A developmental perspective on morphological processing in the flankers task

Christophe Sylvain Cauchi, Elisabeth Beyersmann, Bernard Lété, Jonathan Grainger

Journal of Experimental Child Psychology 221 (2022) 105448

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

A developmental perspective on morphological processing in the flankers task

Christophe Cauchi [a,b,*], Elisabeth Beyersmann [c], Bernard Lété [b], Jonathan Grainger [a,d]

[a] Laboratoire de Psychologie Cognitive, CNRS, and Aix-Marseille University, 13007 Marseille, France
[b] Laboratoire d'Étude des Mécanismes Cognitifs, Université Lumière de Lyon 2, 69676 Bron, France
[c] Department of Cognitive Science, Macquarie University Centre for Reading, Sydney, New South Wales 2109, Australia
[d] Institute for Language Communication and the Brain, Aix-Marseille University, 13007 Marseille, France

ARTICLE INFO

Article history:
Received 25 June 2021
Revised 5 April 2022
Available online xxxx

Keywords:
Reading development
Word recognition
Orthographic processing
Morphological processing
Flankers task
Visual attention

ABSTRACT

Recent research with adult participants using the flankers task has shown that the recognition of central target words is facilitated by the presence of morphologically related flanker words. Here we explored the development of such morphological flanker effects in two groups of primary school children (average ages = 8 years 6 months and 10 years 3 months) and a group of adult participants. We examined effects of a transparent morphological relation in two conditions: one where the target was the stem and flankers were derivations (e.g., *farmer farm farmer*) and the other where the flankers were stems and the target was the derived form (e.g., *farm farmer farm*). Morphological flanker effects were compared with repetition flanker effects with the same set of stimuli (e.g., *farm farm farm*; *farmer farmer farmer*), and effects of related flankers were contrasted with the appropriate unrelated flankers. Results revealed no significant effect of morphological relatedness in the two groups of children and a significant effect in the adult group, but only for suffixed targets and stem flankers. Repetition effects for stem targets were found across all groups, whereas repetition effects for suffixed targets were found only in the older children and adults. These results show that morphological processing, in a context involving multiple words presented simultaneously, takes several years to develop and that morphological complexity

* Corresponding author at: Laboratoire de Psychologie Cognitive, CNRS, and Aix-Marseille University, 13007 Marseille, France.

E-mail address: christophe.cauchi1@univ-lyon2.fr (C. Cauchi).

https://doi.org/10.1016/j.jecp.2022.105448

(stem vs. derived) is a limiting factor for repetition effects in the flankers task with young children.

Introduction

How the morphological structure of words influences reading has been widely debated over the past few decades (see Amenta & Crepaldi, 2012, and Rastle & Davis, 2008, for reviews). Although contested by some, the consensus that has emerged from this research is that morphological structure does have a considerable impact on reading behavior over and above purely form-based and semantic effects (e.g., Beyersmann, Grainger, Casalis, & Ziegler, 2016; Grainger, Colé, & Segui, 1991; Longtin, Segui, & Hallé, 2003; Rastle, Davis, & New, 2004). Much evidence in favor of this consensus has been obtained using the masked priming paradigm combined with the lexical decision task with adult participants (Forster & Davis, 1984; see Grainger et al., 1991, for an early investigation of morphological processing using this paradigm). In the current study, we break with this tradition in two ways: first, by examining the spatial integration of morphological information across multiple words presented simultaneously as opposed to the temporal integration of morphological information using priming and, second, by investigating the developmental trajectory of these processes in two groups of primary school children as well as in a group of adults.

The reading version of the flankers task

The methodological shift to studying word recognition in multiword contexts was motivated by the need to connect single word recognition research with sentence reading research (Grainger, Dufau, & Ziegler, 2016). One particularly important study in this respect was performed by Dare and Shillcock (2013). They adapted the flankers task, initially applied to study attentional influences on object identification (including letters and digits; see Eriksen, 1995), to investigate the influence of orthographic flankers on the processing of central target words. Flankers consisted of two letters placed to the left and to the right of the central target and separated by a single space. Target and flanker stimuli were presented simultaneously for 170 ms. The flanker letters could be either related (e.g., *ro rock ck*) or unrelated (e.g., *pa rock th*) to the target word. Dare and Shillcock (2013) found facilitatory effects of related flankers and, crucially, reported the same amount of facilitation even when the order to flankers was reversed (e.g., *ck rock ro*). Grainger, Mathôt, and Vitu (2014) replicated these important findings and provided a theoretical framework for their interpretation couched in terms of parallel orthographic processing spanning several spatially distinct orthographic stimuli and the spatial integration of this information into a single processing channel for word identification.

Since the seminal work of Dare and Shillcock (2013), the flankers task has been used to investigate the processing of phonological (Cauchi, Lété, & Grainger, 2020), syntactic (Snell, Meeter, & Grainger, 2017), and semantic (Snell, Declerck, & Grainger, 2018) information during reading. Two prior studies are of particular relevance for the current work. One was by Snell, Cauchi, Grainger, and Lété (2021) investigating orthographic flanker effects in primary school children in Grades 1 to 5 and in students in their first year of secondary education. The same conditions as in Dare and Shillcock (2013) were tested as well as a repeated word (vs. unrelated word) flanker condition (e.g., *rock rock rock* vs. *farm rock farm*). The key finding of that study was that facilitatory flanker effects were present even in the youngest readers who were tested. The other relevant study was by Grainger, Snell, and Beyersmann (2021) investigating morphological flanker effects in adult readers. Targets were either semantically transparent derived words (e.g., *farmer*), words with a pseudo-morphological structure (e.g., *corner*), and morphologically simple words with a left edge-aligned embedded word (e.g., *cashew*). Flankers were the stem (e.g., *farm*), pseudo-stem (e.g., *corn*), or embedded (e.g., *cash*) words, and effects of these related flankers were compared with matched unrelated word flankers. Related flankers were found to facilitate central target word recognition in all conditions, but significantly more so when there was a transparent morphological relation between targets and flankers (e.g., *farm farmer farm*). The current work builds on these two prior studies by investigating effects of morphologically related flankers during reading development.

Morphological processing and reading development

Despite the widely recognized importance of morphological knowledge in children's reading development (e.g., Rastle, 2019), the dynamics of morphological processing in children are still not well understood. Compared with the large body of research on morphological processing in adults, findings obtained with the masked priming paradigm from developing readers are sparser and more variable across languages (e.g., Beyersmann, Castles, & Coltheart, 2012; Beyersmann et al., 2015, 2021; Dawson, Rastle, & Ricketts, 2021; Lázaro et al., 2018; Quémart, Casalis, & Colé, 2011; Schiff, Raveh, & Fighel, 2012). A masked priming study with English-speaking 3rd and 5th graders (Beyersmann et al., 2012) reported significant priming effects with semantically transparent (e.g., *farmer–farm*) but not opaque complex (e.g., *corner–corn*) words, suggesting that English-speaking primary school children have not yet acquired the same level of automatization of form-based morphological processing that is typically seen in adults. Similarly, results from Hebrew- and Spanish-speaking children show that opaque morphological priming is absent in 4th and 5th graders but is present in 6th and 7th graders, indicating that form-based morphological processing is not acquired until the start of high school (Lázaro et al., 2018; Schiff et al., 2012). In contrast, Quémart et al. (2011) reported an earlier onset of morphological form priming in French-speaking 3rd, 5th, and 7th graders, suggesting that French-speaking children acquire morpho-orthographic decomposition mechanisms earlier in reading development than English-, Hebrew-, and Spanish-speaking children. This claim finds further support from a recent study by Beyersmann et al. (2021) investigating the developmental trajectory of morphological processing in two large cohorts of German- and French-speaking primary school children, where the authors found that form-based morphological segmentation mechanisms appear to be acquired sooner in French than in German.

