Applied Psycholinguistics (2024), **45**, 419–434
doi:10.1017/S0142716424000134

ORIGINAL ARTICLE

On the learning trajectory *of directional biases in reading:* Evidence from the flankers task

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(Received 6 March 2023; revised 6 December 2023; accepted 18 March 2024; first published online 22 April 2024)

Abstract
Prior research with adult participants reported a rightward bias in the reading version of the flankers task. Here, we investigated how this bias evolves as a function of reading expertise. We tested two groups of French primary school children from Cycle 2 (grades 1 and 2) and Cycle 3 (grades 4 and 5) and one group of adult participants. In the related flanker conditions, the central target word was flanked by the same word either on the left (park park ####), the right (#### park park), or on both sides (park park park). In the unrelated conditions, the repeated flanker words were replaced by a different unrelated word. In the analysis of standardized reaction times (RTs), there was a three-way interaction between the three groups of participants and the impact of flanker relatedness as a function of the position of the related flankers. This three-way interaction reflected the significantly greater increase in effects of flanker relatedness between Cycle 2 and Cycle 3 for the bilateral flanker and the right flanker conditions compared with the left flanker condition. This suggests that the rightward bias is driven by attentional asymmetries that develop during the process of learning to read.

Keywords: child typical language; flankers task; lexical processing; reading development; directional biases

Introduction

The flankers task, traditionally used to study visual and attentional processes in visual object identification (e.g., Eriksen, 1995), has been adapted as a tool for investigating the processes involved in reading multiple words (typically three: a central target word and two flanker words: e.g., Snell et al., 2017) or a single word target flanked by letters on either side (e.g., Dare & Shillcock, 2013; Grainger et al., 2014). Target and flanker stimuli are presented simultaneously for a brief duration (typically 150 ms with adult participants) in order to minimize eye movements, and participants are instructed to pay attention to and respond only to the central target stimulus. Research using the reading version of the flankers task has revealed that when flankers are letter sequences or pseudowords, the orthographic overlap (i.e., the number and the position of letters shared with the central target) determines whether or not flankers have an impact on central target word identification (typically in a lexical decision task). In the seminal study of Dare and Shillcock (2013), bigram flankers (e.g., RO ROCK CK) facilitated target identification relative to unrelated bigram flankers (e.g., BA ROCK TH) and equally so when flanker position was switched (e.g., CK ROCK RO). Using pseudoword flankers (e.g., RONE ROSE RONE), Cauchi et al. (2020) demonstrated that it was orthographic overlap that was critical for observing flanker effects compared with phonological overlap (e.g., ROZE ROSE ROZE), and work using word flankers has found effects of syntactic (Snell et al., 2017), semantic (Snell et al., 2018), and morphological (Grainger et al., 2021) relatedness.

This body of research has led to the conclusion that sublexical orthographic information is pooled across target and flankers (see Grainger et al., 2014, for an account, subsequently adopted in the OB1-reader computational model of word recognition and text reading: Snell, van Leipsig, et al., 2018) and that the identities of target and flanker words can be processed in parallel, hence enabling simultaneous access to the associated syntactic and semantic information (Snell et al., 2017; Snell, Decklerck, & Grainger, 2018). Together, this suggests that the reading version of the flankers task provides an interesting new window on how multiple word sequences are processed (see Snell & Grainger, 2019, for a summary of the arguments). Given that it is widely acknowledged that attentional biases operate during reading, with the bias operating to favor processing in the direction of reading (i.e., to the right in languages read from left to right; see Ducrot & Grainger, 2007, for a review), it is important to demonstrate that such attentional biases are also present in the reading version of the flankers task.

The issue of attentional biases in the flankers task was first investigated by Snell and Grainger (2018). The key conditions tested by Snell and Grainger were when the flanker was the same word as the target and appeared either to the left or to the right and either with no contralateral flanker or a different word in the contralateral flanker location. Flanker repetition to the right facilitated responses to central target words compared with repeated flankers on the left. In a second experiment, Snell and Grainger compared repeated flankers located to the left or to the right, with unrelated flanker words located to the left or to the right, and in both cases with no contralateral flanking stimulus. The effect of flanker relatedness (same word vs. different word) was significantly greater for rightward flankers than leftward flankers. Snell and Grainger concluded that there was a rightward bias in flanker effects obtained with linguistic stimuli (contrary to the leftward bias seen with nonlinguistic stimuli—e.g., Harms & Bundensen, 1983; Hommel, 2003) and that this bias was most likely attentional in nature, with an asymmetric attentional window extended in the direction of reading.

