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Review article / Обзорная статья

Eye Movements During Reading in Bilingual Primary School Children: a Scoping Review

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Abstract. There is a growing interest in the reading development of bilingual children. Surprisingly, however, little research has been conducted on bilingual children's reading acquisition and development. This scoping review synthesized the findings of existing studies on bilingual primary school childrens' eye movements during reading and outlined future research directions. In the review, we mapped the differences between monolingual and bilingual children's eye movements during reading, as well as the differences in bilingual children's eye movements during reading in their first (L1) and second (L2) languages. Additionally, we summarized the factors shown to influence monolingual and bilingual children's eye movements during reading. These factors fell into two categories: linguistic and language-related factors, and factors related to individual differences. The results of the review revealed that differences — or the absence thereof — in the eye movements of bilingual and monolingual readers, as well as the variations in bilingual children's reading in L1 and L2, are influenced by a variety of individual and language-related factors. However, due to the scarcity of existing studies, no definitive conclusions can be drawn at this time. Further eye-movement research is needed to shed light on the reading development of bilingual children.

Keywords: eye-tracking, reading development, primary school students, L1 reading, L2 reading

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Движения глаз во время чтения у детей-билингвов, обучающихся в начальной школе: обзор предметного поля

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Аннотация. Несмотря на возрастающий интерес исследователей к развитию навыков чтения у детей-билингвов, работ, посвященных изучению этого феномена, достаточно мало. В данном обзоре обобщены результаты существующих исследований движений глаз во время чтения у детей-билингвов, обучающихся в начальной школе. В обзоре описаны различия в движениях глаз во время чтения монолингвальных и билингвальных детей, а также различия в движениях глаз у детей-билингвов во время чтения на первом и втором языках. Кроме того, в обзоре систематизированы факторы, влияющие на движения глаз детей во время чтения. Такие факторы подразделяются на две категории: лингвистические факторы (в том числе кросс-лингвистические) и факторы, связанные с индивидуальными различиями. Результаты обзора показали, что на различия или их отсутствие в движениях глаз во время чтения у детей-билингвов и детей-монолингвов, а также на различия в чтении у детей-билингвов на первом и втором языках, оказывает влияние ряд индивидуальных и лингвистических факторов. Среди индивидуальных факторов были рассмотрены такие, как показатели беглости чтения, объем словарного запаса и уровень развития синтаксических навыков. Влияние лингвистических факторов на стратегии чтения осуществляется на различных языковых уровнях, которые включали лексический, словообразовательный, синтаксический и формальный орфографический уровни языка. Кроме того, была рассмотрена роль межъязыковых факторов в формировании паттернов движения глаз. Однако из-за малого количества существующих исследований на данный момент нельзя сделать более систематизированные выводы. Для этого необходимы дальнейшие исследования движения глаз во время чтения у детей-билингвов.

Ключевые слова: айтрекинг, навыки чтения, чтение на первом языке, чтение на втором языке

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Introduction

Reading is a fundamental process that plays an important role in communication, education, and personal development. It is a crucial cognitive skill taught during the preschool and primary school years. Reading is arguably one of the most essential neurocognitive skills that children acquire. In fact, it is closely associated with their academic achievements [1; 2] and further well-being in life [3]. An extensive body of research has examined reading in children, focusing on various

questions such as reading-related skills, reading comprehension [4–6], reading difficulties [7; 8]. However, extant research on reading has mostly investigated reading in monolinguals. Meanwhile, a large portion of the global population are bilinguals or multilinguals, with many individuals learning to read in two or more languages simultaneously [9; 10].

When acquiring reading skills, bilingual children can exhibit different reading profiles. According to Shakory and colleagues [11], bilingual children can fall into one of the following profiles: typical readers who progress well in both languages; readers who experience difficulties in both languages; readers who have difficulties in their first language (L1); and readers who have difficulties in their second language (L2). For the successful development of reading skills in both languages, it is important to understand the underlying processes and factors that influence them. Understanding the specific characteristics of bilingual reading will enable the identification and addressing of difficulties that may arise during the development of reading skills in bilingual children at early stages.

Studies on the reading processes of both monolingual and bilingual children have mostly been conducted using behavioral methods [12]. Behavioral methods provide information on reading-related skills such as phonological awareness, decoding, grapheme-phoneme correspondences, reading speed, vocabulary size, and reading comprehension, as well as insights into whether readers experience reading-related difficulties. However, these methods do not capture the more specific details underlying the reading process. Such detailed information can be captured using advanced methods, among which eye-tracking is one of the most widely used.

