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Review

What Can Eye Movements Tell Us about Reading in a Second Language: A Scoping Review of the Literature

Juan Francisco Quiñonez-Beltran [1,*], Taylor Marissa Seymour [1], Robert A. J. Robbins [2], Ying Xu [2] and R. Malatesha Joshi [1]

[1] Department of Teaching, Learning and Culture, Texas A&M University, College Station, TX 77843, USA; tseymour@tamu.edu (T.M.S.); mjoshi@tamu.edu (R.M.J.)
[2] Department of Educational Psychology, Texas A&M University, College Station, TX 77843, USA; jarobbins93@tamu.edu (R.A.J.R.); ying_x@tamu.edu (Y.X.)
* Correspondence: juan.quinonez@tamu.edu

Abstract: There is a growing interest in the similarities and differences in reading processes in L1 and L2. Some researchers propose that reading shares commonalities across languages, while others state that each language has particularities that would affect reading processes. One way to better understand the reading processes is by using eye-tracking methodologies to explore reading processes online. This review focuses on the research done about reading processes in bilinguals to understand the effect of L1 in L2 processing. We found that most of the studies followed two methods of comparison: Bilinguals vs. monolinguals and L1 vs. L2. In general, bilinguals presented longer times in all reading measures; however, the results are discussed based on different characteristics of the studies and the type of comparison.

Keywords: bilinguals; eye-movements; eye-tracking; bilingualism; reading

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1. Introduction

Bilingualism is a common phenomenon, with more than half of the world's population being bilingual [1]. However, bilingualism is considered a complicating factor in language processes [2]. During the past two decades or so, there has been an increased interest in understanding the effects of bilingualism on cognition and the consequences of it on several processes [2], one being reading. Reading is a crucial skill that requires the translation of print to meaning; this process can be affected by several factors, and learning a second language can beneficially or detrimentally impact reading. This review aims to synthesize the literature on eye movements in bilinguals to explain reading-related processes that might be affected by the acquisition of a second language.

According to Kroll et al. [2], bilingualism occurs in different ways; some people learn a second language early in life, while others later in life; some people learn one language at home but are raised in a society using a different language; and others are raised by parents with different language backgrounds and are exposed to both languages since birth. Due to this situation, studying the effect of bilingualism in reading (as well as other cognitive, behavioral, and neural skills) is complicated, as there are a lot of personal and contextual variables (e.g., exposure to a second language, age of acquisition) affecting reading processes. Moreover, an increasing number of people learn to speak in one language and read in a second language, hence the cruciality of understanding how one's first language (L1) affects reading acquisition in a second language (L2). Given this importance, research has been conducted to explain how bilinguals acquire lexical representations and how they relate to comprehension processes in reading.

Due to the increasing importance of bilingualism in several areas of life, research on these related processes has increased in the past several decades and has become a field of research on its own. The result of this research are models trying to explain bilingual word recognition (e.g., Bilingual Interactive Model, BIA+; for a review, see [3]) and models trying to explain the formation of lexical representations in L2 (e.g., Ontogenesis Model [OM] [4]). With regards to word recognition, two types of models exist: the revised hierarchical model [5] and the Bilingual Interactive Model (BIA+; [3]). In the former model, bilinguals are theorized to have two lexicons, one for each language, and an integrated conceptual system that grants easier access to L1 while access to L2 is contingent on its links with L1, thought to grow stronger with increasing L2 proficiency [6]. Regarding the BIA+ model, bilinguals' access to words is theorized to occur in a non-selective manner due to their integrated lexicon [3] that, when recognizing words during reading, activates orthographic and phonological representations in both languages [6]. A review of the different models and their applicability is beyond the scope of this paper; however, it is essential to know how this field has increased and how technology has helped to improve our understanding of reading processes in bilinguals. Although several models explain reading processes, there is still ambiguity around factors surrounding reading processes in bilinguals. For instance, reading processes may be affected by universal factors, processes present in all orthographies (e.g., maturation processes and increasing efficiency), or language-specific factors, or those that are unique to a given writing system (e.g., alphabetic status, transparency, and morphology) [7]. Eye tracking is one of the most commonly used techniques to unravel reading processes in bilinguals.

Eye tracking is a technique that records participants' eye movements while solving a task. For example, while reading, our eyes stop at a specific point to gather information (i.e., fixations) and then move to the next position (i.e., saccade) where information is available [8]. Eye movement recordings provide information about online cognitive processes, making them a valuable tool in reading research. However, despite the growing body of research focused on bilinguals' eye movements, to our knowledge, there has not been a review synthesizing the results to shed light on reading processes. One reason may be a lack of consensus on a methodological procedure, leading to many reading tasks and eye movement measures that are complicated to compare. Previous reviews about eye tracking have focused on methodological issues and recommendations (e.g., [9]), or have focused on linguistic processes in general (e.g., [10]), not just reading. These reviews show that standardizing eye tracking methodologies is critical to drawing insightful conclusions [9]; however, they have yet to explore other factors that might affect bilingual reading processes. Summarizing the literature to identify gaps and/or difficulties potentially related to the lack of a standardized methodology may be the first step to achieving standardized eye tracking methodologies. Therefore, this review focuses on bilinguals' eye movement while reading, intending to summarize the results of studies and discuss different potential related factors. Our review intends to investigate three primary questions:

1. What are the differences between monolinguals and bilinguals' eye movements during reading?
2. What are the differences between bilinguals' eye movements while reading in their L1 and L2?
3. Which factors affect those differences?

We believe that our findings will help unravel which factors should be considered confounding variables when conducting research on bilingual reading, leading to better interpretation of results. In the next section, we will explain the current study's methodology, followed by the findings, and conclude with a discussion on future recommendations based on the reviewed articles.

2. Methods

The current review uses a scoping review approach. A scoping review aims to map the research literature in a field [11,12] and provide a descriptive overview of the reviewed material. We selected this approach because it is more inclusive with study designs and methodologies [12].

2.1. Search Strategy

The literature search was completed using the following databases: ERIC, PubMed, Web of Science, and PsychInfo. The search terms included: bilingual (OR bilingualism OR bilingual students OR L2 OR multilingual OR L2 learner OR second language learner OR language learner OR cross-cultural studies) AND eye-tracking (OR eye-tracker OR eye movements OR eye) AND reading (OR decoding OR word recognition OR literacy OR visual word OR sight vocabulary). We created our search string using ERIC and adapted it to the other databases. The search produced a total of 937 publications (108 duplicates were removed automatically, and two were removed manually), which were then uploaded into COVIDENCE. We used a time frame (2000–2023) to search for studies as we were concerned with recent publications; the last search was made in June 2023.

2.2. Elegibility Criteria

Next, abstracts and titles were screened utilizing the following inclusion criteria: (1) at least one eye movement measure was reported in the study; (2) the studies recruited healthy (without a history of brain damage or neurological disorders) bilinguals; (3) participants had normal or corrected vision; (4) a reading task was utilized (word, sentence, paragraph, or whole text); (5) the study included at least one comparison (monolinguals vs. bilinguals or L1 vs. L2); and (6) the article is written in English. We excluded studies if (1) they use EEG or fMRI or do not use an eye tracker; (2) the studies used speech processing and/or speech production tasks; (3) the studies focused on switching; (4) the studies used unhealthy participants or compared healthy participants with participants with reading disabilities; (5) the studies were conducted only with monolinguals or using participants who spoke more than two languages; (6) there was a small sample (less than 20 participants in a group); (7) the studies involved tasks mixing stimuli (e.g., visual and auditory); and (8) the studies involved tasks that used idioms. Although our initial exclusion criteria were intended to filter out studies with "participants who spoke more than two languages", this became implausible given that studies provided insufficient details. Therefore, if studies included either bilingual participants or participants reading in L1 and L2, they were initially included. This adjustment will be addressed in the limitations discussed later. We decided to exclude tasks using idioms or multi-word units because we consider these tasks to require other cognitive processes, and we are interested in focusing on just reading processes. Moreover, there is a recent systematic review focused on multi-word units [13].

2.3. Selection of Studies

Initial screening was conducted using Covidence, a collaborative, online literature review software. Therein, each of the four authors independently and anonymously screened article titles and abstracts to determine initial inclusion. During this process, if conflicts arose between two authors, meetings were held with the two authors as well as a third, non-involved author to discuss and resolve the conflict. After the initial screening, 191 studies were eligible for full-text screening (with 85% of intercoder agreement). Four of the authors participated in the full text screening process (with intercoder agreements ranging from 75% to 92%). After screening these 191 studies, 155 were excluded from the final review (see Figure 1). It should be noted that one article [14] entailed an experimental design with a reading and reading + listening condition, both of which were completed by monolinguals and bilinguals. Given our focus on reading (rather than listening), we focused solely on the characteristics of the reading condition for this study.