Evidence in favor of a directional bias in reading had already been obtained with eye-movement recordings during text reading supplemented by gaze-contingent manipulations of the information that is available to the right and to the left of the currently fixated word. For example, in the moving-window paradigm (McConkie & Rayner, 1976), participants read text through a window of variable size that moves with their gaze. Reading performance for manipulated text (i.e., where text outside of the window is modified: e.g., xxx quick brown fox jumps xxxx xxx xxxx xxx) is compared with reading performance for unmanipulated text (e.g., the quick brown fox jumps over the lazy dog). When the size of the moving window is smaller than the perceptual span, then reading is disrupted compared with regular text reading. Although estimates of the size of the perceptual span vary across studies (e.g., Jordan et al., 2014), it is a well-established fact that skilled readers capture more information from the parafovea and peripheral vision when this information is located in the direction of reading (see Rayner, 1998, for a review). These results have typically been interpreted as reflecting an endogenous attentional bias in the direction of reading that prepares readers for upcoming information, hence facilitating the processing of upcoming words, as reflected, for example, in parafoveal preview effects.

This reading-direction attentional bias has also been studied in developing readers using the moving-window paradigm (e.g., Häïkïo et al., 2009; Rayner, 1986; Sperlich et al., 2015). The results of these studies clearly show that the rightward extent of the perceptual span increases during primary education to reach a maximum in adult readers. Closer to the present study is the work of Khelifi et al. (2015, 2017). These authors used a simplified parafoveal priming paradigm, where central target words were preceded by briefly presented primes in the left or right parafovea. The previews were either the same word as the target, words sharing letters with the target word, or unrelated words. Preview priming effects were observed in grade 3, grade 5, and adult participants, with a greater benefit for the identical preview condition found with adults. In terms of the critical effect of reading-direction bias (i.e., greater effects of rightward previews compared with leftward previews), this was more pronounced in grade 5 and adult participants. This prior research therefore points to the development of a reading-direction bias in attentional deployment during the process of learning to read.

In the present study, we use the flankers task in a further developmental investigation of attentional biases during the course of learning to read. Prior work has shown that the performance of beginning readers is influenced by flanker stimuli (Cauchi et al., 2022; Snell et al., 2021). What we do not know is whether the youngest readers show attentional biases in flanker effects, as has been found with adult participants (Snell & Grainger, 2018; Snell, Mathôt, et al., 2018). The goal of the present study was therefore to examine the learning trajectory of such directional biases in the reading version of the flankers task.[1] To do so, we manipulated flanker relatedness (same word as the target vs. different word) and the position of flanker words (left of targets, right of targets, or on both sides—the bilateral flanker condition). Strings of hashtags (####) matched in length to the flanker words were presented at the contralateral location in order to minimize the impact of exogenous attention (i.e., single flankers attracting attention with potential biases in how these exogenous attentional influences operate). In other words, the use of hashtag flankers was aimed at minimizing the impact of low-level attentional factors that are not related to reading. The effects of flanker relatedness and flanker position were studied in three groups of participants comprising children from the two main cycles of post-kindergarten primary education in France: Cycle 2 (grades 1–3) and Cycle 3 (grades 4 and 5) and a group of adult participants. The reason for grouping multiple grades within the cycles defined by the French educational system was twofold. First, this approach follows our previous research employing the flankers task with children (Cauchi et al., 2022). Second, several studies point to a notable shift in reading-related attentional biases between grades 3 and 5 (Khelifi et al., 2015, 2017) and also a notable increase in the perceptual span in grade 4 children (e.g., Häïkïo et al., 2009; Rayner, 1986). These findings provide empirical support for our decision to set a boundary between grades 3 and 4.

The main hypothesis to be tested in the present study is derived from the work of Snell and Grainger (2018). If, as conjectured by these authors, directional biases observed in the flankers task are driven by reading direction impacting the distribution of spatial attention, then one would expect the biases to increase as reading expertise develops. As noted above, prior research with primary school children suggests that this hypothesized change should first be obvious between grades 3 and 4. So the key research question to be addressed in the present work is how the deployment of spatial attention might be affected by reading direction, as suggested in earlier work with adult readers, and how attentional deployment might therefore evolve as a function of exposure to print and reading expertise. The potential applications of the results of the present study concern an improved integration of attentional considerations when developing methods for teaching reading and also for remediation techniques for reading-disabled persons.