The current study

Given the variability in results obtained with the masked priming paradigm as concerns the developmental time course of morphological processing during reading acquisition, here we provide a new line of attack on this issue using the flankers task. Prior research with adults (Grainger et al., 2021) suggests that this paradigm is more sensitive to the processing of semantically transparent morphological relations and therefore might well provide a better means of understanding how such processing changes as children learn to read. To examine the developmental time course of morphological processing in French primary school children, the current study involved a large sample of 3rd, 4th, and 5th graders as well as one group of adults. Derived targets were either accompanied by stem flankers (e.g., *farm farmer farm*) or unrelated control flankers (e.g., *bank farmer bank*). The results reported by Grainger et al. (2021) revealed robust effects of flanker relatedness in these conditions in a group of adults. Here we added a condition where targets were stems and flankers were derived words (e.g., *farmer farm farmer* vs. *banker farm banker*). This was added as a test of the account of morphological flanker effects proposed by Grainger et al. (2021). According to the interpretation of their findings, we expected to observe the same flanker facilitation effect in this condition as in the derived word target–stem flanker condition in our adult participants. However, in anticipation of our results, we note that the relative length of targets and flankers is confounded in this manipulation and that relative target–flanker length might well affect flanker effects. Nevertheless, the focus of the current study was on differences in morphological flanker effects as a function of grade,[1] which were expected to reveal

[1] Note that in the current work we focused on changes in morphological processing as a function of grade rather than reading level given the hypothesized importance of differences in reading instruction across grades (see Method) and the evidence that grade level has a bigger impact on the processing of morphologically complex words (sensitivity to affixes) than reading level (Hasenäcker, Beyersmann, & Schroeder, 2020).

changes in the efficiency with which morphological information is processed and integrated in a simplified reading context. We also included a repetition flanker condition as a baseline, one with stems (e.g., *farm farm farm*), given that we know that such effects can be obtained with the youngest readers (Snell et al., 2021), and one with derived words (e.g., *farmer farmer farmer*).

Method

Participants

A total of 40 adults (35 female), all students at Lyon University in France and ranging in age from 18 to 29 years (M_{age} = 21 years 5 months, *SD* = 2 years 6 months), gave informed consent to participate in this study. Adults were tested individually in an experimental room. In addition, a total of 113 children in 3rd, 4th, or 5th grade were recruited from a primary school in Lyon. They were pretested with the Alouette reading test (Lefavrais, 1967) to ensure that their reading level was not lower than the range of reading levels associated with the respective grade. This led to the exclusion of 27 children. Then we classified the remaining children into two groups based on two of the four French teaching cycles (Cycles 2 and 3). According to the Ministère de l'Éducation Nationale (2020), Cycle 2, referred to as the *fundamental learning cycle,* is considered as the first stage of compulsory schooling for pupils (prior to that there is kindergarten). It covers the first 3 years of primary school (1st grade to 3rd grade, 6–8 years of age). Children are taught the meaning of prefixes and suffixes, and they carry out exercises to locate and group words by morphological analogies. Cycle 3, referred to as the *consolidation cycle,* aims to reinforce the basic knowledge acquired in Cycle 2. Children are expected to reason on the basis of morphological aspects of the language. Children carry out word sense elucidation exercises and verb creation games using implicit morphological knowledge. This cycle covers the last two years of primary school (4th and 5th grades, 9–11 years of age) and the first year of secondary education (6th grade, 11–12 years of age).

Following this strategy, 44 children were recruited in Cycle 2 (all in 3rd grade; M_{age} = 8 years 6 months, *SD* = 5 months), and 42 children were recruited in Cycle 3 (10 in 4th grade and 32 in 5th grade; M_{age} = 10 years 3 months, *SD* = 6 months). Within each cycle, the children's reading age matched their grade's chronological age (Cycle 2 = 8 years 3 months, *SD* = 9 months; Cycle 3 = 10 years 2 months, *SD* = 1 year 2 months). All participants were French native speakers with normal or corrected-to-normal vision and had no history of neurological and/or language impairment. Informed consent was provided by the participants' caregivers prior to experimentation. Ethics approval for this study was granted by the Comité de Protection des Personnes SUD–EST IV.

Stimuli and design

All word stimuli were selected from the MANULEX French grade-level lexical database (Lété, Sprenger-Charolles, & Colé, 2004). We selected root words (stems) that had a semantically transparent suffixed derivations that were already known by Grade 1 children. We built two sets of 24 pairs of words. The first set consisted of 24 stem words (e.g., *danse* ["dance"]) paired with 24 corresponding suffixed words (e.g., *danseur* ["dancer"]), used as target and/or related flankers. The second set consisted of 24 stem words (e.g., *toit* ["roof"]) and 24 corresponding suffixed words (e.g., *toiture* ["roofing"]), which were orthographically, morphologically, and semantically unrelated to the stem targets of the other set and were used as unrelated flankers. From these two sets of items, we constructed eight experimental conditions (see Table 1): two stem–stem conditions where the target stem word was flanked by the same stem flanker (e.g., *danse danse danse*) or by an unrelated stem flanker (e.g., *toit danse toit*), two suffixed–suffixed conditions where the suffixed word target was flanked by the same suffixed word (e.g., *danseur danseur danseur*) or by an unrelated suffixed flanker (e.g., *toiture danseur toiture*), two suffixed–stem conditions where the stem word target was flanked by the corresponding suffixed word (e.g., *danseur danse danseur*) or by an unrelated suffixed word (e.g., *toiture danse toiture*), and two stem–suffixed conditions where the suffixed word target was flanked by the corresponding stem (e.g., *danse danseur danse*) or by an unrelated stem (e.g., *toit danseur toit*).

Table 1
Examples of target and flanker stimuli in the eight experimental conditions.

Flanker	Target	Relatedness	
		Related	Unrelated
stem	stem	danse danse danse	toit danse toit
suffixed	suffixed	danseur danseur danseur	toiture danseur toiture
suffixed	stem	danseur danse danseur	toiture danse toiture
stem	suffixed	danse danseur danse	toit danseur toit

Note. In the example triplets, the target is the central stimulus.

Stems were three to five letters long (average = 4.21 letters), and suffixed words were five to seven letters long (average = 6.33 letters). Word frequency was transformed into Zipf values (van Heuven, Mandera, Keuleers, & Brysbaert, 2014). In the first set, the stem frequency was 6.49 (range = 5.70–7.50) and the suffixed word frequency was 5.83 (range = 5.38–6.83). In the second set, the stem frequency was 5.97 (range = 5.25–6.79) and the suffixed word frequency was 5.28 (range = 4.94–6.43). Pseudoword targets, associated with pseudoword flankers, were used as fillers for the purpose of the lexical decision task and were not considered in the analyses. They were created from the two sets of words by a single letter substitution. The OLD20 values of these pseudowords (Yarkoni, Balota, & Yap, 2008) was 1.79 (range = 1–2.85).