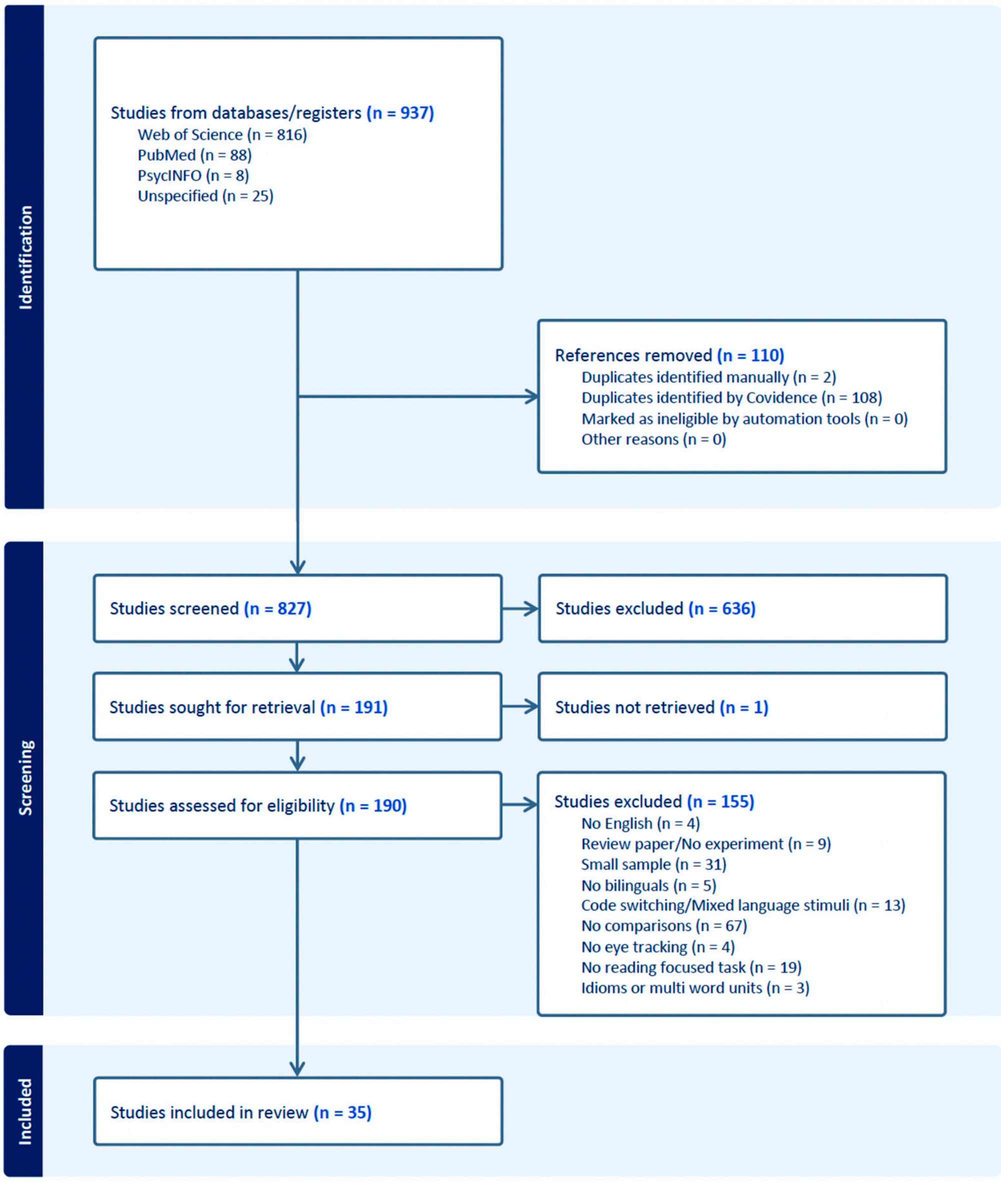

Figure 1. Flow chart for the screening and text review process.

2.4. Data Extraction

Based on our inclusion and exclusion criteria, we obtained coding information from the full text of 35 studies. The following information was extracted: participants' characteristics (mean age, first language, age of acquisition of the second language, and proficiency), task description, languages compared, eye movement measures, characteristics of the languages used, type of comparison (L1 vs. L2; Monolinguals vs. Bilinguals), statistical analysis used, and main findings. During the coding process, only one author coded the data (see Table S1 in Supplemental materials for the reliability of the accepted studies). However, 25% of the papers were checked by two authors. Given the wide variety of methodologies used, we only coded the characteristics and statistical significance of study analyses and results, respectively, and did not calculate effect sizes.

3. Findings

Of the 35 studies, 21 compared monolinguals' performance to bilinguals' performance on different reading tasks, 14 compared bilinguals' performance on reading tasks using their L1 and L2, and one study performed both comparisons. In the following sections, we will summarize the results of both types of comparison separately, discussing the tasks, eye movement measures, and results. Table 1 explains the characteristics of the participants and the explored orthographies and Table 2 contains a summary of the characteristics of the studies. We also separated the findings according to the task used: natural reading or natural reading with any type of manipulation. We defined natural reading tasks as those that only asked participants to read (words, sentences, or paragraphs) in one condition and did not manipulate the stimuli to create different conditions. Due to the differences between tasks, it is impossible to achieve a generalizable conclusion of these studies, even though, in some cases, they investigated similar variables. For example, ambiguity resolution in L2 was explored in two studies [15,16]; however, the stimuli focused on different characteristics. Therefore, we will give a brief overview of the results of each study, considering their characteristics and reporting only the results that compared monolinguals and bilinguals or L1 vs. L2′s eye movements.

3.1. Monolinguals vs. Bilinguals

3.1.1. General/Background Study Information

Among the 21 studies comparing monolinguals' to bilinguals' performance and eye movements, seven employed natural reading tasks with alphabetic (n = 6 [17–22]) and non-alphabetic (n = 1 [14]) orthographies. Fourteen of the studies included a manipulation in the reading task with alphabetic (n = 8 [15,16,23–28]) and nonalphabetic (n = 6 [29–33]) orthographies, and one study [34] did not specify participants' L1 language background. Across all studies, four types of stimuli were used: words (n = 1), sentences (n = 15), paragraphs (n = 4), and passages (n = 1). The following sections will discuss common trends and findings across prevalent aspects of the monolinguals vs. bilinguals studies.

3.1.2. Natural Reading

Alphabetic Orthographies

Six articles explored eye movements while using a natural reading task in the form of paragraph reading (n = 2; [20,21]), sentence reading (n = 3; [17–19]), or word reading (n = 1; [22]).

Whitford and Joanisse [20] compared the skipping rate, first fixation duration, gaze duration, regressions out, total reading time, and total number of fixations of monolinguals (English) and French–English bilinguals while reading a paragraph. They also controlled the frequency of words in the paragraph. Although they made several comparisons, here we are focusing only on the comparison between monolinguals and bilinguals. Data were analyzed on two levels: global (paragraph) and local (word). Results from the experiment showed significant differences in the global level on all measures except fixation duration, showing that bilinguals were slower to read, had more saccades, and had more fixations than monolinguals. Conversely, results from the local level showed significant differences in all measures except regressions out and skipping rate, showing that bilinguals had longer fixations, gaze duration, and total reading times. Researchers concluded that the results could be due to the low-frequency words in the text and discussed the results using the Weaker Links Hypothesis (also known as the frequency-lag hypothesis), which hypothesises that bilingual individuals split their time between two languages, resulting in less experience with words in each language compared to monolinguals. This reduced experience results in a delay in recalling low-frequency words. However, with increased language proficiency, this effect becomes smaller and low-frequency words are retrieved just as well as high-frequency words [35]. The other study employing paragraph reading [21] used the same sample and task as Withford and Joanisse [20] but measured gaze duration and total reading time only. Their results showed a facilitation effect of orthographic neighborhood density that was more evident in bilinguals than monolinguals, as noted by their longer total reading times.

Sentence reading tasks were the preferred task for comparing monolinguals' and bilinguals' reading behaviors. Parshina et al. [18] compared eye movement data between Russian monolinguals (adults and children) taken from the Russian Sentence Corpus (RSC) to those of English–Russian heritage speakers (low and high proficiency) and L2 learners of Russian in attempts to establish a benchmark for heritage speakers. They measured first fixation duration, single fixation duration, gaze duration, probability of skipping a word, probability of fixating a word only once, total sum of all fixations in a word, probability of regression saccade to the previous word from the current word, probability of regression back to a word from the following word, and probability of fixating a word more than once. Their comparisons showed that heritage speakers with high and low proficiency were significantly different from the monolingual adults in all measures except the probability of regression saccade to the previous word from the current word. However, when highly proficient heritage speakers were compared to monolingual children, the differences were significant only in gaze duration, sum of all fixations, and probability of regression back to a word from the following word. On the other hand, low proficiency heritage speakers showed significant differences in gaze duration, sum of all fixations, probability of regression back to a word from the following word, probability of fixating a word once and more than once, and total number of fixations. The authors interpret these results as evidence showing that heritage speakers' reading behavior is similar to the reading behaviors of monolingual children. In contrast, the reading behavior of low proficiency heritage speakers resembles the behavior of L2 learners.