Methods

Participants

A total of 56 adults (46 females), all students at Lyon 2 University in France and ranging in age between 18 and 29 years (mean age = 20 years 5 months; SD = 2 years 7 months), gave informed consent to participate in this study. Adults performed the task individually in a quiet experimental room. In addition, a total of 179 primary school children from two public primary schools in Lyon (grade 1 = 23 [7 girls, 16 boys], grade 2 = 58 [31 girls, 27 boys], grade 4 = 46 [28 girls, 18 boys], and grade 5 = 52 [27 girls, 24 boys]) were recruited in this study. They were tested in a quiet room in their school. Two groups of children were formed for statistical analysis using two of the four teaching cycles in primary education in France—Cycle 2 and Cycle 3 (see Cauchi et al., 2022 for a previous application of this grouping in terms of cycles). The resulting two groups of children were formed by combining grades 1 and 2 (N = 81) and grades 4 and 5 (N = 98) (i.e., the first two grades of each cycle). It is important to note that grade 3 children were not tested in order to avoid a reading age overlap between Cycle 2 and Cycle 3.[2] The reading age of each child was measured using the Alouette reading test (Lefavrais, 1967) that provides a reading age in months.[3] All children with a reading age that did not correspond to the expected grade were not retained for analysis.[4] Applying this criterion, 70 children were not retained for analysis (grade 1 = 11, grade 2 = 10, grade 4 = 27, and grade 5 = 22). Children's reading age (RA) therefore closely matched their chronological age (CA) in each group (Cycle 2: mean CA = 90 months [range = 73–105], mean RA = 96 months [range = 83–125]; Cycle 3: mean CA = 125 months [range = 106–143], mean RA = 130 months [range = 110–171]). Data from participants who performed below 60% were not

Table 1. Examples of targets (center) and flankers in the six experimental conditions

	Flanker position		
Relatedness	Left	Bilateral	Right
Related	park park ####	park park park	#### park park
Unrelated	nose park ####	nose park nose	#### park nose

retained for analysis (grade 1 = 16, grade 2 = 11, and grade 5 = 1). See Appendix A for details of the selection of participants retained for analysis on the basis of performance on the main task (flanked lexical decision) and their score on the Alouette test. All child 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 participant's caregiver prior to experimentation and after the caregiver had explained the experiment to the child. Ethics approval for this study was granted by the *Comité de Protection des Personnes SUD-EST IV* (No. 17/051).

Stimulus selection and materials

We first selected a set of 120 target-flanker word pairs that served for the unrelated conditions (in the related conditions targets and flankers were the same word). All these words were selected from the Manulex lexical database (Lété et al., 2004). They were four letters long and did not contain any letter repetitions (e.g., *bébé*, *papa*) since letter repetition is known to affect word recognition (Kerr et al., 2021; Trifonova & Adelman, 2019). Moreover, given that the role of diacritics in reading is still poorly understood in adults and even less so in children, we chose not to include words with diacritics in this study. This also has the advantage of facilitating the comparison of our results with those obtained with languages that do not use diacritics. According to the Manulex corpus, the selected words should be known by 1st graders (meaning that these words are regularly encountered in the books used to teach reading in 1st grade). Word frequency was transformed into Zipf values (van Heuven et al., 2014). The average frequency was 6.07 (range = 5.15–7.94) for the target words and 5.89 (range = 4.41–7.77) for the unrelated flanker words. None of the words in the unrelated target-flanker pairs were orthographically or semantically related. A set of 120 nonword pairs was generated using the Wuggy pseudoword generator (Keuleers & Brysbaert, 2010) and was used to create the unrelated flanker condition for nonword targets (related flankers were the same nonword as targets). As with the word stimuli, none of the nonwords in the unrelated target-flanker pairs were orthographically related. Nonwords were included for the purpose of the lexical decision task and were not included in the analyses.

