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Received: 20 April 2020 | Revised: 3 August 2020 | Accepted: 19 August 2020

DOI: 10.1111/desc.13033

Developmental Science WILEY

SHORT REPORT

The sentence superiority effect in young readers

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Funding information
ERC, Grant/Award Number: 742141; French National Research Agency, Grant/Award Number: ANR-11-IDEX-0007 and ANR-11-LAB-0042

Abstract

The sentence superiority effect observed with skilled adult readers has been taken to reflect parallel processing of word identities and the rapid construction of a preliminary syntactic structure. Here we examined if such processing is already present in primary school children in Grade 3 (average age 8.9 years). Children saw sequences of four horizontally aligned words presented simultaneously for 500 ms and followed by a post-mask and post-cue indicating the position for report of one of the four words. Word identification was more accurate in grammatically correct sequences compared with ungrammatical scrambled sequences of the same words, and this sentence superiority effect did not interact with position. This replicates the pattern found in prior research with adults and suggests that parallel word processing and the associated efficiency in syntactic processing arealready in place in Grade 3. We also found that accuracy in identifying words, independently of the surrounding context, correlated with reading age. This points to efficient word-in-sequence identification as one key ingredient of the process of becoming a skilled reader.

KEYWORDS
parallel word processing, rapid parallel visual presentation paradigm, reading development, sentence reading, sentence superiority, syntactic processing

1 | INTRODUCTION

In the rapid parallel visual presentation (RPVP) paradigm, a sequence of words is briefly presented followed by a pattern mask and a post-cue indicating the word in the sequence that participants have to report. Snell and Grainger (2017) found that post-cued word identification was significantly better when the sequence of words formed a grammatically correct phrase or sentence compared with ungrammatical scrambled sequences of the same words. Thus, for example, accuracy in identification of the target word "boy" was found to be greater in the sequence "the boy hates soup" compared with the scrambled version "soup boy the hates". In a follow-up study using event-related potentials (ERPs), Wen, Snell, and Grainger (2019) found that this sentence superiority effect was already present in the ERP waveforms by 300 ms post-sequence onset. The relatively early onset of this effect, they argued, points to the rapid construction of an elementary syntactic structure when one is available, followed by feedback from sentence-level representations to the individual words in the sequence.

In the present study, we provide an initial examination of sentence superiority effects in primary school children. Although beginning readers have already acquired syntactic knowledge via spoken language, it remains to be seen whether the syntactic computations required for skilled reading take time to develop during the first years of reading tuition. One possible specificity of syntactic computations in reading relative to hearing is the hypothesis that skilled reading involves parallel access to syntactic information across several words at a time (e.g., Snell & Grainger, 2019), as opposed to a strictly sequential one-word-at-a-time process that would mimic spoken language processing (e.g., Reichle, Waren, & McConnell, 2009). In the reading development literature, there is now a general agreement that parallel letter processing for efficient word recognition is established quite rapidly during the first year of formal reading instruction (Aghababian & Nazir, 2000; Ducrot, Lété, Sprenger-Charolles, Pynte, & Billard, 2003; Grainger, Lété, Bertrand, Dufau, & Ziegler, 2012; Ziegler, Bertrand, Lété, & Grainger, 2014). For instance, in an eye-tracking

experiment, Aghababian and Nazir (2000) showed that, at the end of the first year of formal instruction reading, children are able to extract visual information from print in the same way as proficient readers. That is, whereas the perceptual span of beginning readers is generally considered as being smaller than the perceptual span in adults (see Grainger, Dufau, & Ziegler, 2016), beginning readers were able to simultaneously process all letters of a word. Some research using ERPs reported a rapid emergence of print tuning in the first years of reading instructions (Cao, Li, Zhao, Lin, & Weng, 2011; Maurer et al., 2006; Varga, Tóth, & Csépe, 2020). Furthermore, Grainger et al. (2012) found that effects of transposed-letters in masked priming paradigm (i.e., jugde-JUDGE) were already present in Grade 2, suggesting that the process of accessing abstract orthographic representations is rapidly established during the first years of reading acquisition (see also Acha & Perea, 2008; Ziegler et al., 2014; Perea, Mallouh, & Carreiras, 2013, for similar evidence in Arabic). Recently, Gomez and Perea (2020) reported masked identity priming effects in Grade 2, regardless of whether or not the letter-case of the prime matched that of the target. Moreover, the size of these priming effects observed in Grade 2 was very similar to the size of the identity priming effects found with adults. Altogether, these studies provide evidence in favor of the rapid emergence of efficient letter and word identification processes during reading development.