Another study by Parshina et al. [19] compared Russian monolingual children to heritage speakers (English–Russian) and L2 learners of Russian (English as L1), exploring whether there were differences in the sensitivity to the lexical and morphosyntactic predictability between the groups. To do this, they considered the first fixation duration, single fixation duration, gaze duration, total reading time, and skipping probability. Results showed that monolingual children and heritage speakers had similar prediction abilities, with no significant differences in gaze durations. However, shorter total reading times were identified for heritage speakers compared to monolinguals, which were interpreted as heritage speakers being more sensitive to the lexical predictability of words. Moreover, the effect of exposure or experience with Russian was also explored and was found to aid prediction in early measures for all groups; nevertheless, they found that the predictability of the words was beneficial only for heritage speakers and L2 learners with less exposure to the language, as seen by the effect in their total reading times.

The last study from our findings using a sentence reading task [17] explored the reading behavior of L1 English speakers with L2 English speakers from different backgrounds (Finnish and German). Their goal was to explore the effect of English skill level of the three groups while reading sentences written in English. Total fixation duration, skipping rate, and total number of fixations were measured, with results showing that highly proficient L2 speakers differ from native L1 speakers of English in that they were slower in reading (as determined by reading rate and total fixation times). Moreover, the German group achieved almost native-like proficiency while the Finnish group did not. Researchers suggest this latter effect results from the characteristics of the orthographies, with German being more similar to English than Finnish.

Only one study used a single word reading task to explore differences between monolinguals and bilinguals. Alhazmi et al. [22] explored the effect of "vowel blindness" on native Arab speakers when reading English words and compared their reading performance to L1 speakers of English. They measured participants' first fixations and total number of fixations and found that the mean number of fixations and the fixation durations were higher for Arab speakers compared to English speakers; however, no differences between the duration or number of fixations of Arab readers when comparing consonants and vowels was found. These results contradict previous research proposing that Arab speakers spent more time on consonants relative to vowels.

Non-Alphabetic Orthographies

Conklin et al. [14] was the only study that compared monolinguals and bilinguals with non-alphabetic orthographies in a natural reading task. The eye movements of L1 (English) and L2 (Various L1–English) speakers were recorded in two conditions: (1) reading in English and (2) reading and listening in English. Here, we are only focusing on the results of the reading-only condition. They used passage reading and compared first fixation duration, first-pass reading time, total reading time, total fixation count, regression count, and skipping rate. Their results showed that L2 speakers had more reading time, as shown by their longer first-pass reading time, total reading time, more fixation count, and lower skipping rate. The effects of the type of L1 orthography (e.g., alphabetic vs. non-alphabetic) were not considered in their study. In other words, all L2 speakers were grouped together regardless of whether their L1 was alphabetic or non-alphabetic. Nevertheless, they discussed their result using the comparison with the reading while listening condition, which is not of interest for this article.

3.1.3. Natural Reading + Manipulation

Alphabetic Orthographies

Fujita and Cunnings [16] explored syntactic ambiguity resolution in monolinguals (English) and bilinguals (Various L1–English) using sentences in English. Although they conducted four experiments, we are only describing the results of the ones using a reading task and measuring eye movements exclusively. In one of their experiments, the task had four conditions: (1) ambiguous with gender match, (2) ambiguous with gender mismatch, (3) unambiguous with gender match, and (4) unambiguous with gender mismatch. They selected four regions of interest in the sentences and measured first-pass reading times, regression path duration, and total viewing times. This experiment showed longer reading times for bilinguals in all models and longer first-pass reading times for bilinguals compared to monolinguals. Another experiment reported in the same paper used sentences in English with four conditions: (1) ambiguous with consistent continuation, (2) unambiguous with consistent continuation, (3) ambiguous with inconsistent continuation, and (4) unambiguous with inconsistent continuation. For this experiment, they measured the same eye movement measures as in the previous one. They found greater regression path times for monolinguals compared to bilinguals.

The other study exploring ambiguity resolution is by Cheng et al. [15]. They explore relative clause (RC) resolution by monolinguals (English) and bilinguals (various L1–English) while reading sentences in English in six different conditions: (1) subject modifying RC, ambiguous; (2) subject modifying RC, low-attachment; (3) subject modifying RC, high-attachment; (4) object modifying RC, ambiguous; (5) object modifying RC, low-attachment; and (6) object modifying RC, high-attachment. They analyzed three eye movement measures: first pass times, regression path times, and total reading times. They found a main effect of group for all three measures, indicating slower reading times for bilinguals. They also reported that monolinguals presented a greater high-attachment effect than bilinguals in total reading times.

Two studies explored the effects of different language characteristics while reading [26,27]. Patterson et al. [26] studied the application and timing of binding condition B during the processing of pronouns in English sentences, using a sample of L1 speakers (English) and L2 speakers (German–English). They conducted three experiments to do this, but only two used eye tracking. In two of the experiments, they manipulated the experimental items by changing the matching (or mismatching) between the names and the pronouns in the item. They measured first fixation duration, first-pass reading time, regression path time, skipping rate, and total viewing time in four different regions of interest. Their results showed that participants reading in an L2 were slower than those reading in their L1, as the differences in all the eye movement measures showed. Moreover, they found differences in first fixation durations in the spillover regions (longer fixations for participants reading in their L2) and lower skipping rates for bilinguals, which they interpreted as bilinguals using a serial strategy for reading.

Sagarra and Rodriguez [27] investigated the processing of subject–verb agreement in Spanish sentences. They compared a group of monolinguals (Spanish) and two groups of bilinguals (English–Spanish) in a reading task where they manipulated the subject–verb agreement. Their results showed that monolinguals had shorter gaze durations compared to both groups of bilinguals. They also found that monolinguals spent more total time looking at the stimuli in incorrect trials compared to bilinguals, indicating that the monolinguals were more sensitive to grammatical violations than the bilinguals.

Hoversten and Traxler [25] explored the eye movement behavior of monolinguals (English) and bilinguals (Spanish–English) while reading sentences. Their goal was to study the effect of sentence context on word recognition using interlingual homographs; they constructed sentences and divided them into congruent and incongruent conditions. They measured the first-pass time, regression path time, and total time and found differences only in total time. Monolinguals spent more time on incongruent conditions when compared to bilinguals. The authors interpreted this as bilinguals having less processing difficulties than monolinguals.

Lastly, Bordag et al. [23] explored the effect of lexical and syntactic substitutions in L2 reading. They did this using a paragraph reading task with lexical and syntactic conditions. They used synonyms and contextual synonym pairs for the lexical conditions, whereas for the syntactic conditions, they used active and passive sentence pairs. Participants had to read one text, solve another task, and then read the text again but with a different condition. They recorded the eye movements of L1 speakers (German) with L2 speakers (Various L1–German) during the first and second readings. They compared the performance between L1 and L2 during the first and second readings. They found that L2 speakers had more and longer fixations than L1 speakers for the lexical and syntactic conditions. Results from the second reading showed a repetition effect for both groups; however, the L2 participants were affected by the alternation of the conditions.

Two studies compared monolinguals and bilinguals, considering the effect of the characteristics of the orthography [24,28]. Winskel et al. [28] compared Thai–English bilinguals to English monolinguals using spaced and unspaced sentences. While Thai is an orthography that usually does not use interword spaces in its writing, English does. They used sentences in Thai and English, with two different levels of interword spacing (spaced and unspaced) and controlling the frequency of the words (high vs. low). They analyzed the obtained data in sentence and word levels. For sentences, they measured total sentence reading time and total fixation count; for words, first fixation duration, gaze duration, total viewing fixation duration, and first fixation landing position. However, they only compared the first fixation landing position between monolinguals and bilinguals. They found a main effect of group: monolinguals had first fixation landing positions closer to the middle of the word than bilinguals. Also, they found an interaction of group in the spacing condition, with bilinguals having their first fixation closer to the beginning of the word compared to the monolinguals. It is important to note that the study's goal was to compare the effect of interword spacing in bilinguals and monolinguals; therefore, the results are discussed considering that the bilingual sample had experience reading Thai without interword spaces and considering the individual results from each group.