The factorial combination of two within-participant factors—flanker relatedness (related, unrelated) and flanker position (left, bilateral, right)—generated six experimental conditions (see Table 1 for a description of these six conditions). Each group of participants (Cycle 2, Cycle 3, and adults) was tested with these six conditions leading to a 2 X 3 X 3 design. Flanker words/nonwords could appear to

https://doi.org/10.1017/S0142716424000134 Published online by Cambridge University Press

Figure 1. Description of the procedure with an example of a related flanker in the rightward position with the stimulus duration used for child participants. After 1000 ms, the fixation cross disappeared, and the target (on fixation) and flankers were displayed onscreen for 300 ms and centered with respect to the vertical fixation bars. There was a time-out of 5 sec to give a lexical decision response before the next trial was initiated.

the left or to the right of the target, with a four hashtags string (####) appearing at the same time in the contralateral location or could appear both to the left and to the right of the target (referred to as the "bilateral" condition). A Latin-square design was used with six experimental lists such that participants saw each target once only in one of the six conditions. All target words were tested in all conditions across the participants. There were 40 items (20 words, 20 pseudowords) per condition per participant. The 240 trials were allocated in 10 blocks. Items and blocks were presented in randomized order. The complete set of word stimuli is provided in Appendix B and the complete set of materials and data at https://osf.io/py2bk/ (URL at the Open Science Framework, OSF).

Apparatus and software

The experiment was implemented with OpenSesame (Mathôt et al., 2012). Stimuli were presented on a DELL Latitude 3400 monitor calibrated in 14-inch (1366 × 768 px, 80 Hz). Participants were seated at approximately 50 cm from the display. Stimuli were displayed in lower case, in Courier New font (monospace), in black on a light gray background. From a viewing distance of 50 cm, each character subtended 0.33 degrees of visual angle.

Procedure

The procedure for a single trial is depicted in Fig. 1. Each trial started with a 1000 ms centralized fixation cross bounded by vertically aligned bars. The target and flanking stimuli were then presented for a duration depending on the participant's group (300 ms for children and 170 ms for adults). Participants had a maximum of 5000 ms to make their lexical decision with a right- ("*m*") or left-handed ("*q*") button press (azerty keyboard layout) for, respectively, word and nonword targets. The response was followed by a 1000 ms empty blank screen preparing the next trial. The trials were subdivided into 10 blocks of 24 trials randomly presented. To avoid fatigue, a break was offered in between blocks. The total duration of the experiment was about 20 min for adults and 25–35 min for children. Children were tested with the Alouette reading test that lasted about 3 min before performing the main task, and all testing took place in a quiet room in the school where the children were tested two at a time.

https://doi.org/10.1017/S0142716424000134 Published online by Cambridge University Press

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 simR package (Version 1.0.5; Green & MacLeod, 2016). The bilateral related versus bilateral unrelated contrast was targeted in this analysis using the observed size of the flanker relatedness effect in RTs in the groups of participants (40 ms in the adult group and 68 ms in the children group). 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 50% reduced sample from the original dataset (i.e., 60/120 items to 28/56 participants from the adult group and 90/179 participants in the children group dataset). In this way, the estimated statistical power was 88.8% in the adult group and 85.5% in the children group. Considering the standard of 80%, we reckoned to have sufficient power in this study.

Results

The data for target words were analyzed using the R statistical computing environment (R Core Team, 2018). In order to avoid over-additive effects due to differences in average RT across groups (Faust et al., 1999), and in order to normalize the RT distributions, the raw RT data of each participant were standardized using a *z*-score transformation (see Cauchi et al., 2022; Lété & Fayol, 2013; Ziegler et al., 2014, for examples of this approach). For *z*-score analyses, linear mixed-effects models were fitted (Baayen, 2008) using the *lmer* function from the lme4 package (Version 1.1–21, Bates et al., 2014) including both the participant and item factors as random effects. The between-group analyses consisted of a full model with relatedness (related or unrelated), flanker position (left, right, bilateral), and group (Cycle 2, Cycle 3, adults) as fixed factors and z-score of logarithmic RT as a continuous variable in which the maximal random effects structure that converged was used (Barr et al., 2013). The significance of the fixed effects was determined with a type III Wald chi-square test using the *Anova* function from the car package (Version 3.0–8, Fox & Weisberg, 2011). 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 the *z*-score analyses, except that the accuracy variable was coded as a binomial response with 1 for a correct response and 0 for an error. For all significant three-way interactions, follow-up analyses were carried out by testing the relatedness by group interaction at each level of the flanker position factor.

Standardized RT analyses

Prior to the *z*-score transformation, all trials with RTs shorter than 300 or longer than 3000 ms (Cycle 2 = 8.4%, Cycle 3 = 1.4%, adults = 1.2%) were excluded. Furthermore, for each group of participants, a null model with a random structure including by-participant and by-item random intercepts was fitted in order to compute standardized residuals from the RTs. All trials with standardized residuals larger than 2.5 standard deviations were excluded (Cycle 2 = 2.9%, Cycle 3 = 2.9%, adults = 2.6%). Incorrect responses were also excluded from the RT analyses (Cycle 2 = 22.3%, Cycle 3 = 9.8%, adults = 4.6%). Condition means of raw RTs and accuracy are provided in Table 2.