Given the evidence for parallel word processing in adult reading studies (see Snell & Grainger, 2019, for a review), the question that needs to be addressed now is when parallel processing at the word level emerges during reading development? Here we provide an initial attempt at answering that question by testing for the presence of a sentence superiority effect in primary school children. Testing children in Grade 3 will help guide future investigations that can either focus on earlier or later developmental trends. Moreover, our brief review of the developmental word reading literature suggests that highly automatized word identification processes are already well-established by Grade 3.

Research Highlights

- The sentence superiority effect was investigated in primary school children.
- Grammatically correct sequences and ungrammatical scrambled sequences of the same words were presented in the rapid parallel visual presentation paradigm.
- Single word identification was better in the context of a grammatically correct sentence than for ungrammatical scrambled versions of the same word sequences.
- Parallel word processing enables efficient syntactic processing during reading acquisition.

2 | METHOD

2.1 | Participants

A total of 33 children[1] (19 boys) with a mean age of 8.9 years (*SD* = 0.3) were recruited from two elementary schools in Lyon. They were all in Grade 3 of primary education. All were monolingual native speakers of French. They were tested at the end of the school year. All children performed a standardized reading test (Alouette: Lefavrais, 1967) that provides their reading level measured as reading age. The mean reading age of the group was higher than the chronological age (9.9 years, *SD* = 1.7). Ethics approval for this research was provided by the Comité de Protection des Personnes SUD-EST IV (no. 17/051). A parent or a legal representative of each child gave his/her informed consent prior to their inclusion in the study.

2.2 | Materials

We first constructed 184 grammatically correct sentences or phrases that consisted of four words each. The constituent words were selected using the Manulex database (Lété, Sprenger-Charolles, & Colé, 2004) that provides word frequencies for each school grade compiled from a corpus of 1.9 million words taken from reading books used in French schools. To ensure that the children were familiar with the words, only words that appeared in Grade 1 were selected to construct the sentences. Word length was on average 4.10 (*SD* = 0.83; from 3 to 5 letters) and word frequency was on average 2604 occurrences per million (*SD* = 2778) which is the equal to 6.01 Zipf (*SD* = 0.67; van Heuven, Mandera, Keuleers, & Brysbaert, 2014). To ensure that the sentences were as neutral as possible, a pre-test were performed with 126 adults (100 women, mean age = 22 years, *SD* = 8.04) in order to obtain cloze probability measures of the last word in each sentence. These measures were collected through an online experiment which consisted of a sentence completion test. Participants were presented with the beginnings of the sentence (i.e., the first three words) and were asked to type the first word that came to their mind as a likely continuation of the sentence. Cloze probability was calculated as the number of answers that corresponded to the word at position 4 in the original sentence divided by the number of participants. The average cloze probability of these words was 0.04 (*SD* = 0.06). For the purpose of the word-in-sequence identification task, one of the four words in every sentence was marked as the critical target at one of the four possible positions, such that there were 46 critical targets for each position. Finally, in order to test our hypotheses, we constructed grammatically incorrect sentences based on this set of 184 sentences by scrambling word order in the correct sentences but keeping the target word in the same position. This led to a 2 × 4 factorial design, with Context (sentence vs. scrambled) and Target Position (1–4) as independent variables. Participants saw each sentence only once in one of the two context conditions but were tested in both context conditions with different sentences. Across participants, each sentence occurred an equal number of times in both grammatically correct and the ungrammatical scrambled conditions.

