

EYE TRACKING SENTENCES IN LANGUAGE EDUCATION

RASTREAMENTO OCULAR DE PERÍODOS NA EDUCAÇÃO LINGUÍSTICA

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The present study reports and discusses the use of eye tracking qualitative data (static and dynamic gaze plots and heatmaps) in reading workshops in a middle school and in Generative Syntax and Sentence Processing courses at the undergraduate and graduate levels. Both endeavors take the sentential level as the proper object to be metacognitively explored in language education in order to develop innate science forming capacity and knowledge of language. In both projects non-discrepant qualitative eye tracking data collected and quantitatively analyzed in psycholinguistic studies carried out in LAPEX-UFRJ (Experimental Psycholinguistics Laboratory of the Federal University of Rio de Janeiro) were displayed to students as a point of departure, triggering discussions. Active, problem-solving based methodologies were employed with the objective of stimulating student participation. The article also discusses the importance of developing full literacy, epistemic vigilance and intellectual self-defense in an infodemic world.

Keywords: Eye tracking. Sentence. Reading. Language Education. Metacognition.

O presente estudo relata e discute a utilização de dados qualitativos de rastreamento ocular (mapas de fixação estáticos e dinâmicos e mapas de calor) em oficinas de leitura no ensino fundamental e em cursos de Sintaxe Gerativa e de Processamento de Frases na graduação e pós-graduação. Ambos os empreendimentos tomam o nível sentencial como o objeto apropriado a ser explorado metacognitivamente na educação linguística, a fim de desenvolver a capacidade inata de formação científica e o conhecimento da linguagem. Em ambos os projetos, dados de rastreamento ocular qualitativos não discrepantes coletados e analisados quantitativamente em estudos psicolinguísticos realizados no LAPEX-UFRJ (Laboratório de Psicolinguística Experimental da Universidade Federal do Rio de Janeiro) foram apresentados aos alunos como ponto de partida, gerando discussões. Foram utilizadas metodologias ativas baseadas em resolução de problemas, com o objetivo de estimular a participação dos alunos. O artigo também discute a importância de desenvolver o letramento pleno, a vigilância epistêmica e a autodefesa intelectual em um mundo infodêmico.

Palavras-chave: Rastreamento ocular. Período. Leitura. Educação linguística. Metacognição.

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1. Introduction

Eye tracking studies have taught us important lessons about the visual scanning of static and dynamic scenes and about reading processes. Since Javal (1879) pioneer stereoscope studies, we have learned that the human eyes do not glide smoothly on the lines of texts, but intermingle stops and jumps, foveally fixating areas of one to two degrees for accurate reading. Modern eye tracking has carefully established the relevance of eye movements in the investigation of the interfaces between language processing, attention, vision, and oculomotor control, spanning basic perceptual information on grapheme recognition and high-level cognitive processes.

Rayner (1998) gives a thorough overview of the research in the last two decades of the 20th century. Schroeder, Hyöna and Liversedge (2015) summarize the state of the art in eye tracking and outline the main research lines in studies presented in a special issue of the *Journal of Cognitive Psychology*, with special attention to developmental aspects of reading. We have learned from Rayner's review that there were three eras in eye tracking studies. The first followed Javal and Huey (1908) research until around 1920, establishing many basic facts concerning eye tracking, such as saccadic suppression, saccadic latency, and the perceptual span. The second era had a more applied focus during the behaviorist mainstream period and, as it could be expected due to the prevailing antimentalism, did not teach us much about cognitive processes. The third era started in 1970 and is responsible for major technological advancements and the development of theories of language processing. It was during this period that influential ideas such as the eye-mind hypothesis were proposed, discussed, and partially refuted. Just and Carpenter (1980) initially formulated the strongest version of the hypothesis, stating that "there is no appreciable lag between what is fixated and what is processed" (*cf.* p. 331). If this was strictly true, wherever our gaze is our attention and mind processing would also be, in a strong cognitive version of *WYSIWYG*.¹ Even though this strong formulation had the potential to provide researchers with a powerful rationale to study and make inferences about visual processing and directly correlate fixation latencies and saccadic movement patterns to attentional and cognitive processes, subsequent studies have disproved the strong version of the eye-mind hypothesis in the light of covert attention and gaze contingency facts. Wright and Ward (2008) reviews the literature on the orientation of attention in detail, including weaker versions of the eye-mind hypothesis, which seem to be more widely accepted nowadays.