The effects of flanker relatedness (in standardized RTs) per flanker position and group are shown in Fig. 2. For the three-way interaction model, the maximal converging random effect structure was one including by-participant random intercept and by-item random intercept and slope among both the flanker relatedness and flanker position. The model formula is the following:

$$\text{z-score(RTs)} \sim \text{Relatedness} \times \text{Position} \times \text{Group} + (1|\text{participant}) + (1 + \text{Relatedness} \times \text{Position}|\text{item})$$

In this model, the main effects of flanker position and flanker relatedness were significant (χ^2 [2] = 12.44, $p < .01$; χ^2 [1] = 152.11, $p < .001$, respectively). The main effect of group was not significant (χ^2 [2] = 4.39, $p > .10$), as to be expected when analyzing normalized RTs. The flanker position by flanker relatedness interaction was significant (χ^2 [2] = 44.37, $p < .001$), with the strongest effects of flanker relatedness in the bilateral flankers condition, followed by the right position and finally the left position. The flanker relatedness by group interaction was also significant (χ^2 [2] = 48.35, $p < .001$), with greater effects of flanker relatedness in the older children of Cycle 3 and in adults. Crucially, the three-way flanker position by flanker relatedness by group interaction was significant (χ^2 [4] = 9.87, $p < .05$). As can be seen in Fig. 2, the increase in effects of flanker relatedness from Cycle 2 to Cycle 3 was much greater for the bilateral and the right position conditions compared with the left condition. Follow-up analyses testing for the flanker relatedness by group interaction as a function of flanker position revealed that the interaction was not significant for the left position (χ^2 [2] = 5.34, $p = .07$). On the other hand, the interaction was significant for the bilateral flankers (χ^2 [2] = 33.99, $p < .001$) and for right flankers (χ^2 [2] = 15.32, $p < .001$).

Accuracy analyses

The effect of flanker relatedness for accuracy rates per flanker position and group is shown in Table 2. For the three-way interaction model, the maximal converging random effect structure was one including by-participant and by-item random intercepts. The model formula is the following:

$$\text{Accuracy} \sim \text{Relatedness} \times \text{Position} \times \text{Group} + (1|\text{participant}) + (1|\text{item})$$

The main effects of flanker relatedness and group were significant (χ^2 [1] = 51.62, $p < .001$; χ^2 [2] = 262.70, $p < .001$, respectively) with higher accuracy in the related flanker conditions and increasing accuracy with age. The main effect of flanker position was not significant (χ^2 [2] = 0.70, $p > .10$). No interaction effects were significant in this analysis.

https://doi.org/10.1017/S0142716424000134 Published online by Cambridge University Press

Table 2. Mean RTs (in milliseconds) and accuracy (probabilities) for word targets in each of the experimental conditions and for the three groups of participants

		RTs/relatedness			Accuracy/relatedness		
	Flanker position	Related	Unrelated	Δ (signif.)	Related	Unrelated	Δ (signif.)
Cycle 2 (n = 81)	Left	1302 (*324*)	1310 (*315*)	8 (*ns*)	.79 (*.11*)	.78 (*.13*)	.01 (*ns*)
	Bilateral	1302 (*345*)	1334 (*307*)	32 (*)	.81 (*.11*)	.75 (*.14*)	.06 (***)
	Right	1295 (*321*)	1316 (*311*)	21 (*ns*)	.78 (*.12*)	.73 (*.15*)	.05 (***)
Cycle 3 (n = 98)	Left	864 (*138*)	904 (*163*)	60 (***)	.91 (*.08*)	.89 (*.12*)	.02 (***)
	Bilateral	841 (*127*)	940 (*166*)	99 (***)	.93 (*.08*)	.88 (*.11*)	.05 (***)
	Right	854 (*140*)	913 (*142*)	59 (***)	.92 (*.07*)	.88 (*.13*)	.04 (***)
Adults (n = 56)	Left	609 (*64*)	618 (*66*)	9 (*)	.96 (*.04*)	.95 (*.07*)	.01 (*ns*)
	Bilateral	603 (*58*)	643 (*66*)	40 (***)	.96 (*.06*)	.95 (*.05*)	.01 (*ns*)
	right	601 (*61*)	632 (69)	31 (***)	.97 (*.04*)	.95 (*.07*)	.02 (*ns*)

Note. Standard deviations in parentheses. Relatedness effects (unrelated–related) and their significance (in parentheses) are provided after the condition means of the relatedness factor. Significance levels:
$^{***}p < .001$, $^{**}p < .01$, $^{*}p < .05$, and $^{ns}p > .10$. Flanker position refers to the position of the related flanker(s).