2.3 | Procedure

Children were first presented with the reading test. Then they were seated in front of a laptop computer. Presentation of the word sequences and recording of responses were carried out using OpenSesame (Mathôt, Schreij, & Theeuwes, 2012). All sequences were presented as white letters in lowercase and centered vertically and horizontally on a grey background. Instructions were given verbally by the experimenter. Children were informed that a sequence of four words was going to be displayed briefly and followed by a pattern mask. They were asked to decide which word they had seen in the position indicated by a dot above the target location that accompanied the pattern mask (i.e., post-cue). Each trial began with the presentation of two vertical bars positioned at the center of the screen and that remained on the screen during the whole trial duration. Participants were asked to focus their attention on the center between the two vertical bars at the beginning of each trial. About 500 ms later, the sentence was centrally displayed during 500 ms (i.e., two words appeared to the left and two to the right of fixation, with equal and normal between-word spacing). This was then followed by a backward mask composed of hash marks at all positions that were occupied by a letter in the previous string, and accompanied by the post-cue for the target word location (i.e., the dot above the target location, see Figure 1). Participants produced verbally their responses and the experimenter typed the response on the keyboard. Once the return key was pressed, the next trial was displayed. A practice session (16 trials) was administered before the main experiment to familiarize children with the procedure. The 184 trials of the main experiment were presented in a random order with three breaks. The experiment lasted approximately 15 min.

3 | RESULTS

3.1 | Main analyses

Probability correct responses were analyzed using generalized linear mixed models including by-item and by-participant random intercepts and random slopes (Baayen, Davidson, & Bates, 2008; Barr, Levy, Scheepers, & Tily, 2013), and with Context and Eccentricity plus their interaction as fixed effects. The logistic mixed-effects model included Context (normal vs. scrambled) and Eccentricity (central [positions 1 and 4] vs. peripheral targets [positions 2 and 3]) as fixed-factors. The models were fitted with the glmer function from the lme4 package (Bates, Maechler, Bolker, & Walker, 2015) in the R statistical computing environment (R Core Team, 2018). The maximal random effects structure that converged was one including by-participant and by-item random intercepts, as well as by-participant random slopes for Eccentricity and by-item random slopes for Context.

The following analyses were conducted taking the correctly ordered sentence condition in which the target words were presented in central positions (i.e., positions 2 and 3) as reference. We report regression coefficients (b), standard errors (SE) and z-values. Fixed effects were deemed significant if $|z| > 1.96$ (Baayen, 2008). Word identification accuracy was higher in the normal sentence condition than in the scrambled ungrammatical sequences ($b = -0.39$, $SE = 0.11$, $z = -3.46$). As can be seen in Figure 2, the effect was virtually equal across all target positions. Moreover, Eccentricity had a significant influence, with targets presented at central position being identified more accurately than targets presented at positions 1 and 4, $b = -1.51$, $SE = 0.26$, $z = -5.80$. The interaction between Context and Target Position was not significant, $b = 0.14$, $SE = 0.16$, $z = 0.87$.

Since overall performance did vary across positions, we further tested whether there was a difference across leftward/rightward target positions. The same glme model was used, replacing the factor Eccentricity by the factor Position (leftward vs. rightward). This analysis revealed higher identification accuracy when targets were presented on the left side of fixation, $b = -1.19$, $SE = 0.30$, $z = -3.925$. As can be seen in Figure 2, this result is driven by the high level of accuracy at position 2. The interaction between Context and Position was not significant, $b = 0.01$, $SE = 0.17$, $z > .1$.

3.2 | Correlations with reading age

We examined the correlations with reading age per child (Alouette reading test score) and the average performance per child on the sentence and scrambled conditions, as well as the difference between these conditions (i.e., the sentence superiority effect). We found strong positive correlations between reading age and performance in both conditions—sentence condition, $r = .652$, $p < .001$; scrambled condition, $r = .713$, $p = .001$. These correlations highlight the fact that children are better able to identify words in sequences as their level of reading expertise increases (see Figure 3, panels a and b), and pretty much independently of the context (sentence or