Eye-tracking, as an online method, provides enhanced precision and accuracy in data collection, encompassing a range of metrics. During reading, the eyes engage in fixations and saccades as they progress through the text. As one of the fundamental components of eye movement, a fixation occurs when the eyes remain relatively stable, allowing the visual system to process information from a specific locus in the visual field. Conversely, a saccade represents a rapid ocular movement that shifts focus from one point to another [13]. In the context of reading research, eye movements can be categorized into local and global measures, corresponding to the word and text levels, respectively. Furthermore, eye movements can delineate and segment cognitive processes during reading into distinct stages, which can be investigated using local-level measures: early (e.g., first fixation duration) and late (e.g., regressions).

There is a substantial body of eye-tracking research on reading in monolingual children. This research reveals how children process information at different developmental stages and how eye movements differ from adult reading [14–16]. For example, it has been established that children's reading is characterized by long fixations and short saccades, while adults make more regression saccades but have shorter fixations and faster reading speeds. Differences in reading between adults and children, however, decrease as children's reading skills improve with age, reaching adult-like reading patterns

at approximately 11 or 12 years [15–18]. However, research on eye movements during reading in bilingual primary school children remains significantly underexplored. This leaves the question of differences in eye movements between monolingual and bilingual children unresolved [12]. Consequently, this review aims to synthesize existing studies on eye movements in bilingual children during reading, with a focus on elucidating the distinctions between monolinguals and bilinguals, between bilinguals' L1 and L2, as well as the factors that may influence these differences.

Methods

Methodological framework

The scoping review followed the methodological framework proposed by Arksey and O'Malley [19] and was structured using the PRISMA-ScR guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews) [20]. The Nested Knowledge AutoLit semi-automated systematic review platform [21] was employed for duplicate removal and double screening of Abstracts.

Identifying the research question

The main research question of this scoping review was: "What evidence exists regarding the differences in eye-movements between monolingual and bilingual primary school children during reading?" Three specific research questions were:

1. What are the differences between monolingual and bilingual children's eye movements during reading?
2. What are the differences between bilingual children's eye movements during reading in their L1 and L2?
3. What factors underlie the identified differences in eye movements of bilingual and monolingual readers, as well as the eye movements of bilinguals when reading in L1 and L2?

Search strategy

Published studies were systematically identified through searches in three electronic databases: PubMed; Scopus, and Web of Science. The search strategy was built around four key concepts: (1) *eye-movements* (eye movements, eye-movement measures, eye-tracking, eye-tracker), (2) *primary school children* (children, schoolchildren, primary school, elementary school), (3) *reading*, and (4) *bilingualism* (bilingual, second language, multilingual, heritage).

Selection of studies

Inclusion criteria. Studies meeting the following inclusion criteria were selected for this review: (1) Studies examine primary school children. School grades may vary depending on the educational systems of the countries where the research was conducted; (2) Studies investigate reading processes; (3) Studies employ the eye-tracking technique and investigate eye-movement measurements.

Exclusion criteria. Studies meeting the following criteria were excluded from the review: (1) Studies focus on clinical populations, such as children with developmental language disorders, dyslexia, reading impairments, autism, or ADHD. However, if the sample included a normotypical control group, the study was included; (2) Studies examine non-primary school children; (3) Studies address irrelevant topics (e.g., writing, oral comprehension, and etc.).

Screening strategy

All extracted articles were imported into the Nested Knowledge AutoLit platform to automatically remove duplicates. Two independent reviewers conducted a double screening of the titles and Abstracts of potentially relevant articles according to the inclusion and exclusion criteria on the same platform. The inter-rater reliability agreement between the reviewers during the Abstract screening was 69%. Disagreements were further discussed until the reviewers reached a consensus. Full-text copies of the articles were then obtained and double-screened based on the eligibility criteria. The inter-rater reliability agreement at the full-text screening stage was 82%. Any disagreements regarding article eligibility were resolved through discussion. A PRISMA flow diagram (Figure 1) summarizes the selection process, showing the number of records identified, included, and excluded along with the reasons for exclusions.