On the other hand, Egan et al. [24] explored the effect of the orthographic consistency of L1 on L2 sentence reading. They compared the eye movements of monolinguals (English) with a group of bilinguals (Welsh–English) in two experiments. In the first experiment, they compared the eye movements of bilinguals while reading in their L1 and L2; this experiment will be explained in the section L1 vs. L2. In the second experiment, they used sentences in English. They did not find significant differences in any of the selected measures, showing that bilinguals' decoding strategies are similar to those of monolinguals.

Non-Alphabetic Orthographies

Brothers et al. [29] explored the effect of ambiguity in a sentence reading task where they controlled object–subject ambiguities by manipulating one verb (intransitive, transitive, and a noun as control condition) in the sentence. They compared the eye movement behavior of a group of native English speakers and a group of Chinese–English bilinguals by analyzing the first pass times, percent of regression, go past time, and total time in six different regions. In general, they found that bilinguals showed longer fixations and total times compared to monolinguals. They also found an effect of ambiguity, with monolinguals spending more time and having more regressions to temporarily ambiguous phrases, while bilinguals did not show an apparent effect. Although they reported that the ambiguity affected both groups, they argue that monolinguals recover faster from this effect than bilinguals. Another significant result from this study is the role of language experience, as bilinguals with more language experience showed more native-like behavior in their eye movements.

Martin and Juffs [31] explored the effect of orthographic consistency when reading in an L2. To do this, they compared the eye movements (skipping rate, first fixation duration, number of first-pass fixations, gaze durations, total number of fixations, target dwell time, and regressions to the target) of one group of native English speakers to two groups of L2 learners of English, Arabic–English and Chinese–English bilinguals, while reading sentences in English. The sentences had target words divided into two conditions: one had consistent graphemes, and the other had inconsistent graphemes. They also controlled the frequency of the words. Results showed that L2 speakers from both groups had longer fixations, more first-pass fixations, longer gaze durations, longer dwell time, total number of fixations, and lower skipping rate than the L1 speakers; the first language of the groups also affected their reading behaviors, as noted by longer fixations, more first pass fixations, and longer gaze durations in the Arabic group compared to the Chinese group. Moreover, they found a frequency effect for all the groups, but it was more prominent for L2 speakers. They interpreted these results as evidence that L2 readers process texts differently than native speakers but also argued that the L1 background affects how texts in L2 are processed.

One study explored the preview benefit of semantically, phonologically, and orthographically related words while reading [32]. Parafoveal processing of words can give a preview benefit to Chinese native speakers, but it was not clear if this benefit extends to L2 speakers of Chinese. Therefore, Xiao et al. [32] used a Chinese sentence reading task where they controlled target words and the words that appear before the target to construct five different conditions: orthographically similar, phonologically similar, semantically similar, identical, and unrelated preview. They compared three eye movement measures, first fixation duration, gaze duration, and total reading time, of native Chinese speakers and bilingual Tibetan–Chinese speakers. They found an interaction (marginal) between the preview benefit (identical) and the group in gaze duration times, showing that both groups had a preview benefit from the identical condition; however, this benefit was more prominent for the native speakers than the bilingual group. Moreover, they found significant differences in total reading times for both groups when comparing the identical preview condition. The authors interpreted this as bilinguals having semantic information of the stimuli at a later stage compared to native speakers.

Cui [33] focused on exploring the effect of interword spacing between monolinguals (Chinese) and bilinguals (English–Chinese) while reading Chinese texts. She used a paragraph reading task, using four paragraphs and constructing four conditions for each: (1) normal unspaced, (2) artificially word-based spaced, (3) nonword spaced, and (4) normal spaced in Pinyin. Participants' eye movements were recorded while reading, and the following measures were analyzed: total passage reading time, mean first fixation duration, gaze duration, number of fixations, number of regressions, regression path duration, skipping probability, and mean landing position. Her results showed that overall, bilinguals had longer reading times, more fixations and regressions, and fewer skipped words than monolinguals. Moreover, the conditions affected the reading performance of both groups. Monolinguals spent more time reading and had more fixations and regression in the Pinyin condition compared to the other groups; however, there was no difference between the other conditions. On the other hand, bilinguals had longer fixations in the unspaced condition, fewer fixations, shorter regression paths in the word-spaced condition, longer reading times in the nonword-spaced condition, and shorter gaze duration in the pinyin condition. Moreover, native speakers tended to land further into a word than bilingual speakers.

Nakamura et al. [30] explored the effect of verb's subcategorization in syntactic processing while reading English sentences. Using a task with three conditions: (1) plausible transitive, (2) impossible transitive, and (3) intransitive condition, they compared eye movements (first-pass, right-bound, and second-pass reading times) of a group of native English speakers to a group of Korean L2 learners of English. They break their sentences into seven regions of interest to analyze the data. Their results showed that L2 learners had more reading time (as noted by longer first-pass and right bound) than L1 speakers; moreover, longer reading times for L2 were related to the intransitive condition. The authors interpreted this as the L2 group requiring more time to process intransitive verbs, probably because they expected a transitive verb. Another interesting result was that L2 learners had longer reading times (marginal difference) when there was a semantically anomalous direct object analysis; this effect was not observed in the L1 speakers, showing that the L2 group had a processing cost with impossible intransitive sentences.

One study by Maie and Godfroid [34] manipulated English's syntactic and morphological structure to create a sentence reading task with grammatically correct and incorrect sentences. They used these sentences to explore the effect of time pressure in lexical processing automaticity and record eye movement behaviors while participants solved an acceptability judgment task in two conditions: timed and untimed. Two groups of participants, English monolinguals and bilinguals (L1 not reported) solved the task while their eye movements were recorded. The results showed that time pressure affected both groups in early and late measures of processing. This effect was more prominent in bilinguals, who had longer first-pass reading times, re-reading times, and more fixations.

3.2. L1 vs. L2

3.2.1. General/Background Study Information

Across the studies comparing bilinguals' L1 versus L2 performance and eye movements, all but two included language(s) that were alphabetic, the exceptions being studies with Japanese and Chinese participants [36,37]. Five studies used tasks in the form of paragraphs (n = 5), individual words (n = 2), sentences (n = 4), a book (n = 2), or "other" (n = 1). Across all studies, gaze duration (n = 10) and total reading time (n = 10) were the most frequent types of eye tracking measures used, followed by first fixation duration (n = 9). Less frequent measures included regression path/go past time (n = 6), skipping rate (n = 4), total number of fixations (n = 3), regressions in (n = 2), regressions out (n = 1), first pass reading time (n = 1), and first pass reading time (n = 1). The following sections will discuss common trends and findings across prevalent aspects of L1 vs. L2 methodologies.

3.2.2. Natural Reading

Alphabetic Orthographies

There were nine studies that recorded eye movements during natural reading tasks with alphabetical orthographies to compare processing in L1 vs. L2 reading. Friesen and Jared [38] looked at eye movements (i.e., overall reading time, fixation durations on cognates, and total fixation times on cognates) of English–French bilingual adults reading pairs of passages (i.e., each pair had one English version and one French version) to understand memory representations and determine cross-language transfer when reading the first passage in one language and the second passage in a second language. Overall reading times for the second passage were shorter when the first passage included translations with synonyms compared to when the first passage was unrelated to the second passage, indicating that meaning transferred independently from surface form. However, overall reading times for the second passage were longer when the first passage included translations with cognates. Less skilled bilinguals had longer gaze durations on cognates in the second passage when the first passage was in French and included cognates compared to when the first passage did not include cognates. In addition, less skilled bilinguals had shorter fixation durations on cognates in the second passage when the initial passage included translations with cognates compared to when the translation did not include cognates.

Whitford and Titone [39,40] conducted two studies in which the primary focus was comparing younger bilingual adults to older bilingual adults; however, results comparing reading in L1 vs. L2 were included. Both studies included French–English bilinguals reading paragraphs in their L1 and L2 while their eye movements were recorded. The 2017 study recorded participants' eye movements (i.e., skipping rates, gaze durations, go-past times, regressions in, regressions out, and total reading times) while reading paragraphs in French and English to examine the effect of word frequency and word predictability on L1 and L2 processing. In addition, they were interested in how current L2 exposure impacted word processing. Results indicate participants had larger word frequency effects in their L2 compared to their L1. When comparing eye movements in L1 and L2 paragraphs, skipping rates were higher for L1 paragraphs; however, gaze durations, go-past times, regressions in, regressions out, and total reading times were shorter, or fewer, for L1 paragraphs. However, word predictability effects were similar across L1 and L2 processing indicated by similar slopes between L1 and L2 skipping rates, gaze durations, and total reading times. In regard to the impact of current L2 exposure on word processing, results indicate that L2 exposure facilitated L2 processing and reduced L1 processing for young adults only, indicated by gaze durations, go-past time, and total reading time measures.