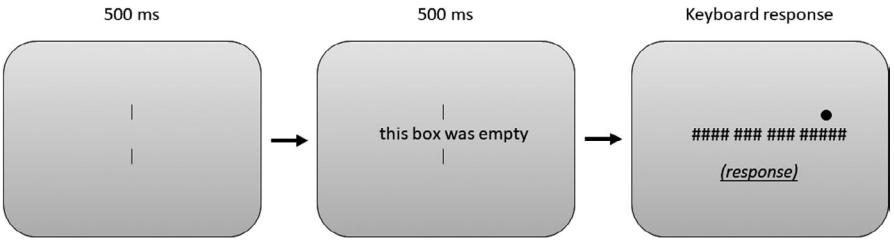

FIGURE 1 The post-cued partial report rapid parallel visual presentation procedure used in the present experiment

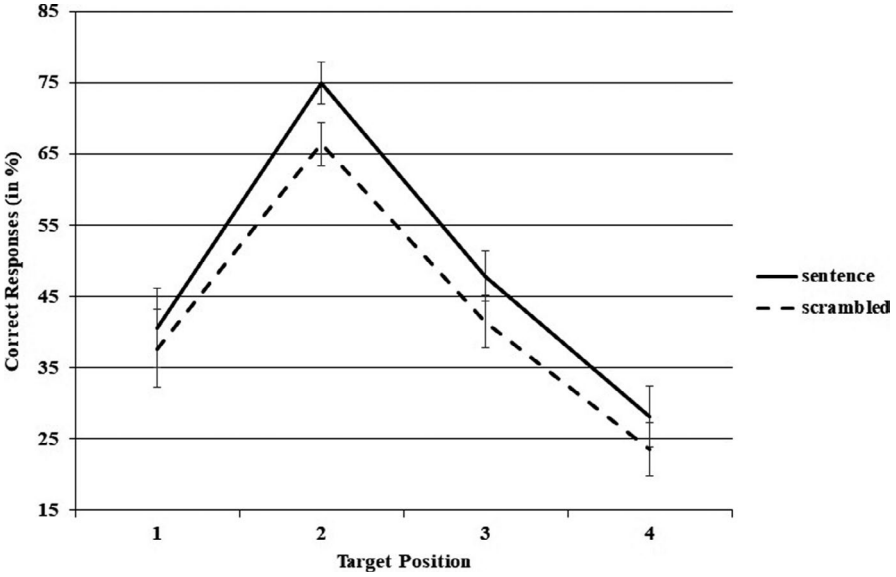

FIGURE 2 Mean accuracy (and standard errors) at the different target positions (1–4) in the grammatical sentence condition (solid line) and in the scrambled ungrammatical condition (dashed line)

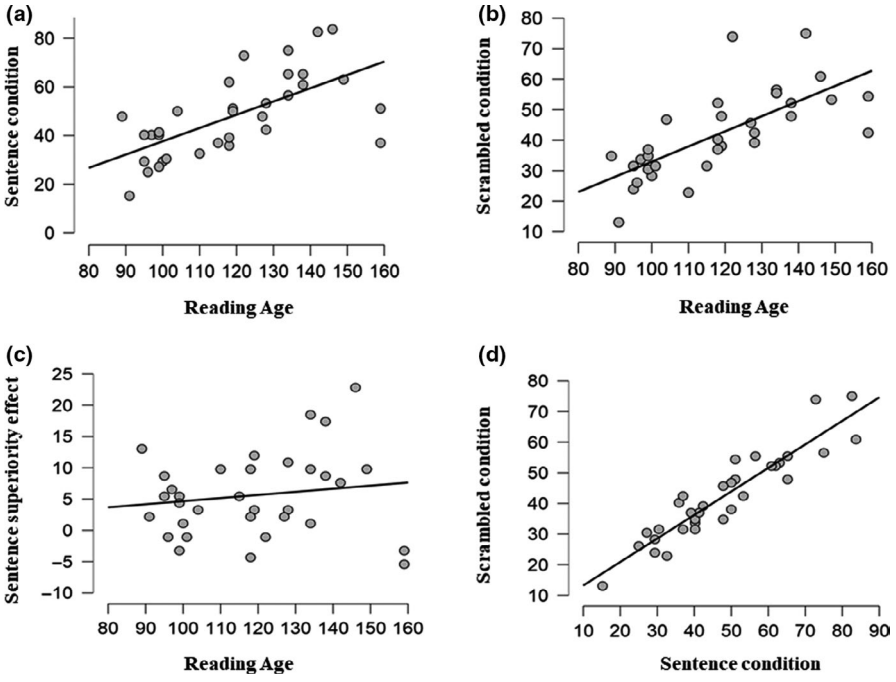

FIGURE 3 Scatterplots showing the relation between reading age (months) and performance (% correct) in the sentence condition (panel a) and the scrambled condition (panel b). The relation between reading age and the difference between these conditions (sentence superiority effect) is also shown (panel c) as well as the relation between performance in the two conditions (panel d). Solid lines indicate the best-fitting regressions