Data extraction

To chart the data and maintain records of the extracted studies, a customized digital spreadsheet-based table was developed to meet the needs of this review. A pilot data extraction was conducted prior to its full implementation. Data charting was carried out by three independent reviewers, who discussed any disagreements to reach a final decision. The extracted data includes information on: (1) bibliography including authors, titles, year of publication, and journal; (2) study aim, hypotheses and/or research question (s); (3) participants' information including sample size, average age, grade, sex, languages spoken, L1 and L2 age of acquisition, country of residence; (4) study design including battery of measures, eye-movement measures, stimuli type, and equipment used; (5) study results including methods used for data analysis, brief results and key findings' description; (6) study limitations and future directions. The full table of extracted data is accessible on the project's page on the OSF platform.[1]

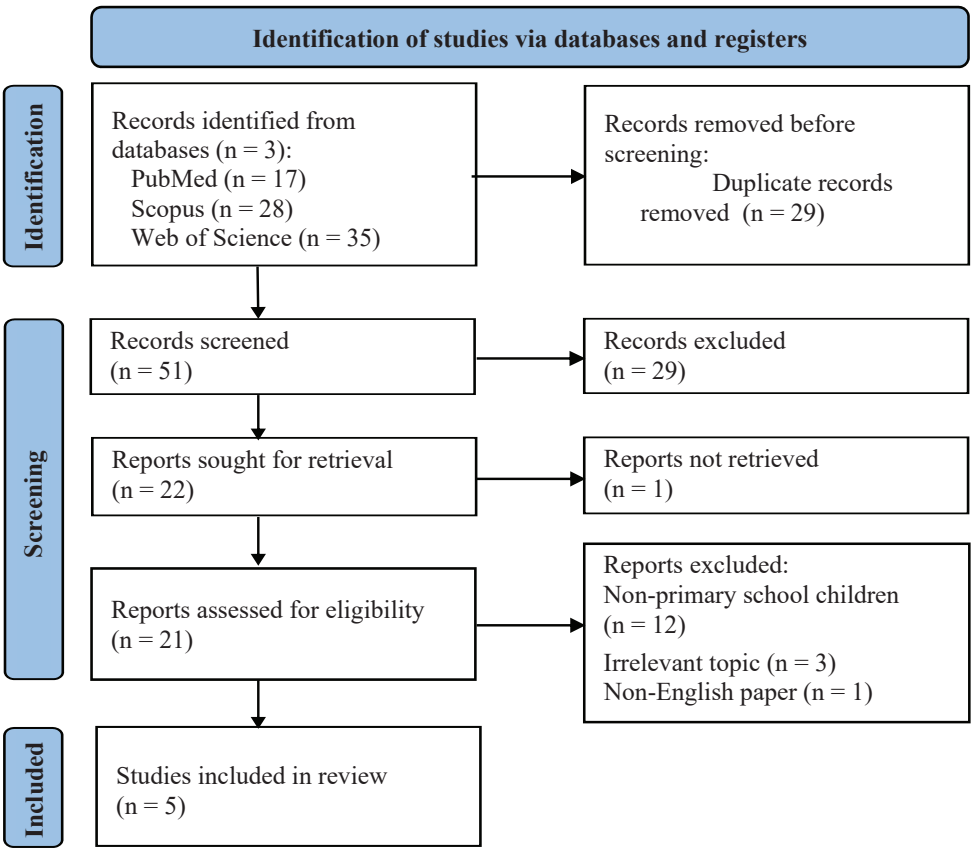
Results

Papers selected

A total of 80 publications were retrieved. After duplicate removal, the titles and Abstracts of 51 articles were screened. From these, 22 articles were selected for full-text screening. One full-text article could not be retrieved, and 15 articles

[1] Retrieved July 12, 2024, from https://osf.io/cztna/?view_only=be113cc1a5414be28a9adef4867e9371

were excluded based on the eligibility criteria. Ultimately, five articles were selected for data synthesis. The results of the search and selection process are summarized in Figure.