A 2 × 2 × 2 design was retained with target type (stem vs. suffixed), relation type (repetition vs. morphological), and relatedness (related flanker vs. unrelated flanker) as within-participant factors. The stem–stem and suffixed–suffixed conditions tested for repetition effects with related target and flankers being the same word, and the suffixed–stem and stem–suffixed conditions tested for morphological effects. For a given stem-derived pair (e.g., *ami–amitié*), each participant saw both the stem (*ami*) and the suffixed word (*amitié*) as targets, within both the related (*amitié–ami; ami–amitié*) and unrelated (*largeur–ami; large–amitié*) flanker conditions, either in the morphological condition (see preceding examples) in one list or in the repetition condition in a different list (e.g., *ami–ami; amitié–amitié; large–ami; largeur–amitié*). As such, each participant saw each target word twice in both the related and unrelated flanker conditions. There were 12 items per condition per participant. See Appendix A for the complete set of word stimuli and their assignment to the two lists.

Procedure

The experiment was implemented with OpenSesame (Mathôt, Schreij, & Theeuwes, 2012). Stimuli were presented on a DELL Latitude 3400 monitor calibrated in 14 inches (1366 × 768 pixels, 80 Hz). They were displayed in lowercase Courier New font (21 point) in black on a gray background. At a viewing distance of 40 cm, each character subtended approximately 0.33° of visual angle. Manual responses were collected with the computer keyboard. Each trial started with two vertical fixation bars above and below a central fixation cross. After 1000 ms, the central fixation cross disappeared and the target (a word or pseudoword), flanked by two words or pseudowords on each side, was presented between the two vertical fixation bars (see Fig. 1). After 250 ms, the stimulus was blanked. Participants needed to indicate as quickly and accurately as possible whether the target was a word or a pseudoword by pressing the right or left button (Q or M, respectively, on an AZERTY keyboard) for participants who declared that they were right-handed; it was inverted for left-handed participants. Participants had a maximum of 4500 ms to make their lexical decision. The experiment lasted 10 to 15 min for adults and lasted 20 to 30 min for children. The 192 trials were divided into four blocks of 48 trials. Blocks and trials were randomized for each participant. A short break was proposed between blocks. The task began with 32 practice trials, followed by the main experiment.

Statistical power estimation

Statistical power was estimated a posteriori using the simulation approach suggested by Brysbaert and Stevens (2018). We employed the Monte Carlo method using the *powerSim* function from the

Fig. 1. Illustration of the experimental procedure with an example stem target word flanked by related suffixed word flankers. The fixation cross was presented for 1000 ms, followed by the experimental items for 250 ms. Targets were centered with respect to the vertical fixation bars. After the stimuli disappeared, participants had a maximum of 4500 ms to indicate whether the central stimulus was a word or not.

simR package (Version 1.0.5; Green & MacLeod, 2016). The stem–stem related versus stem–stem unrelated contrast was targeted in this analysis using the observed size of the relatedness effect in reaction times (RTs) in the three groups of participants (35 ms in the adult group, 63 ms in Cycle 3, and 84 ms in Cycle 2). At each iteration, the program selected a random sample of items and participants from the original dataset and fitted a linear mixed-effects model from which the statistical power was estimated 20 times. Each sample selection was constrained to retain a 75% reduced sample from the original dataset (e.g., 18/24 items and 30/40 participants from the adult group dataset). Thus, the estimated statistical power was 98% in the adult group, 91% in Cycle 3, and 81% in Cycle 2. Given the standard of 80%, we reckoned to have sufficient power in this study.

Results

Pseudoword fillers were excluded from the statistical analysis. The data were analyzed in the R statistical computing environment (R Core Team, 2018). For the RT analyses, linear mixed-effects models were fitted (Baayen, 2008) with the *lmer* function from the lme4 package (Version 1.1–21; Bates, Maechler, Bolker, & Walker, 2014). The RT variable was log-transformed to meet normality assumptions. For the accuracy analyses, a generalized mixed-effects model was fitted with the *glmer* function from the package cited above using the same structure as the models used for RT except that the accuracy variable was used as a binomial response. The by-group analyses consisted of a full model with target type (stem or suffixed), relatedness (related or unrelated), and relation type (repetition or morphological) as fixed factors and logarithmic RT as a continuous variable in which the maximal random-effects structure that converged was used (Barr, Levy, Scheepers, & Tily, 2013). Due to the complexity of the experimental design with the inclusion of group as a three-level factor, the results of such a $2 \times 2 \times 2 \times 3$ analysis are not reported here. Instead, we report the results of analyses including group as a two-level factor (Cycle 2 vs. Cycle 3 or Cycle 3 vs. adults). The significance of the fixed effects was determined with Type III model comparisons using the *Anova* function from the car package (Version 3.0–8; Fox & Weisberg, 2011). Post hoc analyses were carried out to follow up the significant two-way and three-way interactions using cell means coding and single *df* contrasts with the *glht* function of the multcomp package (Version 1.4–13; Hothorn, Bretz, & Westfall, 2008) using the normal distribution to evaluate significance (see Table 2).

By-group analyses

Reaction times

All trials with RTs lying beyond 300 and 3000 ms (Cycle 2 = 5.6%, Cycle 3 = 1.6%, adult group = 0.1%) were excluded. Incorrect responses were excluded from the RT analyses (Cycle 2 = 12.1%, Cycle 3 = 4.8%, adult group = 3.4%). In each group, a null model with a random structure including by-participant and by-item random intercepts was fitted to compute standardized residuals from

Table 2
Mean RTs (in milliseconds) and accuracy (probabilities) for each condition and each participant group.

			RTs / Relatedness		Δ (signif)	Accuracy / Relatedness		Δ (signif)
	Flanker	Target	Related	Unrelated		Related	Unrelated	
Cycle 2 (*n* = 44)	stem	stem	1104 (*258*)	1188 (*283*)	84 (***)	.92 (*.09*)	.89 (*.12*)	.03 (*)
	suffixed	suffixed	1221 (*308*)	1207 (*278*)	−14 (*ns*)	.88 (*.12*)	.84 (*.14*)	.04 (*)
	stem	suffixed	1178 (*290*)	1185 (*290*)	7 (*ns*)	.87 (*.15*)	.82 (*.16*)	.05 (*)
	suffixed	stem	1112 (*234*)	1113 (*250*)	1 (*ns*)	.91 (*.11*)	.88 (*.13*)	.03 (*ns*)
Cycle 3 (*n* = 42)	stem	stem	846 (*162*)	909 (*180*)	63 (***)	.96 (*.07*)	.96 (*.08*)	.00 (*ns*)
	suffixed	suffixed	884 (*165*)	925 (*178*)	41 (***)	.97 (*.04*)	.94 (*.07*)	.03 (ns)
	stem	suffixed	915 (*204*)	922 (*177*)	7 (*ns*)	.96 (*.06*)	.93 (*.07*)	.03 (*ns*)
	suffixed	stem	908 (*165*)	911 (*166*)	3 (*ns*)	.95 (*.08*)	.94 (*.10*)	.01 (*ns*)
Adults (*n* = 40)	stem	stem	594 (*83*)	629 (*73*)	35 (***)	.97 (*.04*)	.96 (*.06*)	.01 (*ns*)
	suffixed	suffixed	592 (*81*)	633 (*85*)	41 (***)	.96 (*.05*)	.97 (*.05*)	-.01 (*ns*)
	stem	suffixed	609 (*87*)	632 (85)	23 (***)	.97 (*.06*)	.96 (*.05*)	.01 (*ns*)
	suffixed	stem	622 (*85*)	627 (*76*)	5 (*ns*)	.97 (*.05*)	.96 (*.05*)	.01 (*ns*)