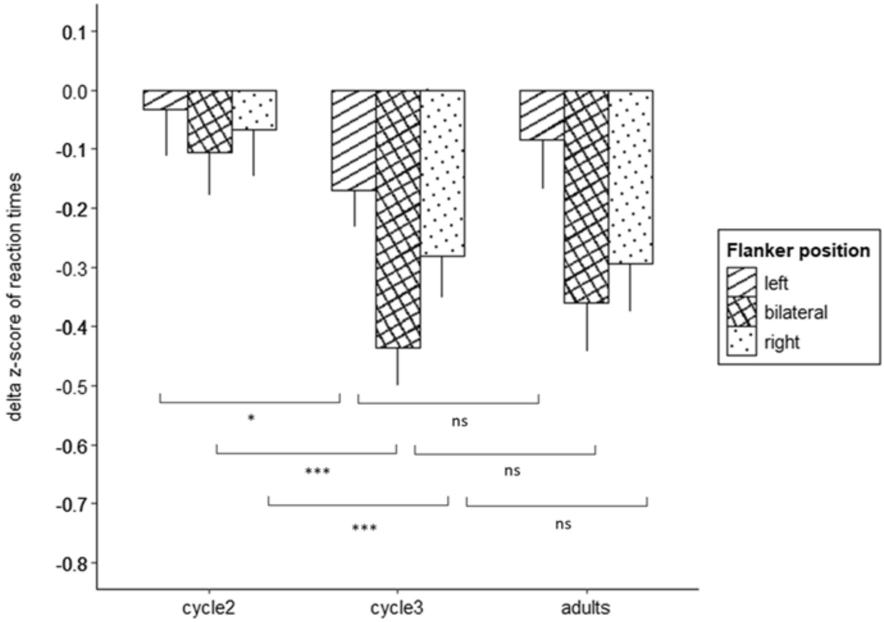

Figure 2. Differences (Δ) expressed in *z*-score values between the two flanker relatedness levels (related minus unrelated) for each flanker position (left, bilateral, right) and for each group (Cycle 2, Cycle 3, adult). Significance brackets correspond to pairwise flanker relatedness by group interactions (Cycle 2 vs. Cycle 3; Cycle 3 vs. adults) for each flanker position. Significance levels: $^{***}p < .001$, $^{**}p < .01$, $^{*}p < .05$, and $^{ns}p > .10$. Error bars are the within-participant 95% CIs (Cousineau & O'Brian, 2014).

Discussion

Prior research with adult participants reported a rightward bias in the reading version of the flankers task (Snell & Grainger, 2018). Word flankers located to the right of central target words had a bigger impact on target word processing (i.e., a greater effect of target-flanker relatedness) than flankers located to the left. Here, we investigated the learning trajectory of this bias. We tested one group of adult participants and two groups of French primary school children from the "Fundamental Learning Cycle" (Cycle 2: 1st and 2nd grades) and "Consolidation Learning Cycle" (Cycle 3: 4th and 5th grades) in primary education in France. In the related conditions, the central target word was flanked by the same word either on the left (park park ####), on the right (#### park park), or on both sides (park park park). In the unrelated conditions, the related flankers were replaced by a different unrelated word.

In an analysis of standardized RTs (*z*-score transformation), we found a significant three-way interaction between flanker relatedness, the position of the related flankers, and the three groups of participants. Effects of flanker relatedness did not significantly vary as a function of reading expertise in left flanker condition. On the other hand, in the bilateral and right position conditions, there was a significant increase in effects of flanker relatedness as reading expertise increased, which was mostly evident when comparing the two groups of children (see Fig. 2). Thus, when there was a related flanker located to the right of targets (i.e., in the bilateral and the right position conditions), then effects of flanker relatedness increased significantly across the two groups of children (grades 1 and 2 vs. grades 4 and 5). However, we note that the mean raw RTs per condition, presented in Table 2, reveal a slightly different pattern. That is, the increase in effects of flanker relatedness between Cycle 2 and Cycle 3 was comparable for the left and right flanker positions, with the bilateral condition generating the strongest effects in both groups. The emergence of a rightward bias in the raw RTs was only evident in the comparison of Cycle 3 and adults, where there was a greater decrease in the effects of flanker relatedness for flankers in the left position. Nevertheless, it is clear from both the analysis of standardized RTs and the examination of raw RTs that the rightward bias in effects of flanker relatedness does develop as reading expertise increases. These results confirm the interest of using a z-score transformation of RTs to reveal differences in effects of a given variable on RTs across groups that exhibit large individual differences in average RT (Cauchi et al., 2022; Lété & Fayol, 2013; Ziegler et al., 2014).