PRISMA Flow Diagram for the Search on September 05, 2024

General characteristics

The five studies included a total sample of 280 participants (145 bilinguals, 135 monolinguals), with sample sizes ranging from 37 to 67 participants per study. The participants' ages spanned from 7 to 12 years, with a combined mean age of 10.97 years. Children in the selected studies attended grades 3 through 5. The participants resided in various countries at the time of the study: Canada (n = 2), the Netherlands (n = 2), and the UK (n = 1). Bilingual participants spoke different language pairs: English — French [12], [22], Turkish — Dutch [23], Frisian — Dutch [13]. In Hessel and colleagues [24], bilinguals had different L1s (e.g., Arabic, Kiswahili, French, and others) and English as their L2. Participant-related information of the included studies is presented in Table 1. All five studies employed natural reading tasks with alphabetic orthographies, non-alphabetic orthographies were not represented.

Table 1

Participant-related information from the included studies

Author (s), year	Groups, sample size	Age range, Mean (SD)	Grade	Sex Female/ Male	Language (s)	Country of residence
Bosma & Nota, 2020	Bilingual children: 37	[8.5–12.11], 10.5 (1.2)	NA	23/14	Frisian–Dutch	Netherlands
Whitford & Joanisse, 2021	1) Monolingual children: n = 34 2) Bilingual children: n = 33	1) [7–12], 9.82 (1.10) 2) [7–12], 10.02 (1.32)	4 (elementary school)	1) 20/14 2) 20/13	English-French	Canada
Whitford & Joanisse, 2018	1) Monolingual children: n = 34 2) Bilingual children: n = 33	1) [7–12], 9.82 (1.10) 2) [7–12], 10.02 (1.32)	4 (elementary school)	1) 20/14 2) 20/13	English-French	Canada
Hessel et al., 2021	1) Monolingual children: n = 40 2) Bilingual children: 23	[9–10]	5 (primary school)	1) 22/18 2) 11/12	Arabic/Italian, Japanese, Malay, Malayalam, Filipino, Serbian, Shona, German, Urdu, Welsh, Zulu, and Hawaiian pidgin-English	UK
van den Bosch et al., 2018	1) Monolingual children: n = 27 2) Bilingual children: 19	1) 8.11 (0.6) 2) 9.0 (0.6)	3 (primary school)	1) 14/13 2) 10/9	Dutch Turkish-Dutch	Netherlands

Source: compiled by Elena Yu. Semenova, Marina V. Norkina, Ruzalina I. Shaikhutdinova.

Data charting

To synthesize the results of the five reviewed studies, we grouped them based on their specific research focus (Table 2). The studies examined various factors influencing differences in monolingual and bilingual children's eye movements during reading. Two groups of factors were identified. The first group encompassed linguistic factors, which were explored in four studies [12; 22–25]. The second group comprised factors related to readers' individual differences, analyzed in two studies [23; 24]. In the following paragraphs, we summarized the findings according to this classification, with the focus on: a) differences between monolingual and bilingual children's eye movements during reading; and b) differences in bilingual children's eye movements when reading in their L1 and L2. For each study, we detailed the following: sample, languages, tasks and stimuli, eye-movement measures, and results.

The range of eye-movement measures were analyzed across the reviewed studies. Eye-movement measures can be categorized into early- and late-stage measures. Early-stage measures reflect lexical access and include: (1) first fixation duration (FFD) — the duration of the first fixation on the target word if that fixation is progressive; (2) gaze duration (GD) — the total duration of all fixations

on a target word during the first pass; (3) first-pass duration (FPD) — the total time a reader spends looking at a specific area of interest during the initial gaze; (4) skipping rate (SR) — the probability of fixating on a word during the first pass. Late-stage measures reflect post-lexical integration and include: (1) go-past time (GPT) — the total duration of all fixations on a target word until the eyes fixate on a different word that is progressive to the target word provided that the first fixation is progressive; (2) regressions out (RO) — the number of times a viewer returns to an area of interest after initially leaving it; (3) total reading time (TRT) — the total duration of all fixations on a target word; (4) second pass duration (SPD) — the total time a viewer spends fixating on an area of interest during a subsequent visit after initially viewing it [13; 26].