Note. Standard deviations are in parentheses except when displaying significance. RT, reaction time. Δ, difference; signif, significance. Relatedness effects (unrelated minus related) and their significance (in parentheses) are provided after the condition means of the relatedness factor (*ns, p* >.10; **p* <.05; ***p* <.01; ****p* <.001).

the logarithmic RTs. All trials with standardized residuals larger than 2.5 in absolute value were excluded (Cycle 2 = 2.2%, Cycle 3 = 2.9%, adult group = 2.3%). Raw means for each condition and for each group are provided in Table 2.

To simplify the description of the model outputs, here we only summarize the main effect of relatedness (factor of interest) and its interaction with relation type and target type. See Appendix B for the complete model outputs.

In Cycle 2, the main effect of relatedness failed to reach significance, $\chi^2(1) = 2.91$, p =.08. The three-way interaction among relatedness, relation type, and target type was significant, $\chi^2(1) = 4.56$, p <.05. Follow-up analyses revealed that the Relatedness × Relation Type interaction was not significant for suffixed targets, $\chi^2(1) = 0.03$, p >.10, but was significant for stem targets, $\chi^2(1) = 7.82$, p <.01. Further post hoc comparisons (see Table 2) revealed that there was a significant effect of relatedness only in the stem–stem (repetition) condition.

In Cycle 3, the main effect of relatedness was significant, $\chi^2(1) = 19.06$, p <.001, with faster responses in the presence of related flankers. The three-way interaction among relatedness, relation type, and target type was not significant, $\chi^2(1) = 0.32$, p >.10. The Relatedness × Relation Type interaction was significant, $\chi^2(1) = 12.14$, p <.001. Follow-up analyses revealed that the relatedness effect was significant for repetition flankers, $\chi^2(1) = 23.28$, p <.001, but not for morphological flankers, $\chi^2(1) = 0.38$, p >.10. Further post hoc comparisons (see Table 2) revealed that there was a significant effect of relatedness in the stem–stem and suffixed–suffixed conditions.

In the adult group, the main effect of relatedness was significant, $\chi^2(1) = 33.09$, p <. 001, with faster responses in the presence of related flankers. The three-way interaction among relatedness, relation type, and target type was not significant, $\chi^2(1) = 1.03$, p >.10. The Relatedness × Relation Type interaction was significant, $\chi^2(1) = 14.47$, p <.001). This interaction was driven by the greater effects of relatedness obtained with repetition flankers, $\chi^2(1) = 47.03$, p <.001, than with morphological flankers, $\chi^2(1) = 9.20$, p <.01. As can be seen in Table 2, the reduced effect of relatedness in the morphological condition was primarily driven by the absence of an effect with stem targets and derived word flankers.

Accuracy

Condition means for accuracy are provided in Table 2. In Cycle 2, the main effect of relatedness was significant, $\chi^2(1) = 15.72$, p <.001, with higher accuracy in the presence of related flankers compared with unrelated flankers. No significant interactions were found.

There were no significant effects of accuracy in the Cycle 3 and adult groups.

Between-group analyses of RTs

The goal of these analyses was to study the evolution of the different flanker relatedness effects from children to adults. To avoid over-additive effects due to differences in average RT across groups (Faust, Balota, Spieler, & Ferraro, 1999), the raw logarithmic RT data of each participant were standardized using a *z*-score transformation (see Lété & Fayol, 2013; Ziegler, Bertrand, Lété, & Grainger, 2014), such that each participant had a mean of zero and a standard deviation equal to 1 across conditions. These analyses consisted of a model including relatedness (related or unrelated) as a within-participant factor, group (Cycle 2, Cycle 3, or adults) as a between-participant factor, and the z-score of the logarithmic RT as the dependent variable. In this section, we report the main effect of group and the critical Relatedness × Group interaction tested in each of the four conditions formed by the combination of relation type and target type (stem–stem, suffixed–suffixed, suffixed–stem, or stem–suffixed). The differences between the two relatedness levels (i.e., effects of flanker relatedness) expressed in *z*-score differences are plotted in Fig. 2.

In the stem–stem condition, the main effect of group was not significant, $\chi^2(2) = 2.44$, $p > .10$, and neither was the Relatedness × Group interaction, $\chi^2(2) = 3.52$, $p > .10$. In the suffixed–suffixed condition, the main effect of group was significant, $\chi^2(2) = 17.54$, $p < .001$, and the Relatedness × Group interaction was significant, $\chi^2(2) = 22.69$, $p < .001$. As can be seen in Fig. 2, the interaction was due to an increase in the effects of relatedness with increasing age. In the suffixed–stem condition, the main effect of group was significant, $\chi^2(2) = 24.08$, $p < .001$. However, the Relatedness × Group interaction was not significant, $\chi^2(2) = 0.34$, $p > .10$. Referring back to Table 2, we note the absence of a significant effect of relatedness in this condition for all groups. In the stem–suffixed condition, the main