The reading-related attentional bias account of previous findings (Snell & Grainger, 2018) predicted that the rightward bias should increase as reading expertise increases. Our findings are in line with this account since we found an increase in the rightward flanker bias (i.e., greater effects of flanker relatedness for rightward and bilateral flankers) with increasing reading expertise. Moreover, there were no significant changes in effects of flanker relatedness for leftward flankers across the three reading-level groups. On the other hand, the effects of flanker relatedness for rightward and bilateral flankers increased from Cycle 2 to Cycle 3 and then remained stable. In Cycle 2, the effects of flanker relatedness did not depend on flanker position, whereas they did in Cycle 3 and adults. In Cycle 3, bilateral flankers generated the greatest effects, followed by the right flanker condition and then the left flanker condition. In the adult group, bilateral flankers and right flankers produced the greatest facilitation and did not differ significantly. This is clear evidence that the rightward bias seen in prior work with the flankers task and adult participants (Snell & Grainger, 2018) requires a minimum amount of reading expertise to emerge.

The results of the present study therefore align with the results of prior developmental work using gaze-contingent manipulations with eye-movement recordings (e.g., Haïkïo et al., 2009; Rayner, 1986; Sperlich et al., 2015) or a parafoveal priming paradigm (Khelifi et al., 2015, 2017). These studies revealed that an increase in rightward biases accompanied an increase in reading expertise. For example, the Häïkïo et al. study reported that for 2nd graders, the perceptual span extends at least to the end of the currently fixated word and sometimes (when fixating a short word) to the beginning letters of the following word. For 4th graders, the perceptual span extends approximately seven characters to the right of fixation, whereas 6th graders and adult participants both showed a perceptual span that extended approximately nine characters to the right of fixation. Moreover, the present results provide support for the proposal of Khelifi et al. (2015) that attentional biases, thought to be responsible for the rightward asymmetry seen in sentence reading (in languages read from left to right), may be less pronounced in isolated word recognition and especially in young readers with fewer than 3 years of reading instruction.

https://doi.org/10.1017/S0142716424000134 Published online by Cambridge University Press

Finally, the present work provides a further demonstration that the reading version of the flankers task provides a reasonable, albeit highly simplified, approximation to the conditions of regular text reading. Our results provide support for the proposal (Snell et al., 2021) that the flankers task can be usefully applied to study attentional deployment in beginning readers and furthermore provides a sensitive measure of changes in such attentional deployment as a function of reading expertise. The advantage of the flankers task compared with parafoveal priming, for example, is that it captures spatial integration processes that operate when multiple words are presented simultaneously, as we believe is the case during regular text reading. Moreover, there are obvious advantages in using simplified reading paradigms when testing beginning readers, and we suspect that the flankers task holds great promise in this respect. Such simplified reading paradigms could be usefully employed in larger-scale studies of reading development, the results of which could motivate changes in the methods used to teach reading in primary school children and, crucially, help those children who have difficulties with this essential learning process.

Conclusions

In the present study, we investigated changes in reading-direction attentional biases as a function of reading expertise using the reading version of the flankers task. We tested two groups of children and one group of adults in conditions where related flankers could either be located to the left, to the right, or on both sides of the central target word. The left and right flanker conditions had a string of hash marks (####) on the contralateral side in order to control for exogenous attention. We found an increase in effects of flanker relatedness in the right flanker and bilateral flanker conditions. We interpret this pattern as reflecting a change in reading-direction attentional biases during the course of learning to read, and we further conclude that the flankers task provides an easy-to-use simplified multi-word reading task that mimics the conditions of regular text reading.

Replication package. Scripts of the data analyses presented in the present work are available at https://osf.io/py2bk/.

Data availability. The dataset used to conduct the statistical analyses, the complete list of stimuli, and all model outputs are available at https://osf.io/py2bk/ (Anonymized URL at the Open Science Framework, OSF).

Competing interests. The authors declare none.

