–138. https://doi.org/10.1016/j.jml.2015.06.003

Savill, N., Ellis, R., Brooke, E., et al. (2018). Keeping it together: Semantic coherence stabilizes phonological sequences in short-term memory. *Memory & Cognition, 46*(3), 426–437. https://doi.org/10.3758/s13421-017-0775-3

Schönbrodt, F. D. (2016). *BFDA: Bayes factor design analysis package for R*. https://github.com/nicebread/BFDA

Schönbrodt, F. D., & Wagenmakers, E. J. (2018). Bayes factor design analysis: Planning for compelling evidence. *Psychonomic Bulletin & Review, 25*(1), 128–142. https://doi.org/10.3758/s13423-017-1230-y

Schweickert, R. (1993). A multinomial processing tree model for degradation and redintegration in immediate recall. *Memory & Cognition, 21*(2), 168–175. https://doi.org/10.3758/BF03202729

Schweppe, J., Schütte, F., Machleb, F., & Hellfritsch, M. (2022). Syntax, morphosyntax, and serial recall: How language supports short-term memory. *Memory & Cognition, 50*(1), 174–191. https://doi.org/10.3758/s13421-021-01203-z

Schwering, S. C., & MacDonald, M. C. (2020). Verbal working memory as emergent from language comprehension and production. *Frontiers in Human Neuroscience, 14*, 68. https://doi.org/10.3389/fnhum.2020.00068

Snell, J., & Grainger, J. (2017). The sentence superiority effect revisited. *Cognition, 168*, 217–221. https://doi.org/10.1016/j.cognition.2017.07.003

Thuilier, J. (2012). *Contraintes préférentielles et ordre des mots en français* [Preferential constraints and word order in French] (Doctoral dissertation, Université Paris-Diderot-Paris VII).

Thuilier, J. (2013). Syntaxe du français parlé vs. écrit: le cas de la position de l'adjectif épithète par rapport au nom [Syntax of spoken French vs. written: The case of the position of the adjective epithet in relation to the noun]. *TIPA. Travaux interdisciplinaires sur la parole et le langage*, *29*. https://doi.org/10.4000/tipa.1066

Thuilier, J., Fox, G., & Crabbé, B. (2010a). Approche quantitative en syntaxe: l'exemple de l'alternance de position de l'adjectif épithète en français [Quantitative approach in syntax: The example of alternating position of the adjective epithet in French]. In *Traitement Automatique des Langues Naturelles* (pp. 71–80).

Thuilier J., G. Fox & B. Crabbé (2010b). Fréquence, longueur et préférences lexicales dans le choix de la position de l'adjectif épithète en français [Frequency, length and lexical preferences in the choice of the position of the adjective epithet in French]. *Actes du 2ème Congrés Mondial de Linguistique Française—CMLF 2010* (pp. 2197–2210).

Wagenmakers, E.-J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., Love, J., Selker, R., Gronau, Q. F., Šmíra, M., Epskamp, S., Matzke, D., Rouder, J. N., & Morey, R. D. (2018). Bayesian inference for psychology. Part 1: Theoretical advantages and practical ramifications. *Psychonomic Bulletin & Review, 25*(1), 35–57. https://doi.org/10.3758/s13423-017-1343-3

Walker, I., & Hulme, C. (1999). Concrete words are easier to recall than abstract words: Evidence for a semantic contribution to short-term serial recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25*(5), 1256. https://doi.org/10.1037/0278-7393.25.5.1256

Watkins, O. C., & Watkins, M. J. (1977). Serial recall and the modality effect: Effects of word frequency. *Journal of Experimental Psychology: Human Learning and Memory, 3*(6), 712. https://doi.org/10.1037/0278-7393.3.6.712

Wilmet, M. (1980). Corneille (Jean-Pierre). La linguistique structurale: Sa portée, ses limites. *Revue belge de Philologie et d'Histoire*, *58*(3), 702–703.

Zamuner, T. S., Gerken, L., & Hammond, M. (2004). Phonotactic probabilities in young children's speech production. *Journal of Child Language, 31*(3), 515–536. https://doi.org/10.1017/S0305000904006233