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Eye-tracking in vocabulary research: Introduction to the special issue

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ABSTRACT

Vocabulary researchers are increasingly making use of the eye-tracking method to investigate topics that were traditionally examined using offline tests. Eye-tracking provides a direct measure of processing effort and attention allocation to lexical items. Previous research has provided useful insights about how different types of lexical items are processed in context and of the factors that affect processing patterns. More recent research has also contributed to our understanding of how unknown lexical items are processed in different learning conditions and its relation to learning gains. While eye-tracking has clearly supported researchers in gaining a clearer and more comprehensive understanding of vocabulary processing and learning, and has become a crucial tool in vocabulary research, currently there are no methodological discussions of eye-tracking with a particular focus on vocabulary. This special issue aims at addressing this gap and provides a detailed discussion of the uses and applications of eye-tracking in vocabulary research. This introduction to the special issue provides a brief review of current topics in eye-tracking based vocabulary research, identifying the main gaps that the special issue sets to answer, and introduces the different contributions of the special issue. The collection of papers that constitute this special issue aims at supporting researchers in conducting eye-tracking studies on lexical processing and learning and thus will help to move the field forward.

Introduction

Eye-tracking, which refers to the recording of eye movements, has been used for decades in cognitive psychology as a tool to measure online processing behavior. The use of eye-tracking to examine cognitive processing tasks is based on the eye-mind hypothesis, namely the assumption that the eye is a window to the mind (Just & Carpenter, 1980). This means that the amount of time spent fixating an item reflects the cognitive effort involved in processing it. One of the main advantages of the eye-tracking method is that it provides a direct measure of processing effort during a task, without the need to employ a decision, recall, or production task, which can be subject to strategic effects (Conklin et al., 2018). Its temporal precision allows researchers to obtain a rich record of behaviour from the initial perception of the visual stimulus until it disappears, or participants stop looking at it (Pellicer-Sánchez & Conklin, 2020).

In recognition of these benefits, applied linguists have recently started to use eye-tracking to examine topics that were traditionally examined with offline measures. In the last decade, we have witnessed a remarkable increase in the number of eye-tracking studies.

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This increased interest has been reflected in the publication of recent monographs (Godfroid, 2020; Conklin et al., 2018), special issues (e.g., Godfroid et al., 2020; Winke et al., 2013), and multiple papers and chapters in methodology books introducing the technique to applied linguists (e.g., Godfroid & Hui, 2020; Conklin & Pellicer-Sánchez, 2016, 2022; Pellicer-Sánchez et al., 2022; Pellicer-Sánchez & Siyanova-Chanturia, 2018). Among the various topics that have been investigated using eye-tracking in second language acquisition and bilingualism research, vocabulary has been identified as one of the main strands in text-based eye- tracking studies (Godfroid, 2020). An ever-increasing number of vocabulary researchers are using eye-tracking as a method to explore the cognitive processes underlying the processing and learning of vocabulary. However, very few of the existing methodological discussions on eye-tracking have focused on vocabulary. While the recent methodological guides have provided useful information for researchers on how to conduct eye-tracking studies, there is currently no methodological discussion on eye-tracking with a particular focus on vocabulary. The aim of this special issue is thus to present a detailed discussion of the different applications of eye-tracking in vocabulary research, supporting researchers in advancing the field in the most innovative directions.

Current topics in eye-tracking based vocabulary research

In eye-tracking based vocabulary research, we can identify two main strands: (1) studies focusing on lexical processing, i.e., the examination of how lexical items are processed and factors affecting processing patterns; (2) and studies looking at lexical learning, i.e., the investigation of how unknown lexical items are processed in various input and instructional conditions and its relationship with learning gains. In what follows, we provide a brief summary of topics addressed in these two strands and identify the main gaps that the special issue attempts to address.