Table 2

Eye-movement measures in the reviewed studies

Article	Research focus	Eye-movement measures
Whitford & Joanisse, 2018	Word frequency	Global measures: reading rate, average fixation duration, total number of saccades (both progressive and regressive), total number of words fixated, total reading time Local measures: first fixation duration, gaze duration, skipping rate, regressions out, total reading time
Whitford & Joanisse, 2021	Orthographic neighborhood density	Early measures: gaze duration Late measures: total reading time
Bosma & Nota, 2020	Cognate facilitation	Early measures: first fixation duration, gaze duration, skipping rate Late measures: go-past time, total reading time
Hessel et al., 2021	Comprehension monitoring, reading fluency, vocabulary size	Early measures: gaze duration Late measures: go-past duration, egression out probability, rereading probability, regression in probability, rereading time
Van den Bosch et al., 2018	Coherence marking, linear order of clauses, syntactic knowledge	Global measures: total fixation duration

Note: The classification of eye-movement measures for each study was retained as presented in the original articles.
Source: compiled by Elena Yu. Semenova, Marina V. Norkina, Ruzalina I. Shaikhutdinova.

Linguistic factors

The analyses of the reviewed studies revealed that linguistic factors influenced reading strategies, as reflected in eye-movement behavior, across various linguistic levels, including lexical [12; 24], formal orthographic [22], word formation [25], and syntactic [23] levels. Furthermore, the role of cross-linguistic factors in shaping eye-movement patterns was examined in two studies [23; 25] by van den Bosch et al. and Bosma & Nota.

The first study in this group was the study by Whitford and Joanisse [22] who examined the influence of the formal orthographic feature, namely orthographic

neighborhood, on reading behavior. Orthographic neighbors are words differing by a single grapheme at intralingual and interlingual levels. The authors compared eye movements across monolinguals and bilinguals, and between bilinguals' L1 and L2 reading. The study included 34 English monolingual children and 33 English-French bilingual children, all aged 7–12 years. The sample also included mono- and bilingual adults. However, for the purpose of this scoping review, we focused only on the results pertinent to children. Participants read four paragraphs consisting of English and French versions of fiction and nonfiction texts. Two eye-movement measures were analyzed: gaze duration and total reading time. The findings indicated that the activation of multiple visually similar word forms facilitated target word recognition during L1 reading. Both groups of children exhibited facilitatory neighborhood density effects, but the magnitude of these effects was most evidenced in bilingual children. Notably, bilinguals faced greater difficulty processing words with few within-language neighbors compared to monolinguals, as evidenced by longer total reading times. Furthermore, unlike in L1 reading, no neighborhood density effect was observed in bilingual children during L2 reading.

Furthermore, regarding the cross-language neighborhood density effect, facilitatory total cross-language (L2) orthographic neighborhood density effects were reported across both early- and late-stage measures. Words with many cross-language orthographic neighbors were characterized by shorter gaze durations and total reading times than those with fewer neighbors. However, these findings did not distinguish between monolingual and bilingual children. Finally, for bilingual children, a facilitatory effect of total cross-language (L1) orthographic neighborhood density was observed, reflected in shorter gaze durations. Words with many within-language neighbors were easier to process than those with fewer neighbors.

The second study also examined orthographic neighborhood effects [25]. However, the authors used the terms "interlingual homographs" (also referred to as ''false friends") to describe this phenomenon. Interlingual homographs/orthographic neighbors were examined with identical and non-identical cognates in Dutch and Frisian. These languages are closely related, with Frisian being a minority language in the province of Friesland in the Netherlands. Eye movements were compared as bilinguals read in both their L1 and L2. Monolinguals were not included in the study. The participants in their study were 37 Frisian–Dutch bilingual children aged 8–13 years. The stimuli for the cognate reading task included 42 Frisian–Dutch translation equivalents: 14 identical cognates, 14 non-identical cognates, and 14 non-cognates. Five reading measures were analyzed: first fixation duration, gaze duration, skipping, go-past time, and total reading time. The results showed a cognate facilitation effect in Frisian but not in Dutch. In Frisian, the effect was non-gradual: first fixation duration, gaze duration, go-past time, and total reading time for identical cognates were significantly faster than for non-identical cognates and non-cognates. but there was no significant difference between non-identical cognates and non-cognates. No cognate facilitation effect was observed

for skipping in either Frisian or Dutch. However, there was a significant main effect of language, with more skipping in Dutch than in Frisian. Thus, the results suggest that bilingual children used the knowledge of their dominant language (Dutch) when reading in their non-dominant language (Frisian).