Eye tracking has also had many applications ever since its inception with Laval in the turn of the 19th to the 20th century. Laval himself had an ophthalmological laboratory at the Sorbonne and, in addition to his pioneer original research on eye movements during reading, he had an applied interest in the study of strabismus and glaucoma. Duchowski

¹ According to the Oxford Dictionary, *WYSIWYG* (/ˈwɪziwɪɡ/ WIZ-ee-wig), is an acronym for What You See Is What You Get, referring to a system in which an editing software allows content to be edited in a form that resembles its appearance when printed or displayed as a finished product, such as a printed document, web page, or slide presentation.

(2002) discusses eye tracking applications in the fields of Neuroscience, Psychology, Engineering, Marketing/Advertising, in what he calls the fourth era of eye tracking, adding to Rayner's typology alluded above. This fourth era would be characterized exactly by the emergence of several interactive applications in many different areas.

An area in which eye tracking has been explored is the Human Factors Engineering (*cf.* Kovesdi, Spielman, LeBlanc & Rice 2017), pertaining to measurement, evaluation, and control of human visual behavior in different settings. In a world in which information collection is an important asset in marketing research with sophisticated systems to detect consumers' preferences, the detailed information on human visual behavior, such as the frequency of fixations and saccades, the progressive and regressive scan path with fixation durations in precise areas of the visual scanning process and even pupil diameter and blink rates, offers a very accurate tool to monitor citizens. If, on the one hand, smarter cities have been envisaged with the remote eye tracking capture of citizens' gaze, allowing hands free operation in cell phones, elevators, ATM bank machines and even including algorithms capable of detecting and preventing shoplifting behavior in stores, on the other hand, neo-totalitarian surveillance systems by means of mass monitoring of citizens with the objective of control and manipulation should not be discarded. Chomsky's 1986 characterization of Plato's and Orwell's problems² would also offer in our view a proper framework to analyze the different applications of the eye tracking technology. If the educational possibilities may be mindboggling, for example, in the coupling of eye tracking and virtual reality systems (VR), a burgeoning field (*cf.* Clay, König & König 2019), allowing preliminary explorations of VR 3D spaces of different natures, providing potentially transforming VR sensorial experiences yet to be fully explored in all fields of knowledge, the use of such systems for manipulation and control must be surveyed and in itself controlled in democratic societies.³ In this sense there is even urgency that universities and other scientific research institutions investigate and develop educational uses of the eye tracking technologies, creating expertise, and offering knowledge and democratic alternatives to surveillance and control as intellectual self-defense to societies. In July 2020, during the pandemic, the World Health Organization called the First WHO Infodemiology Conference intended to contribute "to understand, measure and control infodemics" (WHO 2020)⁴, the overabundance of information, especially low-quality manipulative information (fake news), people are massively exposed to in the world. The WHO evaluated that as the pandemic requires actions of epidemiological vigilance, the infodemic requires actions of epistemic vigilance. It is our intention that the educational proposals we advance in this article may take advantage of the eye tracking technology and contribute to improve language awareness, develop

² Chomsky (1986) characterizes the two most important intellectual problems which, in his view, deserve serious consideration and people's attention. Plato's problem is defined by the question "how can we know so much, if we have so little evidence?" and is discussed in terms of the poverty of stimulus problem in language acquisition. Orwell's problem is defined by the question "how can we know so little, if we have so much evidence?" and is discussed in terms of political, religious or corporate manipulation in societies.

³ Morais (2017) discusses the role of literacy in democracies, which he analyzes as actually pseudo-democracies where the public opinion is shaped by ideology and political marketing interests. In such contexts, scientists would have a collective responsibility in promoting full literacy, enhancing free, argumentative and critical thinking, inspired by humanist values.

⁴ https://www.who.int/health-topics/infodemic#tab=tab_1

language literacy, and enhance epistemic vigilance (*cf.* Sperber *et al.* 2010) at schools and universities, so students and society at large can be better equipped to face the challenges posed by infodemics.

The objective of the present article, therefore, is of course not to fully review the vast eye tracking basic and applied literature as a whole, but to focus on studies which report the educational use of eye tracking in order to set the foundations to allow the presentation and discussion of our own educational experiences with the use of qualitative analyses of eye tracking heatmaps and gazeplot videos, presentially in sentence reading workshops in a middle school, and later, in the remote classrooms we have been teaching linguistics in Brazil during the pandemic. In order to support both the reflections on the use of the eye tracking technology in sentence reading workshops in the middle school and in undergraduate and graduate linguistics classes at the university level, we need to discuss the concepts of sentence and metacognition, which we will take up, respectively, in sections 2 and 3 of the article, before we discuss the project in middle school in section 4 and the activities at the university in section 5. Section 6 will offer the final considerations of the article.