scrambled). Indeed, performance on the two contexts was highly correlated, $r = .923$, $p < .001$ (see Figure 3, panel d), pointing to a general ability in identifying words in sequences. However, the correlation between reading age and the sentence superiority effect was not significant, $r = .150$, $p > .1$ (see Figure 3, panel c). This non-significant correlation is mostly driven by the fact that the two children with the highest reading-level showed negative effects of sentence superiority (i.e., better performance in the scrambled condition). It is therefore possible that a significant correlation would emerge with a larger sample of children.

4 | DISCUSSION

The present study examined sentence superiority effects in children attending Grade 3 of primary education in France, with an

average chronological age of 8.9 years, and an average reading age of 9.9 years. We found a robust sentence superiority effect that did not depend on the position in the sequence, although this factor did influence word identification accuracy. Children were more accurate in identifying a word in a briefly presented and backward-masked four-word sequence when that sequence was grammatically correct compared with ungrammatical scrambled versions of the same four words. This is evidence that children of this age and reading ability have already acquired mechanisms for the rapid identification of words in multi-word sequences and the computation of some form of syntactic structure most likely on the basis of the parts-of-speech associated with word identities (see e.g., Declerck, Wen, Snell, Meade, & Grainger, 2020). In future research it will be interesting to investigate how differences in word-order constraints across different languages might impact on the sentence superiority effect and its emergence during reading development.

The group of children we tested varied in reading age (from 7.5 to 13.3 years), hence enabling a preliminary investigation of the impact of this factor on performance in the word-in-sequence identification task. These correlational analyses revealed that reading age determined word-in-sequence identification independently of grammaticality, with better readers performing with higher accuracy in this task. This finding points to bottom-up word identification processes as a key factor related to reading development. Whether or not isolated word identification ability can account for this finding rather than word-in-sequence identification ability, remains an important point for future investigations. In this respect, future research should include a measure of single word identification ability as well as the word-in-sequence identification task used in the present study. On the other hand, reading level did not significantly determine the size of the sentence superiority effect. This could be due to the fact that efficient syntactic processing is already acquired via spoken language, and therefore top-down effects from syntactic representations to word identification processes might already be relatively stable by Grade 3. What is still developing would be the specialized interface between word identification processes and the construction of a syntactic representation from print. Clearly, future research testing a larger sample of children, and including younger children, is necessary in order to better specify the developmental trajectory of the processes involved in bottom-up word-in-sequence identification and top-down effects of sentence structure during reading.

ACKNOWLEDGMENTS

The authors thank Christophe Cauchi for his help in preparing the experiment and in analyzing the data. J.G. was supported by ERC grant 742141. This work was supported by the LABEX CORTEX (ANR-11-LAB-0042) of Université de Lyon, within the "Investissements d'Avenir" program (ANR-11-IDEX-0007) operated by the French National Research Agency (ANR).

CONFLICT OF INTEREST

The authors have declared that no conflict of interest.

DATA AVAILABILITY STATEMENT

The authors confirm the availability of shared data. The dataset and analysis scripts used with R are accessible on the OSF website at: https://osf.io/jtd68/

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ENDNOTE

[1] The sample size in the present study was based on previous reading research with children of the same age that had similar sample sizes (see Acha & Perea, 2008; Cao et al. 2011; Ducrot et al., 2003; Gomez & Perea, 2020; Maurer et al., 2006; Perea et al., 2013).

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How to cite this article: Massol S, Grainger J. The sentence superiority effect in young readers. *Developmental Science*. 2020;00:1–6. https://doi.org/10.1111/desc.13033