The third study focused specifically on lexical accessibility, indexed by word frequency effects [12]. The sample and stimuli were the same as those used in [22]. The authors compared eye movements both between monolinguals and bilinguals, and between bilinguals' L1 and L2 reading. The following eye-movement measures were analyzed: average fixation duration, total number of saccades (both progressive and regressive), total number of words fixated, first fixation duration, gaze duration, skipping rate, and regressions out. The results revealed that bilingual children exhibited reduced global (text-level) and local (world-level) L1 reading performance compared to monolingual children, including larger L1 word frequency effects. In terms of global measures, monolingual children demonstrated faster reading rates, fewer saccades, shorter total reading times, and fixated on fewer words than bilingual children during L1 reading. For local measures, monolingual children had shorter first fixation durations, gaze durations, and total reading times than bilingual children during L1 reading. Furthermore, bilingual children exhibited reduced global and local L2 reading performance compared to their L1, including larger L2 word frequency effects. In terms of global measures, bilingual children had more saccades, longer total reading times, and fixated on more words during L2 reading compared to L1 reading. For local measures, a statistically significant effect of language was found for regressions out and total reading time, with bilingual children showing more regressions out and longer total reading times during L2 reading than during L1 reading.

The fourth study, conducted by Hessel and colleagues [24], investigated comprehension monitoring in bilingual children. The authors defined comprehension monitoring as the process of checking and regulating one's understanding when reading sentences containing semantic inconsistencies. Sixty-three 9–10-year old children read texts containing lexical inconsistency. Bilingual children in their study began learning English as an additional language upon arrival in the UK, with a mean age of L2 acquisition of 1.01 years (SD = 1.06). In their experiment, children read two-sentence stories. The following eye-movement measures were examined: early (gaze duration), and late (go-past duration, regression out probability, rereading probability, regression-in probability, rereading time, and both early and late (total time) measures). The results showed that there were no interactions between any of the eye-movement measures and language groups. Monolingual and bilingual children did not differ in their online monitoring of inconsistent target words.

The final study in this group investigated the influence of syntactic features on eye-movement patterns in bilingual children [23]. The authors used an online sentence reading task that included 16 two-clause Dutch sentences with a causal

relationship. The task aimed to investigate two textual factors related to syntactic structure, namely coherence marking and linear order of clauses. Specifically, the study examined the effects of subordinating conjunctions in complex sentences and the impact of linear versus non-linear clause order on eye-movement patterns. The sample consisted of two groups of 8–10-year old readers: Dutch monolingual children and Turkish-Dutch bilingual children, with Dutch as their L2. The bilingual children were born in the Netherlands and were exposed to both Turkish and Dutch from birth. The following eye-movement measures were analyzed: the average processing time per word and total fixation duration. The results showed that bilingual children with less developed syntactic skills (for more details, see "Individual Differences") had longer processing times for sentences without a connective than for sentences with a connective. This suggests that the presence of connectives helps bilingual readers with weaker syntactic skills process causal relations more efficiently. At the same time, monolingual readers did not show significant differences in processing times based on the presence or absence of connectives. Specifically, reversing the order of the clauses did not influence children's online processing time, and no facilitative effect was observed for the bilingual readers.

Individual differences

Among the selected studies, two investigated the role of children's individual differences in their reading behaviors. In [24], individual differences included reading fluency, and vocabulary size. Van den Bosch and colleagues [23] examined individual differences in syntactic knowledge.

The study by Hessel and colleagues [24] investigated the relationship between online indicators of comprehension monitoring and individual differences in vocabulary size and reading fluency among monolingual and bilingual 9–10-year-old children. The study focused on whether individual differences influenced the detection of semantic inconsistencies. Details of the sample, stimuli, and examined eye-movement measures are provided in the "Linguistic factors" section. The results showed that individual differences in vocabulary size and reading fluency predicted variations in children's online reading performance, regardless of their language group (monolinguals or bilinguals). Both vocabulary and fluency were associated with overall faster reading. Children with larger vocabularies were significantly better at detecting and responding to inconsistencies in the text, demonstrating stronger comprehension monitoring. Specifically, larger vocabulary size was linked to shorter gaze durations, although this effect was not observed across other reading time measures. Additionally, children with larger vocabularies were more likely to make direct regressions to inconsistent target words and to spend more time rereading them. This pattern was consistent for both monolingual and bilingual children. However, bilingual children with smaller vocabularies exhibited longer gaze durations when reading inconsistent words compared to consistent ones. This

effect persisted when bilingualism was measured as a continuous variable, affecting both gaze duration and total reading time. Furthermore, higher reading fluency was associated with shorter gaze durations, rereading, and total times irrespective of the language group. Based on the findings, the authors concluded that vocabulary knowledge plays a critical role in successful comprehension monitoring, more so than fluency or language group.