Ethics approval. Ethics approval for this study was granted by the *Comité de Protection des Personnes SUD-EST IV* (No. 17/051).

Notes

1 Although the reading version of the flankers task has been criticized for not reflecting a natural reading situation, as in all fields of experimental psychology, simplified paradigms enable a more stringent control over experimental manipulations, and the observed findings can then be related to what is known to occur in more naturalistic settings. We return to this issue in the Discussion.

2 According to an official document published by the French Ministry of Education, Cycle 2, referred to as the "Fundamental Learning Cycle," is considered to be the first stage of compulsory schooling for pupils (after kindergarten). It covers the first 3 years of primary school (1st to 3rd grades, age 6–8 years). Cycle 3, referred to as the "Consolidation Cycle," aims to reinforce the basic knowledge acquired in Cycle 2. It covers the last 2 years of primary school (4th and 5th grades, age 9–11 years) and the first year of secondary education (6th grade, age 11–12 years).

3 The Alouette reading test is considered to be a sensitive screening tool for children and adults with dyslexia (Cavalli et al., 2018), and this test is still widely used to detect reading impairments. The norms from Lefavrais (1967) are still considered to be the best measurement given the large sample sizes on which these norms are based.

4 We insist on the importance of this selection procedure since it enables a conjoint control over reading level and the type of reading instruction received by the different groups of children, hence greatly reducing the noise that is typical of data collected with child participants. Although for ethical reasons all children were tested on the main experiment independently of their score on the Alouette test, this exclusion criterion was determined prior to the experiment, following the example of Cauchi et al. (2022).

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Appendix A

Initial sample sizes and samples remaining after the removal of participants performing below 60% on the lexical decision task and having a reading level (RL) lower than that expected for their learning cycle.

Cycles	Grades	Initial sample size	Accuracy < .60	Cycle–RL matching	Remaining sample size
Cycle 2	Grade 1	50	16	11	23
	Grade 2	79	11	10	58
					81
Cycle 3	Grade 4	73	0	27	46
	Grade 5	75	1	22	52
					98

Appendix B

List of target words and unrelated flankers

Target word	Unrelated flanker	Target word	Unrelated flanker	Target word	Unrelated flanker
abri	muet	face	brun	oser	taxi
agir	cent	faim	cour	pain	trou
aide	mort	fait	rose	parc	kilo
aise	thon	faux	gris	peur	dont
ange	rhum	fier	clou	pied	haut
arme	foin	film	cher	pile	mars
aube	porc	fond	lait	plat	doux
auto	ciel	fort	bleu	poil	neuf
avec	nous	fuir	base	pois	date
bain	tuer	gare	soin	puce	rail

(*Continued*)

https://doi.org/10.1017/S0142716424000134 Published online by Cambridge University Press

(*Continued*)

Target word	Unrelated flanker	Target word	Unrelated flanker	Target word	Unrelated flanker
beau	gros	gras	menu	puis	dent
bien	star	grue	paon	quoi	lent
bond	rime	hier	sauf	rage	poli
bord	tige	hors	cave	rame	pion
boue	mari	joie	plan	rien	coup
bout	cinq	joue	avis	rive	saut
bref	paix	jour	chat	robe	huit
cage	nord	judo	file	rond	aile
camp	sien	juge	stop	roue	banc
cape	unir	jupe	soit	rude	golf
case	four	lame	truc	ruse	laid
cela	soir	lave	crin	sage	noix
cerf	sain	leur	fois	sale	chou
chef	part	lieu	gant	seau	brin
chez	bois	loin	bras	sept	bouc
clef	rang	loup	vert	tard	lion
code	aigu	main	seul	tien	lard
coin	peau	mais	quel	tour	page
cube	ravi	mare	juin	tube	pris
cuir	mets	miel	roux	type	soif
dame	fils	mien	lors	veau	mont
dans	pour	mine	bloc	vent	joli
date	houx	mise	azur	venu	gars
demi	sort	mode	sang	vers	nuit
deux	voir	mois	lune	vide	port
dieu	pont	mule	faon	vite	ours
dire	plus	nage	loir	voix	gens
donc	pays	noir	vase	vous	haie
drap	onze	note	prix	yeux	long
dune	oral	ogre	vain	zone	club

Cite this article: Cauchi, C., Grainger, J., & Lété, B. (2024). *On the* learning trajectory *of directional biases in reading*: Evidence from the flankers task. *Applied Psycholinguistics* **45**, 419–434. https://doi.org/10.1017/S0142716424000134