Eye-tracking and lexical processing in reading

The examination of lexical processing in reading and the description of how words of different properties are processed is crucial to understand the nature of language comprehension and perception. This understanding is also important to build models of lexical development in language learning. Decades of eye-tracking research on reading have provided a very rich understanding of how words are processed in written input and of the many factors that affect processing patterns. The two basic components of eye movements in reading include *saccades*, i.e., the rapid movements of the eyes, and *fixations*, i.e., moments when the eyes remain still. It is during fixations that new information is processed. Fixation durations in silent reading are on average 225–250 milliseconds (ms) and the average saccade length is 7–9 letter spaces. When we read our eyes also move back to earlier parts of a text, i.e., *regressions*. Around 30 % of the words in a text are skipped, with content words being fixated about 85 % of the time and function words about 35 % of the time. Fixation durations on a word are influenced by many different factors including word length, word frequency, familiarity, and predictability, with shorter, higher frequency, and more familiar and predictable words expected to receive shorter and fewer fixations. These factors have been explored in the L1 reading context and to a lesser extent in L2 reading (see Rayner, 2009 for a discussion of main characteristics of eye movements in reading). While traditionally vocabulary research focused on the examination of single words, it is now widely acknowledged that vocabulary knowledge involves knowing lexical items beyond the single word (e.g., idioms, collocations, binomials, lexical bundles, etc.). Eye-tracking has also become a crucial tool in the examination of how multi-word expressions (MWEs) are processed, contributing to our understanding of the mechanisms behind the processing of items above the single-word level. Studies conducted in the last decade have generally reported a processing advantage of various types of MWEs over novel (non-formulaic) phrases (although not reported for all types of phrases in the L2) and have provided useful insights about the factors that explain this processing advantage (e.g., phrase frequency, familiarity, predictability, decomposability, among others). Recent research has also shown that phrase frequency is a major predictor of the processing advantage experienced by different types of MWEs, but that additional effects are shown depending on the properties of the specific type of phrases (Carrol & Conklin, 2020). While existing research has shed light on our understanding of the online processing of formulaic language (see Siyanova-Chanturia & Van Lancker Sidtis, 2019; Conklin, 2020 for an overview), our understanding of the factors that affect different types of MWEs continues to develop.

The vast majority of eye-tracking studies examining lexical processing have focused on reading-only conditions and, while written input is often combined with auditory input, very few studies have described processing patterns in reading-while-listening conditions (e.g., Conklin et al., 2020). The existing research suggests that when auditory input is presented both L1 and L2 readers tend to read ahead of the audio, with L2 readers' eye-movements being more aligned with the audio (Conklin et al., 2020). While this recent research has helped to explain some of the advantages traditionally attributed to reading-while-listening, our understanding of lexical processing in these conditions is still limited.

The increase in eye-tracking studies examining the processing of vocabulary in written input has permitted the compilation of big databases of eye movements (e.g., Cop et al., 2016; Kuperman et al., 2023; Siegelman et al., 2022). These eye-tracking corpora present an excellent opportunity to examine vocabulary processing, but few studies have used these data to study word processing. In order to advance this promising line of research, we need to gain a better understanding of how these databases can be best used to examine crucial questions in lexical processing.

Eye-tracking and vocabulary learning

As indicated above, besides studies examining the processing of single words and multi-word units, eye-tracking has also been used in vocabulary research to examine the learning of unknown vocabulary in written input. It is widely acknowledged that successful

vocabulary learning depends on the degree of attention to and engagement with the unknown lexical items (Schmitt, 2008). Eye-tracking has proven to be an excellent measure of attention to unknown lexical items in reading. Research in this area has been able to show not only the amount of novel words that are learned from reading but also how those words are processed during reading and its relationship with learning gains. Studies have consistently reported increased attention to novel words when compared to familiar words (e.g., Godfroid et al., 2013; Williams & Morris, 2004), and a decrease in reading times as a function of number of encounters (e.g., Elgort et al., 2018; Pellicer-Sánchez, 2016, 2021), with some studies suggesting a positive relationship between processing time and learning gains (e.g., Godfroid et al., 2013; Pellicer-Sánchez, 2016; Yi & DeKeyser, 2022; see Pellicer-Sánchez, 2020, for a discussion). Researchers have also used eye-tracking to investigate how the application of various techniques can drive learners' attention to the unknown vocabulary. Studies in this area have shown, for example, that textual enhancement techniques (e.g., bolding) lead to increased attention (e.g., Choi, 2017), and that instruction prior to reading seems to lead to a processing advantage (e.g., Pellicer- Sánchez et al., 2022). The most recent eye-tracking research on vocabulary learning has started to make use of the gaze contingency paradigm, i.e., stimulus that responds to the participant's gaze, to maximize learning opportunities from written input. Révész et al. (2023) examined the effect that interactive glosses, i.e., glosses that are made visually salient when triggered by fixations on a target word, had on the processing of unknown vocabulary, and reported more and longer fixations on the target words in this interactive condition. While this is a novel and promising application, very little is known about how the gaze contingency boundary paradigm should be used in vocabulary learning studies.