Van den Bosch and colleagues [23] examined to what extent online processing times of sentences with causal relations were influenced by individual differences in syntactic knowledge, as well as coherence marking and linear order of clauses. Details regarding the sample, stimuli, and eye-movement measures are provided in the "Linguistic factors" section. The authors hypothesized that bilinguals, compared to monolinguals, would exhibit lower syntactic knowledge in Dutch. Additionally, they posited that the depth of syntactic knowledge would influence how young readers processed sentences with and without connectives (e.g., "because") and sentences with linear and non-linear clause order. The results confirmed that bilingual readers demonstrated lower syntactic knowledge than their monolingual peers. Furthermore, the level of syntactic knowledge interacted with the processing of sentences with or without connectives as reflected by the eye-movement measures (bilingual readers with lower syntactic knowledge had longer processing times). The details are described in the section above.

Discussion

This scoping review explored existing studies on eye movements during reading in monolingual and bilingual primary school children. With only five studies included, each focusing on varied research areas, it is not possible to draw definitive conclusions. Instead, the findings provide a foundation for tentative assumptions. Overall, the synthesis of research findings demonstrated that bilingual children exhibited reduced eye-movement reading performance compared to monolingual readers [12; 22–24]. However, this trend was influenced by specific factors associated with either language-related aspects, or individual differences. Additionally, bilingual children's reading in their L1 and L2 showed distinct eye-movement patterns [25], with these patterns also shaped by individual differences. The following sections discuss these findings in greater detail.

Reading in L1 in bilingual and monolingual children

Eye-movement measures in the reviewed studies revealed several patterns in bilingual children's reading performance compared to monolinguals. Bilingual children faced greater difficulty reading words with fewer within-language neighbors [22] and showed more reduced reading performance when encountering less frequent words [12]. However, bilinguals and monolinguals did not differ in their eye-movement measures related to the presence or absence of connectives, the linear or non-linear order of clauses [23], or the online monitoring of inconsistent target

words [24]. Furthermore, words with many cross-language orthographic neighbors were read similarly by both groups [22]. Finally, for both monolingual and bilingual children, larger vocabularies and higher reading fluency were associated with overall faster reading [24].

Such mixed findings can be situated within existing theoretical frameworks explaining bilingual language comprehension. This way, the findings that bilingual children demonstrated more reduced eye-movement measures compared to their monolingual peers in relation to lexical factors can be explained by the weaker link hypothesis [27; 28]. The hypothesis posits that a significant consequence of bilingual children learning to read in two reading systems at once is that they inevitably have less exposure and practice with each reading system compared to monolingual children. Therefore, such divided experience may lead to differences in processing individual words and connected texts that can be captured by local and global eye-movement measures. For example, Whitford and Joanisse demonstrated that monolingual children had shorter first fixation durations, gaze durations, and total reading times than bilingual children during L1 reading, including larger word frequency effects [22]. These are local early eye-movement measures that suggest that bilingual children tend to access words from memory slower than monolinguals. This can also suggest that early information integration might be more effective in monolinguals than bilinguals. In addition, monolingual children had faster reading rates, shorter total reading times, made fewer saccades, and fixated on fewer words than bilingual children during L1 reading, also including larger word frequency effects [12]. These local late measures indicate that bilingual children's post-lexical integration tends to occur with less ease than that of monolinguals.

Although there are differences in their eye movements, children from the two language groups have been reported to exhibit comparable levels of reading comprehension in L1 [12]. This suggests that bilingual children may employ adaptive strategies during L1 reading to compensate for their divided language experience. These strategies could include, for instance, spending more time on each fixation. As a result, the observed differences in eye movements may reflect not deficiencies, but rather distinct reading strategies that ultimately support effective comprehension.

While the absence of differences in eye movements between bilingual and monolingual children, in relation to linguistic factors such as syntax, formal orthography, and word formation, can be attributed to various explanations, it should be interpreted with caution given the limited number of studies reviewed. One possible explanation for the discrepancy is the age-related characteristics of reading development. The reviewed studies largely based their assumptions on existing research with adults [12; 22; 24]. However, the effects observed in bilingual and monolingual adults may not necessarily apply to children. Unlike adults, children's relatively limited reading experience may prevent them from forming anticipations about upcoming words and syntactic structures.