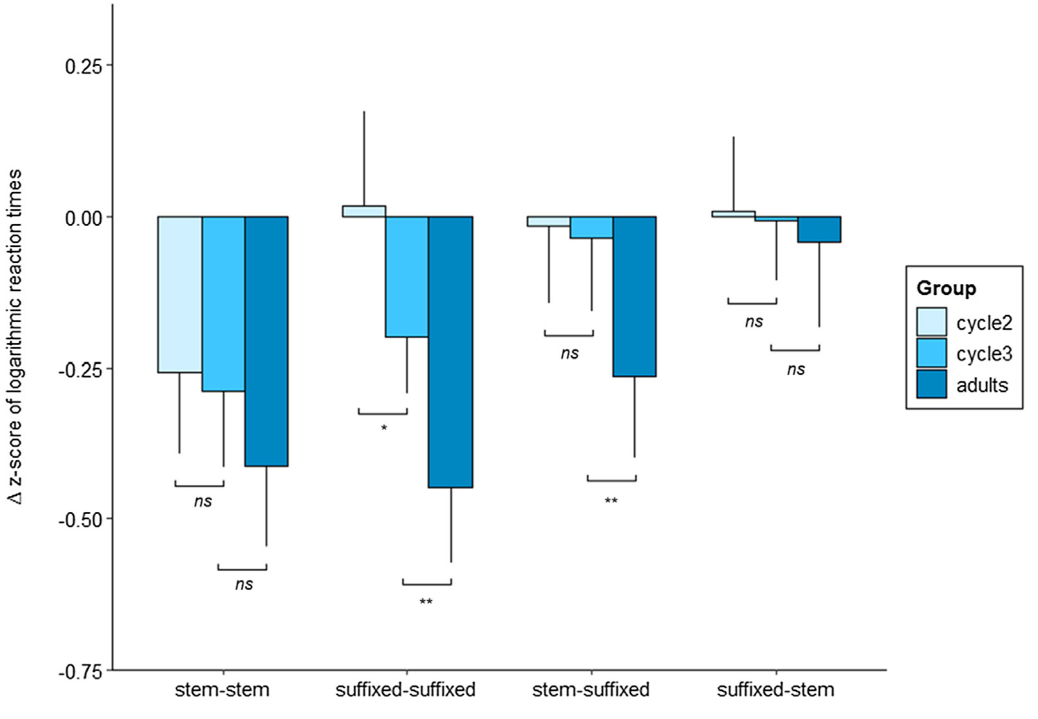

Fig. 2. Differences (Δ) expressed in *z*-score values between the two relatedness levels (related and unrelated) for each condition (stem flanker–stem target, suffixed flanker–suffixed target, stem flanker–suffixed target, and suffixed flanker–stem target) and in each group. Significance brackets correspond to the interaction between relatedness and group involving two adjacent age groups (Cycle 2 vs. Cycle 3 and Cycles 3 vs. adults). Significance levels: *ns*, $p > .10$; *$p < .05$; **$p < .01$.

effect of group was not significant, $\chi^2(2) = 2.88$, $p > .10$, but the Relatedness × Group interaction was significant, $\chi^2(2) = 10.00$, $p < .01$. As shown in Fig. 2, this interaction was due to the increase in relatedness effects with age, particularly between Cycle 3 and adults. Indeed, as can be seen in Table 2, the effects of relatedness in the stem–flanker, suffixed–target condition were significant only in the adult group.

Discussion

In the current study, we investigated two types of flanker relatedness, repetition and morphological, in the flankers task in two groups of children and a group of adult participants. The study was motivated by our prior work revealing effects of orthographic relatedness in the flankers task in the youngest participants who were tested (Snell et al., 2021) and by work showing effects of morphological relatedness in the flankers task in adult participants (Grainger et al., 2021). We replicated both of these findings, with flanker repetition effects for stem targets (e.g., *farm farm farm* vs. *bank farm bank*) already present in the youngest children, and morphological flanker effects with derived word targets (e.g., *farm farmer farm* vs. *bank farmer bank*) being observed in the group of adult participants, but only in that group. Repetition effects with derived word targets (e.g., *farmer farmer farmer* vs. *banker farmer banker*) emerged only in the older children and were significantly larger in the adult group. Moreover, the effects of morphological relatedness with stem targets (e.g., *farmer farm farmer* vs. *banker farm banker*) failed to reach significance in all groups of participants. The key findings emerged in RTs rather than in error rates, and the overall pattern is summarized in Fig. 2.

There are two main conclusions to be drawn from the current findings. First, the effects of flanker relatedness can be found in beginning readers but are limited to sequences of short, morphologically simple words. Snell et al. (2021) tested short, morphologically simple words and found effects of repetition flankers (as in the stem target condition of the current study) and bigram flankers (e.g., *ro rock ck* vs. *st rock ep*). In line with the results of Snell et al. (2021), the size of repetition flanker effects seen for the short words tested in the current work (i.e., the stem–stem condition) did not change significantly across the three groups of participants we tested.[2] On the other hand, the repetition effects obtained with longer words (i.e., the suffixed–suffixed condition) did vary significantly across the three groups of participants, with a nonsignificant effect in the youngest readers becoming significant in the older children and with the largest effects seen in the adult group. This pattern of results points to a key role for stimulus length in determining flanker effects with young readers, possibly related to changes in the span of spatial attention during reading development. Moreover, it might well have been the combination of quite brief stimulus exposure durations (250 ms) along with combined target and flanker length that was the limiting factor concerning repetition flanker effects in the youngest children. Future research could independently manipulate these two factors (i.e., stimulus length and stimulus duration) in order to better understand how they contribute to flanker effects in beginning readers. We return to discuss the impact of relative target–flanker length below and whether or not this indeed reflects an impact of stimulus length as opposed to differences in the morphological status of targets and flankers.

The second main conclusion is that the morphological flanker effects reported by Grainger et al. (2021) with derived word targets and stem flankers in adult participants, an effect that was replicated in the current work, require quite some reading experience before being observable, with the effect in the oldest children tested in the current study being nonsignificant (7 ms; see Table 2). Crucially, as can be seen in Fig. 2, the interaction between group (Cycle 3 vs. adults) and relatedness was significant. This pattern suggests that the flankers task compared with masked priming, for example, might be a more sensitive measure of the later stages of development of morphological processing for reading comprehension. One key difference between the flankers task and masked priming is that the flankers task is thought to reflect the kind of spatial integration of

[2] We acknowledge here, and elsewhere, that any conclusions based on null effects must be taken with appropriate caution, particularly when there are numerical differences across conditions.

information spanning adjacent words that occurs in normal sentence reading,[3] whereas masked priming reflects the temporal integration of stimuli presented at the same spatial location and is thought to be an excellent measure of basic processes involved in single word recognition (see Snell, Bertrand, Meeter, & Grainger, 2018, for a comparison of flanker and priming effects with the same stimuli). In other words, the flankers task might provide a better window on the use of morphological information for reading comprehension as opposed to single word recognition. This makes sense given that word recognition efficiency is the skill that develops the fastest among the multiple skills required to become an expert reader and therefore might be less sensitive to the linguistic skills that take more time to develop and that might require more explicit teaching as provided in primary school education. Thus, the reason why masked priming studies have found evidence for morphological effects in French primary school children (Beyersmann et al., 2021; Quémart et al., 2011) would be that these investigations were tapping into the already automatized process of single word recognition. The flankers task, on the other hand, would be mainly sensitive to the spatial pooling of orthographic information that occurs during sentence reading (Angele, Tran, & Rayner, 2013; Dare & Shillcock, 2013; Snell, Bertrand, Meeter, & Grainger, 2018) as well as the rapid activation of higher-level syntactic (Snell et al., 2017) and semantic (Snell et al., 2018) information that is necessary for computing sentence-level representations. In that sense, the flankers task may be better-suited to capture higher-level reading skills that are relevant for sentence-level processing. Indeed, recent research with Italian skilled readers revealed that eye movements are affected by the semantic transparency of morphologically complex words, thereby providing evidence for the early involvement of semantics in complex word processing during sentence reading (Amenta, Marelli, & Crepaldi, 2015; Marelli & Luzzatti, 2012).

One unexpected finding of the current work is the absence of an effect of morphologically related flankers in the adult participants when the targets were stems and the flankers were derived words. Given the interpretation offered by Grainger et al. (2021) for the effects they found with derived word targets and stem flankers, one would have expected to observe the same pattern with the opposite manipulation of target–flanker complexity. That is, if morphological flanker effects reflect the excitatory connectivity between truly morphologically related words, such as *farm* and *farmer* (and not pseudo-morphologically related words, such as *corn* and *corner*), then facilitatory effects should have also been observed with stem targets and derived word flankers. This null effect, to be interpreted with caution, nevertheless points to the need to either abandon or at least modify the explanation offered by Grainger et al. (2021) for the morphological flanker effects they observed with adults, a point that remains to be addressed in future research.