The 2019 study [40] used eye movements, including first fixation duration, gaze duration, go-past time, and total reading time, to better understand lexical entrenchment (i.e., reduced lexical quality and accessibility in bilinguals due to less experience with each language) and cross-transfer activation. Results indicate lexical entrenchment and cross-language activation were found to influence word recognition. For example, as L2 cross-language neighborhood density (i.e., words being more recognizable when the target word in one language has similarity with more words in the second language) increased, gaze duration and total reading times in L1 decreased, indicating word recognition was facilitated when words had a greater cross-language neighborhood density. The same pattern was found for L1 cross-language neighborhood density on L2 reading.

Bosma and Nota [41] examined the eye movements of Frisian–Dutch bilingual children as they read Frisian and Dutch sentences to better understand cognate facilitation (i.e., cognates being processed more quickly than non-cognates) in this population. These children primarily spoke Frisian at home, but Dutch was their dominant reading language. Results indicate first fixation durations, gaze durations, go-past times, and total reading times were significantly faster when children read identical cognates in Frisian sentences compared to when they read non-identical cognates or noncognates in Frisian sentences, thus supporting a cognate facilitation effect when children read Frisian sentences. This cognate facilitation effect was not found when reading Dutch sentences, as there were no differences in the aforementioned eye movement measures when reading identical cognates, non-identical cognates, or noncognates. These results suggest that when children read in their non-dominant reading language, they utilize their dominant reading language; however, when children are reading in their dominant language, they do not utilize their non-dominant reading language.

Demareva et al. [42] examined the correlations of eye movements in Russian–English bilingual adults when reading paragraphs in their L1 vs. L2. Findings suggest that eye movements varied when text was read in L1 or L2, such as fixations being longer and saccades shorter when text was read in their L2. In addition, when determining the effect of proficiency on eye movements, results indicate the level of proficiency changed eye movements when reading texts in L2; specifically, when individuals are more proficient in L2, their eye movements begin to resemble the eye movements of native speakers.

Whitford and Titone [35] measured the eye movements of English–French and French–English bilingual adults while they read paragraphs written in English and French to examine how L2 exposure impacts word frequency effects (i.e., high-frequency words being recognized more quickly than low frequency words). Eye movement data indicated gaze durations were shorter for L1 vs. L2 reading, total reading times were shorter during L1 vs. L2 reading, and skipping rate was higher in L1 vs. L2. Furthermore, it was found that current L2 exposure was an important determining factor of word frequency effects; specifically, lower L2 exposure resulted in larger word frequency effects and higher L2 exposure resulted in smaller gaze duration fixations between L1 and L2 reading.

Dirix and Duyck [43] performed two experiments in which Dutch–English bilinguals read words and whole books while their eye movements, including first fixation duration, gaze duration, and total reading times, were recorded to examine the effect of age of acquisition on L2 processing. L1 age of acquisition had an effect on L2 processing in which L2 words had shorter fixations when the L1 translation of the word was learned earlier. Further, L2 age of acquisition had an effect on early and late measures of L2 reading in that L2 words that were learned earlier had shorter fixation times.

Rodriguez et al. [44] examined German–French bilingual adults reading words in their L1 and L2 to determine if different language situations impact their eye movements, specifically first fixation durations. Results indicate that these bilinguals' first fixation locations were closer when reading German (i.e., transparent orthography) words compared to when reading French (i.e., opaque orthography) words, indicating that language opacity impacts eye movement patterns in word reading.

To better understand how L2 learners process morphologically complex words, Clahsen et al. [45] examined the eye movements of adults with English as an L1 and adults with English as an L2 (i.e., Dutch–English bilinguals) while they read paragraphs written in English. Eye movement data, including first fixation duration, gaze duration; regression path (go-past time), total reading time, and re-reading were examined. L2 participants, compared to L1 participants, were slower at processing morphologically complex words. Further, L2 participants reading L2 text did not process morphological information at the same level as L1 participants did when reading L1 text.

Non-Alphabetic Orthographies

There were two studies that recorded eye movements during natural reading tasks with non-alphabetic orthographies to compare processing in L1 vs. L2 [36,37]. Taylor and Mukai [36] measured eye movements (i.e., first fixation duration, gaze duration, and total number of fixations) in Japanese–English bilingual adults while reading Japanese and English words to determine if language processing is restricted in L1 (i.e., nonselective language processing) and determine if L1 and L2 processing are affected by the same cross-linguistic factors. Cross-linguistic factors varied in degree and direction across L1 and L2 processing. For example, increased phonological similarity affected L1 and L2 processing differently: it slowed down L2 processing and increased L1 processing.

Sui et al. [37] examined Chinese–English bilinguals' eye movements during whole book reading to compare differences between participants when reading L1 versus L2. Participants spent more time reading in their L2 compared to reading in their L1 as indicated by statistically significant differences for all five reading time measures (e.g., first fixation durations, single fixation durations, gaze duration, and total reading time). In addition, word frequency effects were similar, but larger, for L2 than for L1.

3.2.3. Natural Reading + Manipulation

Alphabetic Orthographies

Whitford and Titone [46] examined how 95 bilinguals' divided exposure to first and second languages (either French or English) impacted reading fluency and word processing. Participants read sentences in both languages using a moving window paradigm, which manipulated the amount of parafoveal information available. Results indicated reduced L2 reading fluency relative to L1, characterized by slower reading rates, longer fixation durations, and more regressions. Importantly, increased L2 exposure correlated with improved L2 reading fluency but diminished L1 fluency, indicating a significant trade-off. Furthermore, bilinguals exhibited similar L1 and L2 perceptual spans (i.e., less than 10, but greater than 6 characters to the right of fixation). However, the impact of decreasing parafoveal window size during L1 and L2 reading was modulated by individual differences in current L2 exposure. Specifically, bilinguals with high versus low L2 exposure were more negatively affected by reductions in window size during L2 reading (indicative of a larger L2 perceptual span) but were less negatively affected by reductions in window size during L1 reading (indicative of a smaller L1 perceptual span).

Whitford and Titone [47] investigated reading fluency and perceptual span in 31 older and 31 younger bilingual French–English adults. Participants read English and French sentences within a moving window paradigm that varied their available parafoveal information. The findings revealed that older adults exhibited lower reading fluency across L1 and L2, with slower reading rates, longer fixation durations, and more regressions compared to younger adults. However, the perceptual span, or the amount of text processed visually during a fixation, was similar across both age groups. L2 reading fluency was also generally lower than L1 for all participants, and individual differences in current L2 exposure influenced reading fluency.

Egan and colleagues [24] conducted two experiments to explore whether Welsh–English bilinguals adjust their grain size (the unit of graphemic processing) between consistent (Welsh) and inconsistent (English) orthographies. The authors examined participants' first-pass fixations to explore how they decoded words in sentences of each language. Theoretically, a smaller grain size (more fixations) would be needed for the consistent orthography due to its predictability, whereas a larger grain size (fewer fixations) would suffice for the inconsistent orthography. Results from the first experiment indicated that bilinguals indeed adapt their reading strategies based on the language context, fixating more on words when presented in a Welsh context compared to an English context. This adaptation was more pronounced for real words than for pseudowords. The second experiment compared these bilinguals to English monolinguals reading in English. It found no significant differences between bilinguals and monolinguals in decoding strategies in English, suggesting that bilinguals can effectively switch between grain sizes based on the language context without their reading in one language being permanently affected by knowledge of another.

Mor and Prior [48] investigated 66 Hebrew–English bilinguals' reading efficiency during English and Hebrew sentences that were either high or low in word predictability. The first and main finding demonstrated that only language-specific vocabulary knowledge modulated the efficiency of L2 lexical access. Furthermore, there were significant word frequency effects in both languages, which were more pronounced in L2. Although L2 proficiency was crucial for predicting frequency effects, it didn't significantly modulate predictability effects. The study also observed larger predictability effects in L2, positing increased reliance on context for less proficient readers. These findings support the notion that the magnitude of word frequency effects is a marker of reading efficiency, which is highly associated with language use and proficiency, as predicted by the frequency-lag hypothesis [35] and suggested by the lexical entrenchment approach [49].

Table 1. Participants and Orthography Features.