The authors also acknowledge that the research designs could have limited the detection of expected effects [23; 24]. Therefore, there is a compelling need for new, well-designed studies to address these gaps.

Reading in L1 and L2 in bilingual children

Reduced reading performance in bilingual children in L2 compared to L1 was observed in both global and local eye-movement measures. This was evident in larger L2 word frequency effects [12], and the absence of the neighborhood density effect on L2 reading [22]. However, bilingual children demonstrated more efficient reading in their L2 when it was their dominant language, as shown by the cognate facilitation effect [25]. Additionally, reading performance in both L1 and L2 was found to be influenced by individual differences in syntactic knowledge. For example, L2 readers with lower syntactic knowledge exhibited longer processing times when reading sentences with or without connectives [23]. Similarly, bilingual children with smaller vocabularies showed longer gaze durations when reading inconsistent compared to consistent words [24].

These findings can be explained by the varied language experiences of bilinguals. Reduced performance in either L1 or L2 may result from the more restricted linguistic environments in which bilinguals encounter their languages (e.g., home, work, community). Limited access to oral or written texts in either language hinders the development of semantic diversity and word-related knowledge. For example, the study by Bosma and Nota [25], which demonstrated more skipping in L2 than L1 in Frisian-Dutch bilinguals, illustrates that bilinguals are often exposed to their dominant L2 more than to their non-dominant L1. This aligns with the assumptions of the lexical legacy hypothesis [29], according to which engaging with languages in a variety of contexts is essential for the development and maintenance of reading skills. On the other hand, Whitford and Joanisse reported reduced performance in bilinguals' L2 compared to their L1 in relation to the word frequency effect, as evidenced by both local and global measures [22]. While the authors did not provide data on the bilinguals' dominant language, it can be inferred that, being from a highly bilingual Canadian region, the bilinguals in their study likely use both languages equally often. Therefore, their findings might not align with the lexical legacy hypothesis. Instead, they could be corroborated by the work of Cop and colleagues [30], and Whitford and Titone [31; 32], who proposed that bilinguals' ability to access and integrate word-related information in L2 tends to be reduced throughout life. Similarly, Van den Bosch and colleagues highlighted that syntactic knowledge is related to children's proficiency in L2 in general, which tends to be limited for bilinguals [12]. In this context, the findings by Hessel and colleagues, showing that bilingual children with smaller vocabularies had slower lexical access, as reflected in their eye movements, further emphasize the critical role of L2 proficiency [14].

Future directions

Unlike eye movement research with bilingual adults, studies focusing on bilingual children remain significantly limited. Therefore, to better understand the developmental characteristics of bilingual readers, future research should prioritize gathering more data on children's individual differences, language-related factors, and their interaction. Individual differences, in particular, play a crucial role in children's reading development [33]. For bilinguals, these differences also encompass bilingualism-specific factors. Such factors include proficiency in L1 and L2, degree of bilingualism, age of L2 acquisition, exposure to L1 and L2, and contexts of language use [34]. For instance, it has been suggested that comparable levels of L1 proficiency, and levels of L1 exposure, can lead to similar eye movement patterns between language groups [12]. Furthermore, it is argued that reading patterns could vary according to the languages spoken and cross-language influence [35]. Cross-linguistic research on eye movements in reading has primarily focused on European Roman script-based [36; 37], Slavic Cyryllic script-based [35], and Asian logographic [38] languages. However, such studies are relatively scarce, especially when considering the world's approximately 80 writing systems. The lack of diversity constitutes a significant gap in the field of reading research [39].

Conclusions

Eye-tracking, as an online method, adds value to behavioral studies of reading, which often cannot capture the detailed dynamics of this complex process. Eye-movement research provides insights into how lexical information is accessed and integrated in both languages of bilingual readers. This knowledge is particularly important for studying reading development in bilingual children. The results of this scoping review demonstrate that differences — or the lack thereof — in the eye movements of bilingual and monolingual readers are influenced by various individual and language-related factors. However, given the limited number of existing studies, no definitive conclusions can be drawn at this time. Future research will help shed more light on bilingual children's reading development as evidenced through their eye movements.

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