However, it might also be that the relative length of target and flanker stimuli is playing a role here. Absolute target–flanker length (i.e., the combined length of target and flanker stimuli) cannot account for this pattern because this was matched across the stem and derived word target conditions when target and flankers were morphologically related. Relative target–flanker length (i.e., the difference in length between the target and flanker words) and differing morphological status of targets and flankers therefore are the two key candidate explanations for the absence of an effect of flanker relatedness with stem targets and derived word primes, which we now discuss.

According to the differing morphological status scenario, morphological decomposition would be automatically triggered when recognizing a derived word (e.g., Grainger & Beyersmann, 2017), and this process would be facilitated by the presence of related stem flankers. On the other hand, because stem targets would not undergo morphological decomposition, they would not benefit from related derived word flankers because the targets themselves do not require morphological processing in order to be identified. So, rather than postulating bidirectional

[3] Here we point readers to the seminal work of Dare and Shillcock (2013), who found the same evidence for spatial integration of orthographic information in the flankers task and in a sentence reading experiment (see also Snell & Grainger, 2019, and associated commentaries for a discussion on the relative merits of using artificial paradigms, such as the flankers task, to study reading). Nevertheless, we do acknowledge that the flankers task is a relatively superficial reading task and that experiments involving more natural reading conditions are necessary in order to fully test the framework that we propose here.

excitatory connectivity between morphologically related words, as proposed in Grainger et al. (2021), here we propose that the automatic decomposition of complex word targets (e.g., *farmer*) into stem (*farm*) and affix (*_er*) benefits from the presence of the stem as a flanker because this will boost activation of the stem word in the central processing channel. On the other hand, complex word flankers would not be automatically decomposed into stem and affix and therefore would have no impact on target processing over and above effects driven by the orthographic overlap between derived word and stem. In other words, there would be no connectivity between representations activated in the central processing channel, and flanker effects would result uniquely from the spatial pooling of orthographic information activated in parallel by the target and flanker stimuli.[4]

According to the relative target–flanker length scenario, flanker words that are shorter than target words would have a greater impact on flanker relatedness effects, possibly due to the deployment of spatial attention in this condition (i.e., more attention deployed to flanker words when they are shorter than the target word). Clearly, the obvious way to put these two scenarios to test is to compare flanker effects with truly morphological (e.g., *farmer–farm*), pseudo-morphological (e.g., *corner–corn*), and non-morphological (e.g., *cashew–cash*) stimuli with both stems (*farm*), pseudo-stems (*corn*), and embedded words (*cash*) as targets in one condition and as flankers in another condition. The morphological account predicts that differences in target–flanker length should be observable only in the truly morphological condition (and possibly to some extent in the pseudo-morphological condition), whereas the relative length account predicts that the asymmetry should be observed in all three conditions. As a first step in this endeavor, future research could investigate non-morphological flanker effects with different target–flanker lengths (e.g., *cash–cashew, cashew–cash*) in order to elucidate the impact of relative target–flanker length on orthographic flanker effects.

In sum, in the current study, we have shown the potential for the reading version of the flankers task to reveal differences in the processing of central target words as a function of their morphological complexity and participants' grade level. Although the morphological interpretation of the current findings requires further experimentation in order to rule out a contribution of relative target–flanker length, we consider that the flankers task will provide an interesting new angle on the developmental trajectory of other types of morphological complexity, such as inflectional morphology and compounding, and across languages that differ in morphological structure.

Acknowledgments

We thank Jana Hasenäcker and two anonymous reviewers for their thoughtful and valuable comments. This research was supported by the Australian Research Council (DE190100850) and the European Research Council (ERC742141). We thank the primary school in Lyon (France), children, teachers, and headmaster for their participation in this research.

Data availability

The stimuli and model outputs are listed in Appendixes A and B. The data and main statistical analyses are available at the Open Science Framework (https://osf.io/t5kec).

Appendix A

Stimuli material with list allocation of target words or flankers in each experimental condition (List 1 stimuli without a background and List 2 stimuli with a gray background)

[4] It is important to note that this does not imply that morphological information is not processed in the parafovea. That assertion would be contrary to studies showing a facilitatory influence of morphologically related parafoveal previews (e.g., Dann, Veldre, & Andrews, 2021). We simply argue that such information is not integrated across foveal and parafoveal words during identification of the foveal word.

Item number	Relatedness	Stem	Suffixed	Conditions			
				stem-stem	suffixed-stem	suffixed-suffixed	stem-suffixed
1	REL	ami	amitié	ami ami ami	amitié ami amitié	amitié amitié amitié	ami amitié ami
	UNR	large	largeur	large ami large	largeur ami largeur	largeur amitié largeur	large amitié large
2	REL	beau	beauté	beau beau beau	beauté beau beauté	beauté beauté beauté	beau beauté beau
	UNR	tas	tasser	tas beau tas	tasser beau tasser	tasser beauté tasser	tas beauté tas
3	REL	bon	bonne	bon bon bon	bonne bon bonne	bonne bonne bonne	bon bonne bon
	UNR	sport	sportif	sport bon sport	sportif bon sportif	sportif bonne sportif	sport bonne sport
4	REL	cause	causer	cause cause cause	causer cause causer	causer causer causer	cause causer cause
	UNR	son	sonore	son cause son	sonore cause sonore	sonore causer sonore	son causer son
5	REL	cave	caverne	cave cave cave	caverne cave caverne	caverne caverne caverne	cave caverne cave
	UNR	ski	skieur	ski cave ski	skieur cave skieur	skieur caverne skieur	ski caverne ski
6	REL	chat	chaton	chat chat chat	chaton chat chaton	chaton chaton chaton	chat chaton chat
	UNR	sage	sagesse	sage chat sage	sagesse chat sagesse	sagesse chaton sagesse	sage chaton sage
7	REL	cri	crier	cri cri cri	crier cri crier	crier crier crier	cri crier cri
	UNR	sac	sachet	sac cri sac	sachet cri sachet	sachet crier sachet	sac crier sac
8	REL	danse	danseur	danse danse danse	danseur danse danseur	danseur danseur danseur	danse danseur danse
	UNR	toit	toiture	toit danse toit	toiture danse toiture	toiture danseur toiture	toit danseur toit
9	REL	droit	droite	droit droit droit	droite droit droite	droite droite droite	droit droite droit
	UNR	rêve	rêverie	rêve droit rêve	rêverie droit rêverie	rêverie droite rêverie	rêve droite rêve
10	REL	grand	grandir	grand grand grand	grandir grand grandir	grandir grandir grandir	grand grandir grand
	UNR	point	pointer	point grand point	pointer grand pointer	pointer grandir pointer	point grandir point
11	REL	gros	grossir	gros gros gros	grossir gros grossir	grossir grossir grossir	gros grossir gros
	UNR	peur	peureux	peur gros peur	peureux gros peureux	peureux grossir peureux	peur grossir peur
12	REL	jour	journée	jour jour jour	journée jour journée	journée journée journée	jour journée jour
	UNR	mari	mariage	mari jour mari	mariage jour mariage	mariage journée mariage	mari journée mari
13	REL	matin	matinée	matin matin matin	literie matin literie	matinée matinée matinée	lit matinée lit
	UNR	lit	literie	lit matin lit	matinée matin matinée	literie matinée literie	matin matinée matin
14	REL	neige	neigeux	neige neige neige	neigeux neige neigeux	neigeux neigeux neigeux	neige neigeux neige
	UNR	honte	honteux	honte neige honte	honteux neige honteux	honteux neigeux honteux	honte neigeux honte
15	REL	ours	ourson	ours ours ours	ourson ours ourson	ourson ourson ourson	ours ourson ours
	UNR	jet	jeter	jet ours jet	jeter ours jeter	jeter ourson jeter	jet ourson jet
16	REL	part	partie	part part part	partie part partie	partie partie partie	part partie part
	UNR	roche	rocher	roche part roche	rocher part rocher	rocher partie rocher	roche partie roche
17	REL	pays	paysan	pays pays pays	paysan pays paysan	paysan paysan paysan	pays paysan pays
	UNR	flot	flotter	flot pays flot	flotter pays flotter	flotter paysan flotter	flot paysan flot
18	REL	pêche	pêcheur	pêche pêche pêche	pêcheur pêche pêcheur	pêcheur pêcheur pêcheur	pêche pêcheur pêche
	UNR	film	filmer	film pêche film	filmer pêche filmer	filmer pêcheur filmer	film pêcheur film
19	REL	plat	plateau	plat plat plat	plateau plat plateau	plateau plateau plateau	plat plateau plat
	UNR	épine	épineux	épine plat épine	épineux plat épineux	épineux plateau épineux	épine plateau épine
20	REL	poule	poulet	poule poule poule	poulet poule poulet	poulet poulet poulet	poule poulet poule
	UNR	dos	dossier	dos poule dos	dossier poule dossier	dossier poulet dossier	dos poulet dos
21	REL	tout	toute	tout tout tout	toute tout toute	toute toute toute	tout toute tout
	UNR	début	débuter	début tout début	débuter tout débuter	débuter toute débuter	début toute début
22	REL	train	trainer	train train train	trainer train trainer	trainer trainer trainer	train trainer train
	UNR	col	collier	col train col	collier train collier	collier trainer collier	col trainer col
23	REL	vite	vitesse	vite vite vite	vitesse vite vitesse	vitesse vitesse vitesse	vite vitesse vite
	UNR	bord	bordure	bord vite bord	bordure vite bordure	bordure vitesse bordure	bord vitesse bord
24	REL	vol	voleur	vol vol vol	voleur vol voleur	voleur voleur voleur	vol voleur vol
	UNR	barre	barreau	barre vol barre	barreau vol barreau	barreau voleur barreau	barre voleur barre