Authors	Participants	Monolingual Language	Bilingual Languages	L1 Orthography Characteristics	L2 Orthography Characteristics
Nakamura et al. [30]	Monolinguals; Bilinguals	English	L1 Japanese, L2 English	Non-alphabetical	Alphabetical
Friesen & Jared [38]	Bilinguals		L1 English, L2 French	Alphabetical	Alphabetical
Xiao et al. [32]	Monolinguals; Bilinguals	Chinese	L1 Tibetan, L2 Chinese	Alphabetical	Non-alphabetical
Patterson et al. [26]	Monolinguals; Bilinguals	English	L1 German, L2 English	Alphabetical	Alphabetical
Sagarra & Rodriguez [27]	Monolinguals; Bilinguals	Spanish	L1 English, L2 Spanish; L1 Spanish, Dominant in English	Alphabetical	Alphabetical
Martin & Juffs [31]	Monolinguals; Bilinguals	English	L1 Arabic or Chinese, L2 English	Non-alphabetical	Alphabetical
Demareva et al. [42]	Bilinguals		L1 Russian, L2 English	Alphabetical	Alphabetical
Nisbet et al. [17]	Monolinguals; Bilinguals	English	L1 Finnish or German, L2 English	Alphabetical	Alphabetical
Rodriguez et al. [44]	Bilinguals		L1 German, L2 French	Alphabetical	Alphabetical
Cheng et al. [15]	Monolinguals; Bilinguals	English	Various L1s: Spanish, Italian, German, Dutch, French, Russian, Portuguese, Greek, and Arabic; L2 English	Alphabetical	Alphabetical
Whitford & Titone [47]	Bilinguals		L1 French, L2 English	Alphabetical	Alphabetical
Alhazmi et al. [22]	Monolinguals; Bilinguals	English	L1 Arabic, L2 English	Alphabetical	Alphabetical
Brothers et al. [29]	Monolinguals; Bilinguals	English	L1 Chinese, L2 English	Non-alphabetical	Alphabetical
Fujita and Cunnings [16]	Monolinguals; Bilinguals	English	Various L1s, L2 English	Alphabetical	Alphabetical
Mor & Prior [48]	Bilinguals		L1 Hebrew, L2 English	Alphabetical	Alphabetical
Cui [33]	Monolinguals; Bilinguals	Chinese	L1 English, L2 Chinese	Alphabetical	Non-alphabetical
Whitford and Joanisse [21]	Monolinguals; Bilinguals	English	L1 English, L2 French	Alphabetical	Alphabetical
Clahsen et al. [45]	Bilinguals		L1 English, L2 Dutch	Alphabetical	Alphabetical
Taylor & Mukai [36]	Bilinguals		L1 Japanese, L2 English	Non-alphabetical	Alphabetical

Table 1. *Cont.*

Authors	Participants	Monolingual Language	Bilingual Languages	L1 Orthography Characteristics	L2 Orthography Characteristics
Bordag et al. [23]	Monolinguals; Bilinguals	German	L1 Various Slavic and Romance Languages, L2 German	Alphabetical	Alphabetical
Sui et al. [37]	Bilinguals		L1 Chinese, L2 English	Non-alphabetical	Alphabetical
Whitford & Titone [35]	Bilinguals		L1 French, L2 English; L1 English, L2 French	Alphabetical	Alphabetical
Whitford & Titone [46]	Bilinguals		L1 French, L2 English; L1 English, L2 French	Alphabetical	Alphabetical
Maie & Godfroid [34]	Monolinguals; Bilinguals	English	Various L1s, L2 English	Alphabetical	Alphabetical
Hoversten & Traxler [25]	Monolinguals; Bilinguals	English	L1 Spanish, L2 English	Alphabetical	Alphabetical
Parshina et al. [18]	Monolinguals; Bilinguals	Russian	English–Russian Heritage Speakers; L1 not reported, L2 Russian	Alphabetical	Alphabetical
Parshina et al. [19]	Monolinguals; Bilinguals	Russian	English-dominant heritage speakers of Russian; English-dominant L2 learners of Russian	Alphabetical	Alphabetical
Bosma and Nota [41]	Bilinguals		L1 Frisian, L2 Dutch	Alphabetical	Alphabetical
Whitford & Joanisse [20]	Monolinguals; Bilinguals	English	L1 English, L2 French	Alphabetical	Alphabetical
Egan et al. [24]	Monolinguals; Bilinguals	English	L1 Welsh, L2 English	Alphabetical	Alphabetical
Dirix & Duyck [43]	Bilinguals		L1 Dutch, L2 English	Alphabetical	Alphabetical
Winskel et al. [28]	Monolinguals; Bilinguals	English	L1 Thai, L2 English	Alphabetical	Alphabetical
Conklin et al. [14]	Monolinguals; Bilinguals	English	Various L1s, L2 English	Alphabetical	Alphabetical
Whitford & Titone [39]	Bilinguals		L1 French, L2 English	Alphabetical	Alphabetical
Whitford & Titone [40]	Bilinguals		L1 French, L2 English	Alphabetical	Alphabetical

Table 2. Basic Study Features.

Authors	Year	Comparisons	Type of Stimuli	Language of Stimuli	Stimuli Focus	Reading Eye Movement Measures
Nakamura et al. [30]	2021	Monolingual vs. Bilingual	Sentences	English	Natural reading + manipulation	First-pass reading time; Second-pass reading time
Friesen & Jared [38]	2007	L1 vs. L2	Paragraph	English and French	Natural reading	Gaze duration; Total reading time
Xiao et al. [32]	2023	Monolingual vs. Bilingual	Sentences	Chinese	Natural reading + manipulation	First fixation duration; Gaze duration; Total reading time
Patterson et al. [26]	2014	Monolingual vs. Bilingual	Sentences	German and English	Natural reading + manipulation	First fixation duration; First-pass reading time; Regression path (go-past time); Total reading time; Re-reading
Sagarra & Rodriguez [27]	2022	Monolingual vs. Bilingual	Sentences	Spanish	Natural reading + manipulation	First fixation duration; Gaze duration
Martin & Juffs [31]	2021	Monolingual vs. Bilingual	Sentences	English	Natural reading	Skipping rate; First fixation duration; First-pass reading time; Gaze duration; Regression path (go-past time); Total number of fixations
Demareva et al. [42]	2022	L1 vs. L2	Paragraphs	Russian and English	Natural reading	First fixation duration; Total reading time; Total number of fixations
Nisbet et al. [17]	2022	Monolingual vs. Bilingual	Sentences	English	Natural reading	Skipping rate; Total reading time; Total number of fixations
Rodriguez et al. [44]	2016	L1 vs. L2	Words	German and French	Natural reading	First fixation duration
Cheng et al. [15]	2020	Monolingual vs. Bilingual	Sentences	English	Natural reading + manipulation	First-pass reading time; Regression path (go-past time); Total reading time
Whitford & Titone [47]	2016	L1 vs. L2	Sentences	French and English	Natural reading + manipulation	Reading rate; Total number of regressions
Alhazmi et al. [22]	2018	Monolingual vs. Bilingual	Words	English	Natural reading	First fixation duration; Total number of fixations
Brothers et al. [29]	2021	Monolingual vs. Bilingual	Sentences	English	Natural reading + manipulation	First-pass reading time; Regression path (go-past time); Total number of regressions; Total reading time

Table 2. *Cont.*

Authors	Year	Comparisons	Type of Stimuli	Language of Stimuli	Stimuli Focus	Reading Eye Movement Measures
Fujita and Cunnings [16]	2021	Monolingual vs. Bilingual	Sentences	English	Natural reading + manipulation	First-pass reading time; Gaze duration; Regression path (go-past time)
Mor & Prior [48]	2022	L1 vs. L2	Sentences	Hebrew and English	Natural reading + manipulation	Skipping rate; First fixation duration; Gaze duration; Total reading time
Cui [33]	2023	Monolingual vs. Bilingual	Paragraph	Chinese	Natural reading + manipulation	First fixation duration; Gaze duration; Regression path (go-past time); Total number of regressions; Total reading time; Total number of fixations
Whitford and Joanisse [21]	2021	Monolingual vs. Bilingual	Paragraph	English and French	Natural reading	Gaze duration; Total reading time
Clahsen et al. [45]	2012	L1 vs. L2	Paragraph	English	Natural reading	First fixation duration; Gaze duration; Regression path (go-past time); Total reading time; Re-reading
Taylor & Mukai [36]	2023	L1 vs. L2	Words	Japanese and English	Natural reading	First fixation duration; Gaze duration; Total number of fixations
Bordag et al. [23]	2021	Monolingual vs. Bilingual	Paragraph	German	Natural reading + manipulation	Gaze duration; Total number of fixations
Sui et al. [37]	2022	L1 vs. L2	Whole book reading	Chinese and English	Natural reading	First fixation duration; Gaze duration; Regression path (go-past time); Total reading time
Whitford & Titone [35]	2012	L1 vs. L2	Paragraph	French and English	Natural reading	Skipping rate; First fixation duration; Gaze duration; Regressions in; Total reading time
Whitford & Titone [46]	2015	L1 vs. L2	Sentences	French and English	Natural reading + manipulation	Reading rate; Forward fixation duration
Maie & Godfroid [34]	2021	Monolingual vs. Bilingual	Sentences	English	Natural reading + manipulation	First-pass reading time; Regression path (go-past time); Re-reading; Total number of fixations