2. The case for the sentence

The study of the sentence is the focus of three subfields of Linguistics and Psycholinguistics that present issues that have been investigated in Brazil for more than two decades by the author of this paper: Grammatical Theory, Sentence Processing and Experimental Syntax. As we reviewed in Maia (2014a), the tensions between these areas can be better framed by the proposal of a single cognitive system, measured at different levels (*cf.* Lewis & Phillips 2015). From a non-reductionist standpoint, this same single system can be viewed from different related, but ontologically autonomous angles: a more theoretical one, which describes its general properties (Grammatical Theory), another that studies the system's implementation in relation to other cognitive functions, such as memory and attention and in situations of ambiguity and depth of analysis (Sentence Processing). The third angulation – intermediate to the first two – would be Experimental Syntax – the proposal of off-line and on-line investigation of the computation of grammar in processing, abstracting it, however, from mnemonic, attentional as well as uncertainty and depth of analysis. This present article explores grammatical (and ungrammatical) constructions in these three areas from an educational perspective, always taking the sentence as a central category.

Gallego and Chomsky (2020) reviews some of the basic properties of sentence generation and takes into consideration the advantages of incorporating some of these ideas in secondary education, as they may prove useful to develop what Chomsky (1988) has called science forming capacity. The science forming capacity is the innate ability to formulate and entertain questions that we do not know the answer to. It is an immensely complex skill, derived from many other auxiliary skills. Honda and O'Neil (1993) propose that the innate science forming capacity can be triggered by properties of the formulation of linguistic theories and methodologies which can be constituted as epistemic tools to be used in the development of basic reasoning skills – observation of

empirical data, generalizations, formulation of hypotheses, comparison and evaluation of explanatory theories. In Brazil, Pilati (2017) pioneered proposed a new understanding of the role of grammar in linguistic education. Pilati's *Gramaticoteca* includes the building and the use of sets of concrete manipulable materials actively constructed by teachers and students to learn different grammar topics based on Generative Linguistics principles.

Noam Chomsky, the main proponent of Generative Linguistics in the mid-fifties, has published himself a book called *On Miseducation* (2004), in which necessary educational reforms are discussed in the light of social change and the modern democracy crises. In more recent work, Gallego and Chomsky (2020), in addition to the presentation of generative grammar key ideas, such as the sentence compositional operation MERGE⁵, also discuss the role of grammar in educational programs in terms of reduction of contents and focus on small objects. In Roeper, Maia & Pilati (2020), we suggest that the sentence would be the proper small object to be explored in language education. Phrase compositional recursive merge has been shown to be directly related to a type of active constructive imagination called Prefrontal Synthesis (PFS). Vyshedskiy (2019) proposes that "PFS is defined neurobiologically as the conscious, purposeful process of synthesizing novel mental images from two or more objects stored in memory" (*cf.* p.5), and states that Chomskyan Merge, defined as a process of combining any two syntactic objects to create a new one could be taken as the linguistic equivalent of PFS. According to Vyshedskiy (2019), research has shown that children who were not exposed to recursive merge may have PFS disabilities. Vyshedskiy, Mahapatra and Dunn (2017) reviewed research that demonstrate that "individuals deprived of recursive conversations until puberty performed poorly in all PFS tests, both verbal and nonverbal, despite focused multi-year post-pubertal rehabilitation efforts" (*cf.* p. 30). Therefore, it seems only natural that sentential merge processes, including recursion, would be an important small object to be explored in language education.