Note. REL, related; UNR, unrelated.

Appendix B

Analysis of variance outputs for the by-group reaction times and accuracy analyses

	Reaction times analyses				Accuracy analyses			
Cycle 2	χ^2	*df*	*p* Value	Signif.	χ^2	*df*	*p* Value	Signif.
(Intercept)	41213.29	1	<.001	***	150.71	1	<.001	***
Target Type	8.54	1	<.01	**	9.79	1	<.01	**
Relatedness	2.91	1	.0881	+	15.72	1	<.001	***
Relation Type	2.42	1	.1194		0.01	1	.9201	
Target Type × Relatedness	2.20	1	.1383		0.003	1	.9559	
Target Type × Relation Type	0.03	1	.8545		1.19	1	.2755	
Relatedness × Relation Type	2.53	1	.1115		0.04	1	.8495	
Target Type × Relatedness × Relation Type	4.56	1	.0326	*	0.06	1	.7974	
Cycle 3	χ^2	*df*	*p* Value	Signif.	χ^2	*df*	*p* Value	Signif.
(Intercept)	59354.82	1	<.001	***	360.33	1	<.001	***
Target Type	1.22	1	.2698		0.09	1	.7674	
Relatedness	19.06	1	<.001	***	2.56	1	.1093	
Relation Type	10.29	1	<.01	**	3.38	1	.0661	+
Target Type × Relatedness	0.24	1	.6223		2.74	1	.0979	+
Target Type × Relation Type	1.91	1	.1659		0.55	1	.4568	
Relatedness × Relation Type	12.14	1	<.001	***	0.35	1	.5544	
Target Type × Relatedness × Relation Type	0.32	1	.5709		1.25	1	.2634	
Adults	χ^2	*df*	*p* Value	Signif.	χ^2	*df*	*p* Value	Signif.
(Intercept)	98392.12	1	<.001	***	145.45	1	<.001	***
Target Type	0.31	1	.5795		0.32	1	.5721	
Relatedness	33.09	1	<.001	***	0.71	1	.4005	
Relation Type	9.21	1	<.01	**	0.13	1	.7228	
Target Type × Relatedness	2.74	1	.0978	+	0.05	1	.8557	
Target Type × Relation Type	1.22	1	.2696		0.15	1	.7023	
Relatedness × Relation Type	14.47	1	<.001	***	1.51	1	.2186	
Target Type × Relatedness × Relation Type	1.03	1	.3096		0.65	1	.4194	

Note. Signif., significance.
+p <.10.
*p <.05.
**p <.01.
***p <.001.

Appendix C. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2022.105448.

References

Amenta, S., & Crepaldi, D. (2012). Morphological processing as we know it: An analytical review of morphological effects in visual word identification. *Frontiers in Psychology, 3*. https://doi.org/10.3389/fpsyg.2012.00232.

Amenta, S., Marelli, M., & Crepaldi, D. (2015). The fruitless effort of growing a fruitless tree: Early morpho-orthographic and morpho-semantic effects in sentence reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 41*, 1587–1596.

Angele, B., Tran, R., & Rayner, K. (2013). Parafoveal–foveal overlap can facilitate ongoing word identification during reading: Evidence from eye movements. *Journal of Experimental Psychology: Human Perception and Performance, 39*, 526–538.

Baayen, R. (2008). *Analyzing linguistic data: A practical introduction to statistics using R*. Cambridge, UK: Cambridge University Press.

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language, 68*, 255–278.

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2014). *lme4: Linear mixed-effects models using Eigen and S4.* R package Version 1.1-6. Retrieved from http://CRAN.R-project.org/package=lme4.

Beyersmann, E., Castles, A., & Coltheart, M. (2012). Morphological processing during visual word recognition in developing readers: Evidence from masked priming. *Quarterly Journal of Experimental Psychology, 65*, 1306–1326.

Beyersmann, E., Grainger, J., Casalis, S., & Ziegler, J. C. (2015). Effects of reading proficiency on embedded stem priming in primary school children. *Journal of Experimental Child Psychology, 139*, 115–126.

Beyersmann, E., Mousikou, P., Schroeder, S., Javourey-Drevet, L., Ziegler, J. C., & Grainger, J. (2021). The dynamics of morphological processing in developing readers: A cross-linguistic masked priming study. *Journal of Experimental Child Psychology, 208* 105140.

Beyersmann, E., Ziegler, J. C., Castles, A., Coltheart, M., Kezilas, Y., & Grainger, J. (2016). Morpho-orthographic segmentation without semantics. *Psychonomic Bulletin & Review, 23*, 533–539.