While most of these eye-tracking based vocabulary learning studies have focused on exploring vocabulary learning from reading, a number of studies have also investigated vocabulary learning from multimodal input such as captioned (i.e., subtitles in the L2) audio-visual input. Since this type of input is dynamic in nature with timed on-screen text and moving images, word processing may be different from word processing in (static) text-based eye-tracking studies. In addition, the input presents redundancy (e.g., overlap between spoken text and captions) which means that processing may not only happen in the written text. Previous research has examined how learners' reading times in captions relate to vocabulary learning gains (e.g., Montero Perez et al., 2015; Wang & Pellicer-Sánchez, 2022), and whether textual enhancement influences reading times in captions (Puimège et al., 2021). Studies have shown that reading times on a given word are related to vocabulary post-test scores for that word, with longer reading times related to higher learning gains for single words (e.g., Wang & Pellicer-Sánchez, 2022) as well as for multiword units (Puimège et al., 2023). In addition, it was found that textual enhancement in the captions (bolding and underlining) induced longer reading times and less word skipping (Puimège et al., 2023). However, more research in this area is needed, especially concerning the specific challenges associated with the timed and dynamic nature of the input and how this influences L2 learners' vocabulary processing.

Eye-tracking based vocabulary research has contributed to our understanding of the processes underlying vocabulary learning in a variety of contexts. However, important limitations have also been identified. While eye-tracking has proven to be a useful measure of attention in various learning conditions, researchers have claimed that the underlying cognitive mechanisms are often difficult to identify. Longer reading times of novel items could be reflecting participants' conscious effort to encode the new form and its meaning to memory, or it could also be a sign of comprehension difficulties. For example, in the context of learning from viewing, Montero Perez (2019) found similar fixation data for words that had been taught before the viewing activity and for words that had not been taught, and suggested that while fixation times for pre-taught items could reflect rehearsal or retrieval practices, fixation times on items that had not been learned prior to the viewing activity could be indicative of participants' lack of familiarity with the word. Examining eye movements to lexical items on its own does not allow us to identify specific underlying processes. Thus, researchers have started to suggest the combination of eye-tracking with other measures, such as stimulated recalls or ERP recordings, to provide a more comprehensive view of the cognitive processes involved in vocabulary learning (e.g., Godfroid & Winke, 2015). While there is clear potential in the combination of eye-tracking with other techniques (see Godfroid et al., 2020), there has been little discussion in vocabulary research on how this novel combination and triangulation of methods should be conducted.

As shown above, eye-tracking based vocabulary research has provided a wealth of findings but has also shown some notable gaps. While the eye-tracking technique has achieved a certain level of maturity in the field, a detailed discussion of its various strands and applications is necessary to support vocabulary researchers in advancing the field in these innovative directions. This special issue presents a collection of six articles from leading researchers in the field of eye-tracking based vocabulary research, addressing the gaps identified in this section and providing an overview and discussion of the different uses of eye-tracking in vocabulary research so far as well as novel applications.

Overview of the special issue

The special issue consists of a variety of manuscript types (research review, empirical article, brief report, and method tutorial), representing the existing diversity within this growing field of research, and addressing the gaps identified in the previous section. The first five contributions can be categorized around two main themes: studies presenting specific applications of eye-tracking in vocabulary research (Siyanova-Chanturia & Fioravanti with multiword expressions; Conklin & Alotaibi on reading-while-listening; and Elgort & Veldre on the gaze-contingency boundary paradigm); and those exploring the combination of eye-tracking with other methods (Wang & Pellicer-Sanchez on the combination of eye-tracking with stimulated recalls; and Conklin & Pulido on eye-tracking and EEG). The final paper adopts a broader focus and calls for larger studies with eye movements and discusses applications of eye-movement corpora (Brysbaert & Drieghe). Each of the contributions are now introduced in turn.