However, despite the very clear potential of the sentence in language education, Scott (2009), in her "A case for the sentence in reading comprehension", points out that:

I will make the case that sentence comprehension is a culprit for some readers and is commonly overlooked when thinking about improving reading comprehension and content knowledge. If a reader cannot derive meaning from individual sentences that make up a text, that is going to be a major obstacle in text-level comprehension. This statement seems so obvious that it is all the more puzzling that so little attention has been paid to sentence parsing as a component of reading comprehension. The word sentence does not even appear among the recommended domains of best practice instruction taken up by the National Reading Panel (2000) and popularized as the five topic headings of phonemic awareness, phonics, fluency, vocabulary, and text comprehension. Nor are sentences discussed at all under the topic of text comprehension. (*cf.* Scott 2009, p. 184)

In Brazil, the negligence towards the sentence in language education is unfortunately also prevailing. Lobato (2003) in a lecture published in Pilati, Vicente, Naves and Lima-Salles (2014) proposes that taxonomic grammatical teaching should be

⁵ Gallego and Chomsky (2020) define MERGE as "a simple compositional operation, ..., which applies to two objects, α and β , to yield a third one, K , which we can represent as $[K \alpha, \beta]$ " (*cf.* p. 5).

abandoned at the schools but that a new perspective of grammatical teaching has to remain, making explicit reference to the sentential level. Lobato ponders that the same abstract grammar underlies words, phrases, clauses, sentences, and texts and points out that the human mind would have to be antieconomic if there had to be different principles to each of these levels. She recognizes that there are principles that may go beyond the limits of the sentence, but these principles cannot be different in nature of the principles that govern sentences (*cf.* p. 25).

As a matter of fact, in Brazil, there has been an important proposal to focus on the articulation of clauses at the sentential level in language teaching. However, this proposal has been little explored at the schools, which in general adopt textbooks where larger texts of different genres are most often chosen as the main object of study. Othon Moacyr Garcia's book *Comunicação em Prosa Moderna – aprendendo a escrever, aprendendo a pensar*⁶, on the other hand, argues that the logical analysis of clauses in sentences and sentences in paragraphs would be fundamental to developing reading and writing skills. Garcia's book does not only discuss theoretical issues, but mainly proposes a variety of exercises of clause articulation that have the potential to shed light on the important notion of **perspective**, established by the syntactic hierarchy and semantic autonomy of the main clause, especially in adjective clause modification and adverbial clause contexts in complex subordinate sentences, which are also compared to flatter coordination processes. Therefore, the central syntactic processes of coordination, adjunction and embedding are actively practiced in Garcia's manual so that students do have a proper small object (*cf.* Gallego & Chomsky 2020) to become aware of core structural properties of sentential organization and, in a next step, of the organization of sentences in paragraphs. Even though the psycholinguistics of reading concept of **gist**⁷ is not explicitly mentioned in the book, Garcia's notion of syntactic and semantic perspective does the job quite well. The book also explores other central notions in the study of sentences, such as viewpoint, emphasis, parallelism, and even prosody notions as rhythm and cadence. Maia (2006) further elaborates on Garcia's ideas and exercises, but as evaluated for the US⁸ in Scott (2009), it is regrettable that also in Brazil there are few language manuals and textbooks with a real focus on the sentence.

⁶ Communication in Modern Prose: learning to write learning to think. (https://www.amazon.com.br/Comunica%C3%A7%C3%A3o-prosa-moderna-Moacyr-Garciaebook/dp/B01695S0LU/ref=tmm_kin_swatch_0?_encoding=UTF8&qid=&sr=)

⁷ In Psycholinguistics, gist has been defined as “the residue of linguistic input that remains as time passes”. The concept has been broadened to “encompass nonlinguistic as well as linguistic, patterns of sense that are present in incoming information, especially the crucial background data that accompany thinking, reasoning and learning tasks. (...) Gist is not simply the ghost of degraded verbatim information. Instead it consists of memory representations that are extracted in parallel with the encoding of such information, and it is thought to function independently of verbatim information once it has been stored”. (*cf.* Braynerd & Reyna 2012).

⁸ In the US, Tankersley (2003, 2005) discuss and propose practices focusing on the articulation of clauses in sentences as part of literacy strategies.

3. Metacognition

The simplest definitions of metacognition are generally phrased as “thinking about thinking” or “cognition about cognition”. The term, however, covers phenomena that are anything but simple. As evaluated by Mahdavi (2014), since its introduction by the developmental psychologist John Flavell in the seventies (*cf.* Flavell 1979), the term has become an umbrella for the most different purposes in a wide range of areas. Metcalfe (2008) discusses the importance of self-reflective cognition in the evolution of human consciousness and reviews investigations of its presence in primates and even in rats, to conclude that only humans would really have metacognition, which seems to have evolved relatively recently in the species, as an evolutionary advantage. According to Metcalfe, most claims that other non-human animals would have metacognition could be ruled out as “mere conditioning contingencies” (*cf.* Metcalfe 2008, p. 18). Having acquired this unique capacity of projecting levels of representation beyond the immediate here and now experience, humans would be free “to escape from being stimulus bound, and allow self-control of their learning, and actions” (Metcalfe 2008, p.1). The human metacognitive evolutionary advantage would also extend to auto-noetic consciousness, the capacity to recursively introspect on one’s own subjective experience through time. As pointed out by Metcalfe (2008), “being able to reflect on past occurrences also has its own adaptive value, freeing such an animal from the constraints of the stimulus, and allowing more rational, adaptive future responding” (*cf.* Metcalfe 2008, p. 5).