Table 2. *Cont.*

Authors	Year	Comparisons	Type of Stimuli	Language of Stimuli	Stimuli Focus	Reading Eye Movement Measures
Hoversten & Traxler [25]	2016	Monolingual vs. Bilingual	Sentences	Spanish and English	Natural reading + manipulation	Skipping rate; First-pass reading time; Gaze duration; Regression path (go-past time); Total reading time
Parshina et al. [18]	2021	Monolingual vs. Bilingual	Sentences	Russian and English	Natural reading	Skipping rate; First fixation duration; Gaze duration; Regressions out; Total reading time
Parshina et al. [19]	2022	Monolingual vs. Bilingual	Sentences	Russian and English	Natural reading	Skipping rate; First fixation duration; Gaze duration; Total reading time
Bosma and Nota [41]	2020	L1 vs. L2	Sentences	Frisian and Dutch	Natural reading	Skipping rate; First fixation duration; Gaze duration; Regression path (go-past time); Total reading time
Whitford & Joanisse [20]	2018	Monolingual vs. Bilingual	Paragraph	English and French	Natural reading	Skipping rate; First fixation duration; Gaze duration; Regressions out; Total reading time; Total number of fixations
Egan et al. [24]	2019	Monolingual vs. Bilingual; L1 vs. L2	Sentences	Welsh and English	Natural reading + manipulation	First fixation duration; First-pass reading time; Gaze duration; Regression path (go-past time); Total reading time; Total number of fixations
Dirix & Duyck [43]	2017	L1 vs. L2	Words; Whole book reading	Dutch and English	Natural reading	First fixation duration; Gaze duration; Total reading time
Winskel et al. [28]	2009	Monolingual vs. Bilingual	Sentences	Thai and English	Natural reading + manipulation	First fixation duration; Gaze duration; Total reading time; Total number of fixations
Conklin et al. [14]	2020	Monolingual vs. Bilingual	Passages	English	Natural reading	Skipping rate; First fixation duration; First-pass reading time; Total number of regressions; Total reading time; Total number of fixations

Table 2. *Cont.*

Authors	Year	Comparisons	Type of Stimuli	Language of Stimuli	Stimuli Focus	Reading Eye Movement Measures
Whitford & Titone [39]	2017	L1 vs. L2	Paragraph	French and English	Natural reading	Skipping rate; Gaze duration; Regression path (go-past time); Regressions out; Regressions in; Total reading time
Whitford & Titone [40]	2019	L1 vs. L2	Paragraph	French and English	Natural reading	First fixation duration; Gaze duration; Regression path (go-past time); Total reading time

4. Discussion and Conclusions

4.1. Bilingual vs. Monolingual

Twenty-one studies compared eye tracking measures of monolinguals and bilinguals during reading. These studies included alphabetic and non-alphabetic orthographies, employed natural reading tasks or tasks with some type of manipulation, and analyzed different eye movement measures according to the goal of the study. Findings propose an interplay between factors like syntax and grammar, lexical processing, exposure to language, and individual differences. In general, bilinguals were slower at reading, as demonstrated by longer fixations, more fixations, more saccades, and lower skipping rates. However, compared to bilinguals, monolinguals reading in their language appeared to be more sensitive to violations, showing longer fixations in incorrect trials [27] or in temporary ambiguous sentences [29]. Nevertheless, there were other factors affecting bilinguals' performance. For example, Brothers et al. [29] and Parshina et al. [18] found that bilinguals with more exposure to a second language have similar eye movement behavior to monolinguals, finding that interesting because one of them compared a non-alphabetic orthography to an alphabetic one.

Although bilinguals' reading was usually slower compared to monolinguals, there were factors, besides language exposure, that might play a part in these results. One explored variable was the characteristics of L1 in L2 reading. Nisbet et al. [17] compared the performance of English monolinguals to German–English bilinguals and Finnish–English bilinguals; their findings discussed how the similarities between German and English might facilitate processing English as a L2, while the differences between Finnish and English might work as a difficulty. These factors are discussed in the section "study variables".

4.2. L1 vs. L2

Fourteen studies examined how bilingual individuals' first and second languages impacted eye tracking performance during reading. The bulk of these studies examined alphabetic orthographies, employed natural reading tasks, and used gaze duration and/or total reading time as outcome variables. Findings suggest intricate interplays between language memory, cross-linguistic transfer, and lexical processing. For instance, Friesen and Jared [38] and Whitford and Titone [39,40] found synonyms, cognates, and word frequency to influence reading times, suggesting that meaning transfer occurs independently from the text's surface form.

The impact of current L2 exposure on word processing emerges as a recurrent theme, indicating a facilitative effect on L2 processing and a nuanced influence on L1 reading fluency. For example, Bosma and Nota [41] and Rodriguez et al. [44] found that language dominance and orthographic transparency affected reading speed and eye movement patterns. Furthermore, investigations into morphological processing and grain size adjustment, as observed by Clahsen et al. [45] and Egan et al. [24], provide compelling evidence of the adaptability and complexity inherent in bilingual reading. Their findings suggest that bilinguals can fine-tune their reading strategies based on language-specific characteristics and proficiency levels, thereby supporting theories like the frequency-lag hypothesis and the lexical entrenchment approach.

Only two studies, by Taylor and Mukai [36] and Sui et al. [37], examined non-alphabetic languages, Japanese and Chinese, respectively. Their results illuminate how phonological similarities and language opacity uniquely influence reading behaviors in L1 and L2, often resulting in prolonged reading times and altered eye movement dynamics in L2 contexts. Such findings underscore the distinct cognitive mechanisms engaged by bilingual individuals when navigating between structurally diverse linguistic systems.

4.3. Study Variables

Among the reviewed studies, the effect of L2 proficiency ($n = 14$) was the most frequently investigated variable, followed by orthographical characteristics ($n = 10$). Other variables included the effect of a task ($n = 9$), age of acquisition ($n = 7$) and "other" (a particular manipulation in a study; *n* = 13). The studies can fall into more than one category; however, given their prominence compared to other variables, orthographical characteristics and the effects of proficiency will be discussed in more depth in the following sections.

4.4. Effects of Orthography/Orthographical Characteristics

Taken together, the findings from Cui [33], Egan et al. [24], Friesen and Jared [38], Demareva et al. [42], Rodriguez et al. [44], Whitford and Titone [40], Taylor and Mukai [36], Sui et al. [37], Martin and Juffs [31], Mor and Prior [48], Winskel et al. [28], and Xiao et al. [32] shed light on the relationship between orthographical characteristics and reading in bilingual individuals. For example, findings from Friesen and Jared [38] and Rodriguez and colleagues [44] illuminate the role of language structure. Friesen and Jared found that bilinguals transfer reading strategies based on the shared meaning and orthography across languages. On the other hand, Rodriguez and colleagues found that transparent and opaque languages led to different reading strategies. These studies suggest that orthographic transparency and language-specific characteristics influence reading, with transparent languages promoting more serial and local strategies and opaque languages encouraging parallel and global strategies.

When compared to monolinguals, bilinguals seem to be affected differently by the characteristics of their L1. Martin and Juffs [31] found differences between two groups of bilinguals, when reading in a their L2 (English), although their levels of proficiency and reading skills were comparable. They compared L1 Arabic speakers and L1 Chinese speakers. Both non-native groups were less sensitive to vowel grapheme–phoneme consistency compared to native speakers. Arabic uses a consonantal system, meaning that they do not write vowels, driving a strategy where vowels are ignored [31]. This can affect such individuals during their processing of vowels when reading English, causing downstream variations in eye movements as indicated by first-pass metrics. On the other hand, Chinese entails informationally dense characters such that ignoring certain stimuli in reading/writing (e.g., the vowels) is not as beneficial.

Moreover, Nisbet et al. [17] also compared two groups of bilinguals to monolinguals in a reading task in English and found that participants' L1 was related to their reading skill in L2. They compared reading performance of bilinguals from two transparent languages: German and Finnish. However, other characteristics of the languages make English more closely related to German than to Finnish. The authors proposed that this linguistic distance might affect the acquired reading skill in L2 (English) because participants who had German as their L1 were able to achieve native-like proficiency while reading short words and high-frequency words, whereas L1 speakers of Finnish could not achieve "native-like" proficiency at all.

Demareva and colleagues [42] found that higher proficiency in a foreign language was associated with faster reading rates and larger saccade amplitudes, indicating more efficient processing of orthographic information. Moreover, they also compared the eye movement of highly proficient L2 speakers of English who had Russian as their L1. They found differences in fixation duration and saccade length. These differences might be related to the different alphabets (Cyrillic and Latin) used by these orthographies, and by the linguistic density in each language. Similarly, Sui and associates [37] found that reading times in L2 are longer and more variable than in L1, emphasizing the role of orthographic familiarity in reading efficiency.