As argued in the previous section, while eye-tracking has become a crucial tool in the examination of the processing of different types of MWEs, our understanding of the factors affecting the various types of MWEs continues to develop. Siyanova-Chanturia and Fioravanti's contribution addresses this gap and discusses key methodological issues that should be considered in eye-tracking studies

on the processing of MWEs. The authors first show how eye-tracking has been instrumental in gaining deeper insights into the processing of MWEs and of the various properties that affect processing patterns, including frequency, figurativeness, literality, familiarity, transparency, predictability, semantic association, collocation strength, contextual predictability, adjacency, flexibility, modifiability, and congruency. The authors identify four main methodological issues that are particularly relevant in the design of studies on the processing of MWEs: (1) key properties to consider in the selection of different types of target MWEs (e.g., frequency and association for collocations); (2) selection of areas of interest (AOIs) that are relevant for the study of various types of phrases; (3) selection of relevant eye-tracking measures; (4) and creation of different experimental conditions, with a focus on the design of control conditions. After the presentation of these key methodological aspects, the authors provide a review of 25 experimental studies that investigated the effect of different properties of MWEs on the processing of three types of MWEs (i.e., idioms, collocations, and binomials), focusing on how the aforementioned methodological issues have been implemented in those studies.

Much of the knowledge we have accumulated on lexical processing (both single words and multiword units) has come from studies examining the processing of various types of lexical items in reading-only conditions. Investigations of lexical processing need to be conducted in other input conditions that language users are frequently exposed to. Conklin and Alotaibi's contribution responds to this need by discussing methodological considerations in eye-tracking studies on reading-while-listening. The authors first provide a brief discussion of some of the general considerations when designing eye-tracking studies involving written input, such as position of regions of interest (ROIs), text format, or considerations when comparing reading-while-listening to reading-only conditions. The authors then move on to discuss the main methodological considerations when timelocking audio input with eye movements, which will be important for many studies on reading-while-listening. Detailed guidelines are provided to help researchers to align the occurrence of each word of interest in the audio input to fixations on the screen. These include technical considerations such as the use of computers with good audio timing, compatible sound card drivers, and the use of audio editing software to extract the onset and offset times in the audio stream for the target lexical items. The authors provide detailed examples showing how to extract audio timings using audio editing software. They go through the different steps that need to be taken to find out what participants are fixating when a particular word occurs in the audio input. They then discuss other important considerations of the eye-audio synchronization related to the quality of the audio files and the instructions given to participants. The report finishes with a discussion of main considerations in data processing. The authors explain how the data can be used to determine whether fixations to a particular word are aligned to the occurrence of the same word in the auditory input and the different criteria that can be used to define 'alignment' in these studies. Notably, the considerations presented are relevant both for studies on lexical processing and learning.

Previous eye-tracking research has asked whether word processing starts before our eyes fixate the word or whether an upcoming word can already be processed while the eyes are still fixating a previous word. The latter is called parafoveal processing. However, research on what can be processed parafoveally has received limited attention in L2 learning contexts. In order to address this gap, Elgort and Veldre present a methodological review on the use of the gaze-contingent boundary paradigm (Rayner, 1975). This paradigm is an experimental eye-movement-based research method in which a critical word in a text is replaced by another word (e.g., a pseudoword) until the readers' eyes land just before the target word. When the eyes cross this boundary, the word is replaced by the actual target word. Using this technique, there is thus a difference between the information that was available and the actual information. The study presents the results of a methodological synthesis of 13 articles on the gaze-contingent boundary paradigm in L2 and bilingual reading research. Importantly, Elgort and Veldre argue that the paradigm holds great potential for studies which measure the effects of instructional interventions on vocabulary learning and for L2 vocabulary research in general. For instance, they argue that the model can refine theories on L2 lexical development because it provides a measure to test L2 processing without awareness. Finally, the article provides methodological guidance (e.g., stimulus creation, experimental design) for setting up a study using the boundary paradigm in L2 research.