Brysbaert, M., & Stevens, M. (2018). Power analysis and effect size in mixed effects models: A tutorial. *Journal of Cognition, 1*(1), 9.

Cauchi, C., Lété, B., & Grainger, J. (2020). Orthographic and phonological contributions to flanker effects. *Attention, Perception, & Psychophysics, 82*, 3571–3580.

Dann, K. M., Veldre, A., & Andrews, S. (2021). Morphological preview effects in English are restricted to suffixed words. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 47*, 1338–1352.

Dare, N., & Shillcock, R. (2013). Serial and parallel processing in reading: Investigating the effects of parafoveal orthographic information on nonisolated word recognition. *Quarterly Journal of Experimental Psychology, 66*, 487–504.

Dawson, N., Rastle, K., & Ricketts, J. (2021). Finding the man amongst many: A developmental perspective on mechanisms of morphological decomposition. *Cognition, 211* 104605.

Eriksen, C. W. (1995). The flankers task and response competition: A useful tool to investigate a variety of cognitive problems. *Visual Cognition, 2*, 101–118.

Faust, M. E., Balota, D. A., Spieler, D. H., & Ferraro, F. R. (1999). Individual differences in information-processing rate and amount: Implications for group differences in response latency. *Psychological Bulletin, 125*, 777–799.

Forster, K. I., & Davis, C. (1984). Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10*, 680–698.

Fox, J., & Weisberg, S. (2011). *An R companion to applied regression* (2nd ed.). Thousand Oaks, CA: Sage.

Grainger, J., & Beyersmann, E. (2017). Edge-aligned embedded word activation initiates morpho-orthographic segmentation. In B. Ross (Ed.), *Psychology of learning and motivation* (pp. 285–317). Amsterdam: Elsevier Academic Press.

Grainger, J., Colé, P., & Segui, J. (1991). Masked morphological priming in visual word recognition. *Journal of Memory and Language & Speech, 30*, 370–384.

Grainger, J., Dufau, S., & Ziegler, J. C. (2016). A vision of reading. *Trends in Cognitive Sciences, 20*, 171–179.

Grainger, J., Mathôt, S., & Vitu, F. (2014). Tests of a model of multi-word reading: Effects of parafoveal flanking letters on foveal word recognition. *Acta Psychologica, 146*, 35–40.

Grainger, J., Snell, J., & Beyersmann, E. (2021). Morphological processing in the flankers task. *Language, Cognition and Neuroscience, 36*, 288–295.

Green, P., & MacLeod, C. (2016). simR: An R package for power analysis of generalized linear mixed models by simulation. *Methods in Ecology and Evolution, 7*, 493–498.

Hasenäcker, J., Beyersmann, E., & Schroeder, S. (2020). Morphological priming in children: Disentangling the effects of school-grade and reading skill. *Scientific Studies of Reading, 24*, 484–499.

Hothorn, T., Bretz, F., & Westfall, P. (2008). Simultaneous inference in general parametric models. *Biometrical Journal, 50*, 346–363.

Lázaro, M., Illera, V., Acha, J., Escalonilla, A., García, S., & Sainz, J. S. (2018). Morphological effects in word identification: Tracking the developmental trajectory of derivational suffixes in Spanish. *Reading and Writing, 31*, 1669–1684.

Lefavrais, P. (1967). *Test de l'Alouette: Manuel*. Paris: Les éditions du Centre de psychologie appliquée.

Lété, B., & Fayol, M. (2013). Substituted-letter and transposed-letter effects in a masked priming paradigm with French developing readers and dyslexics. *Journal of Experimental Child Psychology, 114*, 47–62.

Lété, B., Sprenger-Charolles, L., & Colé, P. (2004). MANULEX: A grade-level lexical database from French elementary school readers. *Behavior Research Methods, Instruments, & Computers, 36*, 156–166.

Longtin, C. M., Segui, J., & Hallé, P. A. (2003). Morphological priming without morphological relationship. *Language and Cognitive Processes, 18*, 313–334.
Mathôt, S., Schreij, D., & Theeuwes, J. (2012). OpenSesame: An open-source, graphical experiment builder for the social sciences. *Behavior Research Methods, 44*, 314–324.
Marelli, M., & Luzzatti, C. (2012). Frequency effects in the processing of Italian nominal compounds: Modulation of headedness and semantic transparency. *Journal of Memory & Language, 66*, 644–664.
Ministère de l'Éducation nationale, de la Jeunesse et des Sports. (2020, July 30). *Le Bulletin officiel de l'Éducation nationale n°31 du 30 juillet.* Paris: République Française. https://www.education.gouv.fr/pid285/bulletin_officiel.html?pid_bo=39771.
Quémart, P., Casalis, S., & Colé, P. (2011). The role of form and meaning in the processing of written morphology: A priming study in French developing readers. *Journal of Experimental Child Psychology, 109*, 478–496.
R Core Team (2018). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.
Rastle, K. (2019). The place of morphology in learning to read in English. *Cortex, 116*, 45–54.
Rastle, K., & Davis, M. H. (2008). Morphological decomposition based on the analysis of orthography. *Language & Cognitive Processes, 23*, 942–971.
Rastle, K., Davis, M. H., & New, B. (2004). The broth in my brother's brothel: Morpho-orthographic segmentation in visual word recognition. *Psychonomic Bulletin & Review, 11*, 1090–1098.
Schiff, R., Raveh, M., & Fighel, A. (2012). The development of the Hebrew mental lexicon: When morphological representations become devoid of their meaning. *Scientific Studies of Reading, 16*, 383–403.
Snell, J., Bertrand, D., Meeter, M., & Grainger, J. (2018). Integrating orthographic information across time and space: A comparison of priming and flanker effects with orthographic neighbors. *Experimental Psychology, 65*, 32–39.
Snell, J., Cauchi, C., Grainger, J., & Lété, B. (2021). Attention extends beyond single words in beginning readers. *Attention, Perception, & Psychophysics, 83*, 238–246.
Snell, J., Declerck, M., & Grainger, J. (2018). Parallel semantic processing in reading revisited: Effects of translation equivalents in bilingual readers. *Language, Cognition and Neuroscience, 33*, 563–574.
Snell, J., & Grainger, J. (2019). Readers are parallel processors. *Trends in Cognitive Sciences, 23*, 537–546.
Snell, J., Meeter, M., & Grainger, J. (2017). Evidence for simultaneous syntactic processing of multiple words during reading. *PLoS One, 12*(3) e173720.
Snell, J., van Leipsig, S., Grainger, J., & Meeter, M. (2018). OB1-reader: A model of word recognition and eye movements in text reading. *Psychological Review, 125*, 969–984.
van Heuven, W. J., Mandera, P., Keuleers, E., & Brysbaert, M. (2014). SUBTLEX-UK: A new and improved word frequency database for British English. *Quarterly Journal of Experimental Psychology, 67*, 1176–1190.
Yarkoni, T., Balota, D., & Yap, M. (2008). Moving beyond Coltheart's *N:* A new measure of orthographic similarity. *Psychonomic Bulletin & Review, 15*, 971–979.
Ziegler, J. C., Bertrand, D., Lété, B., & Grainger, J. (2014). Orthographic and phonological contributions to reading development: Tracking developmental trajectories using masked priming. *Developmental Psychology, 50*, 1026–1036.