Whitford and Titone [40] as well as Mor and Prior [48] provide insights into the interplay between orthographic properties and bilingual word recognition. Whitford and Titone found that cross-language neighborhood density facilitated lexical access, suggesting that orthographic similarities across languages can aid in word recognition. Mor and Prior's findings provide further support for this by showing that vocabulary knowledge and the ability to predict upcoming words based on orthographic cues influence L2 lexical access efficiency. Winskel et al. [28] and Cui [33] explored the effect of interword spacing in monolinguals and bilinguals. They found that bilinguals were affected by the lack of spacing, even when they have been studying the language for several years.

Finally, Taylor and Mukai [36] expanded on the theme of cross-linguistic influences, demonstrating that phonological and semantic similarities, as well as cognate frequency, significantly impact reading in both L1 and L2. Their findings align with the Bilingual Interactive Activation Plus (BIA+) model, suggesting that orthographic information is processed early and influences later stages of reading.

Taken together, these studies demonstrate the importance of considering L1 characteristics during L2 reading. For instance, even when proficiency was controlled for, some characteristics of L1 facilitated certain participants' reading performance to the extent that they achieved native-like proficiency. It is important to understand the role of characteristics related to specific languages in achieving L2 reading, especially those not present in English. Daniels and Share [50] stated that many reading theories focus only on characteristics present in the English orthography and therefore proposed other characteristics to help clarify the universal and language-specific processes related to reading. Our findings indicate that, even for same-alphabet writing systems (e.g., English, German, and Finnish), other characteristics, like morphology and transparency, affect eye movement behavior of bilinguals. Furthermore, the strategies used to read in one's first language may not transfer to a second language, as demonstrated by differences between transparent and opaque languages and differences between vowel- and consonant-based writing systems.

Most investigations of reading in different orthographies have focused on the degree of grapheme–phoneme correspondence [50] and tend to overlook factors also related to reading acquisition. For instance, acquiring a second language that has a different directionality (i.e., read from left to right) than one's native language may affect reading acquisition in that second language negatively. Moreover, differences in orthographies between languages pose a challenge for researchers who must create equivalent stimuli despite such variations (e.g., [7]). Remaining aware of L1 effects on L2 performance can help guide researchers in both designing better-designed experiments as well as forming more accurate interpretations of results. It should also be noted that several studies in this review did not report the L1 background of the participants or failed to analyze effects of different linguistic backgrounds on L2 reading. Future studies should take into account the impact of L1 characteristics on L2 reading in order to better delineate their hypothesized effects from error or false positives that may arise from native language effects.

4.5. Effects of Proficiency

Studies by Whitford and Titone [35,39], Mor and Prior [48], Demareva et al. [42], and Clahsen et al. [45] collectively offer insight regarding the relationship between language proficiency and reading in bilingual individuals. For instance, Clahsen and associates [45] found that L2 learners, due to less proficiency, process morphologically complex words differently from native speakers, relying more on lexical properties and less on grammatical analysis. Findings from Whitford and Titone [39] indicate older adults show larger word frequency effects and, as a result, reduced lexical efficiency. Importantly, however, the impact of L2 experience on word processing diminishes with age, implying a ceiling effect in lexical accessibility due to lifelong bilingualism. Whitford and Titone [40] further note that lower L2 exposure leads to larger word frequency effects in L2, implying that proficiency influences lexical activation and reading strategies. Mor and Prior [48] add that vocabulary knowledge and the ability to predict words contextually are vital for L2 reading efficiency, with less proficient readers showing larger effects, suggesting they employ compensatory strategies. Lastly, Demareva [42] observes that higher proficiency in a foreign language correlates with faster reading and more efficient eye movement, indicating proficiency's role in cognitive load and processing during reading. Together, these studies underscore that L2 proficiency critically shapes language processing, reading efficiency, and the strategies bilingual individuals employ to comprehend text. Furthermore, the apparent L2 proficiency effects of bilinguals' eye movement performance approximate those of native readers (e.g., [42]), suggesting similar cognitive processes used between L1 and L2 reading. It is important to consider proficiency as a factor when studying bilinguals' reading skills to better clarify differences due to a lack of L2 proficiency versus the characteristics of the language itself. The effect of proficiency in L2 reading is particularly interesting given that previous research with monolinguals from different orthographies has shown children's eye movement behavior to initially vary between languages and become more homogenous over time and gains in proficiency [7]. It thus appears that improvements in reading involve more universal processes, suggesting that expert readers (whether they are monolingual or bilinguals) may be more similar than they are different.

4.6. Implications for Theory and Practice

Our findings have the potential to improve empirical approaches used to explore bilingual reading and highlight the importance of several factors when designing such experiments and interpreting their results. Characteristics of a bilingual's first language will affect their L2 reading in different ways. For example, if the orthographies of L1 and L2 are similar, L2 reading may be less affected compared to if the L1 and L2 orthographies are more different. Therefore, understanding the characteristics of L1 and the similarities and differences between one's L1 and L2 can inform instructional practices. It has been established that cross-linguistic transfer facilitates L2 reading acquisition by allowing the reader to recognize L1 features during L2 reading, which ultimately enhances their conceptual understanding and skill application for both languages. Recognizing which factors come to bear on L2 reading acquisition is crucial for improving reading programs for bilinguals. Moreover, findings of these studies support that improved L2 proficiency positively impacts L2 reading proficiency, implying the need to focus instruction on improving oral proficiency in order to improve reading proficiency. It should also be noted that, although highly proficient L2 readers approximated monolingual readers' eye movement performance, this effect was modulated by the characteristics of the L1 orthography. This indicates that bilinguals whose L1 and L2 are relatively more similar are, in turn, more prone to facilitatory effects. Our findings emphasize the importance of considering L2 proficiency and L1 and L2 characteristics (beyond merely considering transparency) when designing and conducting investigations of bilingual reading processes.

Advances in technology are enhancing researchers' ability to approximate naturalistic reading contexts, allowing for eye tracking findings to carry more empirical weight when translating findings to real-world applications. Such findings, for instance, can be leveraged to improve assessment and identification of children with reading difficulties (e.g., [51]) and to better understand reading disorder severity (e.g., [52]). Although most of the research has been conducted using monolinguals, improving our understanding of eye movement behavior in bilinguals can improve our approaches to identifying bilingual children at risk of reading difficulties.

Furthermore, recent strides in mobile technology have begun to afford researchers the opportunity to examine eye movements in settings like classrooms. For instance, Valliappan et al. [53] explored the use of smartphones as eye trackers and were able to replicate previous lab-based findings.

5. Limitations and Future Research

We believe that having an open criterion about the eye movement measures to select the articles decreased our ability to achieve generalizable conclusions. As different studies used different measures, one way to improve the conclusions would be to focus on a particular measure (or measures) that reflects a singular process. Focusing on only one type of characteristic or task might facilitate the analysis and comparison of studies. Conklin and Pellicer-Sánchez [6] proposed that standardizing eye tracking methodologies is crucial; we agree with this statement. Using the same measures might help replicate the results or shed light on which measures are helpful for which processes.

Another limitation we encountered was the definition of L1 speaker. As there was no consistency between these terms, it was hard to identify monolingual groups unless it was explicitly stated in the study. Many studies did not clarify if their L1 speakers were monolinguals or bilinguals. In our initial screening criteria, we attempted to include bilingual participants that spoke only two languages with the speculation that it would be easier to draw conclusions about findings given fewer confounding factors related to multiple languages and their characteristics. However, we found that most studies only mentioned L1 and L2 readers, and in some cases did not include more information from the participants' language background. This impacted our ability to differentiate comparisons of monolinguals and bilinguals. For example, some between-subject studies described their participants as merely "L1 readers" and "bilinguals", and never explicitly stated whether participants were monolinguals. Based on the findings from this review, and the effect of L1 in L2 reading, we believe it is important to consider as much information as possible from the language background to improve our understanding of reading processes in bilinguals.

Future studies should report participants' L2 proficiency and the characteristics of both languages as each of these factors are known to affect eye movement behavior in L2 reading. It is also important to delineate different L1 backgrounds of participants rather than grouping them together as an aggregate participant group. Given that differences between L1s may have their own effects on L2 reading, these effects may confound those that are hypothesized to exist between L1 and L2.

Researchers should also be mindful of the interaction between language proficiency and experimental stimuli. Although improvements in L2 proficiency can reduce performance differences between bilinguals and native speakers, this has been shown to be mediated by characteristics of L1. Thus, when designing tasks, researchers should remain vigilant of participants' L2 proficiency as well as factors like L1 and L2 orthographies.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/educsci14040375/s1, Table S1: Reliability of the accepted studies.

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