As argued in the previous section, a combination of eye-tracking and EEG can be considered to refine our understanding of word processing in input. However, since there are currently no studies which have used a combination of these methods in the field of vocabulary learning, a methodological discussion is warranted. In their article, Pulido and Conklin discuss the basic concepts and specificities of eye-tracking and EEG research separately before turning to the unique methodological features of co-registration, that is, the simultaneous and synchronized recording of eye movements and EEG during an experimental study. The authors illustrate the potential of this technique using an existing eye-tracking study (Pellicer-Sánchez, et al., 2022) on the role of pre-learning vocabulary prior to text reading. More specifically, the authors address how this study could be adapted for co-registration. They note first of all that the study should be designed in accordance with methodological requirements of both eye-tracking and EEG. For instance, whereas eye-tracking can be used in both a between and within-subject design, an EEG study requires within-participant brain potentials in order to obtain baseline data. In addition, they consider the role of trial items as well as the study design.

The recent call for triangulation of eye-tracking with other methods is further addressed by the contribution by Wang and Pellicer-Sánchez. In this brief report, Wang and Pellicer-Sánchez discuss in detail how eye-tracking and stimulated recall data can be combined in vocabulary learning research. In particular, the authors propose to use this triangulation of methods to examine vocabulary processing strategies and levels of awareness, two key aspects of cognitive processing during vocabulary learning. The commentary presents two worked examples using data collected by Wang (2022) on incidental vocabulary learning from subtitled viewing. The first worked example aims at examining the association between reported awareness of unknown vocabulary and amount of attention to the target vocabulary during captioned viewing, while the second example aims at exploring the relationship between participants' reported vocabulary processing strategies and the amount of attention paid to unknown vocabulary. The detailed worked examples present various ways in which data can be analysed to achieve these aims. After presenting the benefits of the combination of eye-tracking and stimulated recalls in the two examples, the authors discuss the main methodological challenges of such a combination, particularly in relation to aspects of the research design and data analysis (e.g., use of eye movements as prompts in stimulated

recalls; integration of quantitative and qualitative data in the analysis). The ultimate goal of this contribution is to support vocabulary researchers interested in exploring this combination of methods to investigate vocabulary learning and help to expand this line of research.

Eye-movement corpora, which consist of a large collection of eye movement data, can further advance research on word processing. So far, however, a thorough methodological discussion on the role of these corpora for word processing is lacking. Brysbaert and Drieghe fill this gap with their article on the use of eye-movement corpora in vocabulary research. They start off with a discussion on the complexity of language experiments and the difficulty to obtain full control over conditions. In addition, experiments are often limited in duration which means that many word features cannot be manipulated. They argue that correlational analyses between non-manipulated variables present important research opportunities as long as they are based on large datasets (e.g., megastudies). In their paper, they use examples from previous research to demonstrate the importance of eye-movement corpora. Eye-movement data collected while reading a text are considered to be one of the most natural ways to study visual language processing. Drawing on the richness of these data, Brysbaert and Drieghe make a case for performing secondary analyses, these are additional analyses which are performed on existing (large) datasets. Such analyses can further refine our understanding of language and word processing while reading and clarify factors that influence processing. In their paper, they illustrate the complexity of word processing by discussing factors which may influence gaze duration besides the word itself such as parafoveal processing, spill-over effects, and word predictability. Even though secondary analyses might have important implications for vocabulary research, the availability of these types of corpora is still fairly limited. They therefore conclude their paper with a call to share the data from eye-movement studies. These datasets can be combined in a larger corpus which can then be used for secondary analyses.

Taken together, the six contributions that form this special issue provide readers with in-depth discussions of the various uses to which eye-tracking has and can be put for in vocabulary research and thus supports vocabulary researchers in advancing the field in these directions. The papers in the special issue constitute an important methodological resource in the field as they support researchers in expanding eye-tracking based vocabulary research beyond what has been the focus of the majority of existing investigations, i.e., processing of single words in written input. It provides the background and resources needed to: investigate the processing of items beyond the single word (MWEs) and in combination with auditory input in reading-while-listening conditions; to combine eye-tracking with other data collection methods such as stimulated recalls and EEG; to further explore novel uses of eye tracking in the gaze contingent paradigm; as well as to make better uses of the existing eye-movement corpora in secondary analyses, and encouraging the compilation of new databases. Methodologically sound research in these areas will be a major contribution to our understanding of lexical processing and learning. It is our hope that the papers in this special issue will further contribute to eye-tracking based vocabulary research and inspire researchers to implement the discussed methodological insights in their future investigations.

CRediT authorship contribution statement

Ana Pellicer-Sánchez: Writing – original draft, Conceptualization. **Maribel Montero Perez:** Writing – original draft, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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