As reviewed in Maia (2019a), Hauser, Chomsky and Fitch (2002) argue that the basic property of the human faculty of language would be strictly the recursive operation, which has recently appeared in human phylogeny. This ability to manipulate symbols recursively, embedding and re-embedding them in a creative and unlimited way, to produce and understand utterances never said or heard before, could be thought of as related to the emergence of the capacity of metacognitive representation. According to De Villiers & De Villiers (1999), cognitive development and language acquisition by the child are directly dependent on sophisticated metacognitive faculties such as the Theory of Mind (ToM), the ability to attribute mental states and points of view which are different from our own to others. As discussed in Amaral, Maia, Nevins and Roeper (2018, pp. 5–7), when answering a second-order belief question such as “what did the girl say she bought?” children would have up to a certain age a tendency to respond with what the girl actually bought rather than what she said she did. Obviously, the two things could differ, as the girl could have said, for example, that she bought a toy car, when in fact she would have bought a doll. The attribution of false belief would depend both on metacognitive development and on the full development of recursive subordinate embedding, which according to Roeper & Oseki (2018) would be the final stage of the acquisition path, whose initial stage would be the simple juxtaposition of items. Interestingly, metacognitive abilities seem to be directly relevant to research such as Vyshedskiy’s (2019), briefly reviewed in the previous section, which has shown that children who were not exposed to recursive merge may have PFS disabilities. In this sense, linguistic metacognitive practices as we discuss in this article may be central to language, reasoning and imagination development. In addition to its relevance to ToM and recursion,

metacognition has also been analyzed as comprising different skills which are relevant in developmental psychology research about empathy and perspective taking⁹, including not only their characterization but also disabilities. Metacognitive complex abilities have thus also been object of clinical research on autism (*cf.* Frith & Happe 1999) and schizophrenia (*cf.* Coulacoglou & Saklofske 2017).

The aim of this section is, however, not to fully survey the heterogenous literature on metacognition, but to focus on some concepts and practices more directly related to the topic of the current article, namely, the use of eye tracking as an epistemic tool in language education. In both educational endeavors we describe in this article, we use qualitative eye tracking data as an aid to help students to “go meta”, as put by Mahdavi (2014). Going meta with eye tracking has the potential not only to help students become aware of their own on-line reading properties but also offer them interesting data to exercise their science forming capacity, inspecting, and contrasting gaze plots and heatmaps to make hypotheses, establish variables, make inferences and draw conclusions. In these lines, Mason, Pluchino and Tornatora (2015) proposed the EMME (Eye movement modelling example) model, based on experiments carried out with 64 seventh-year elementary school students in Italy. Considering that modern eye trackers are non-intrusive, allowing not only the capture of fixations and saccades, but also the display of results in the form of videos, the authors hypothesized that the viewing of eye tracking videos, modeling the behavior of more competent readers, could help less proficient readers. The results obtained were discussed by the authors based on theoretical frameworks for the development of self-regulatory observational processes (*cf.* Groenendijk, Janssen, Rijlaarsdam & van den Bergh 2013), demonstrating that the procedures used effectively contributed to refining students' awareness of their strategies for reading texts and images, which were positively impacted.

In the metacognitive workshops we discuss in the present article, we have proposed to start with epilinguistic activities, that is, activities with initial inductive adherence to the playful exploration of data, which are distinguished from “meta” activities that deductively depart from broader analytical categories. According to Garcia and Sista (2020), the concept of epilinguistic activity was first proposed in Culioli (1968), based on the Theory of Predicative and Enunciative Operations. The Brazilian linguist Carlos Franchi, in an article from 2002 and, mainly, in his 2006 book, proposes that these epilinguistic activities deserve to be further explored in language education, in which metalinguistic activities tend to predominate. According to Franchi: “we call epilinguistic activity this practice that operates on language itself, compares expressions, transforms them, experiments with new modes of construction, canonical or not, plays with language, invests linguistic forms with new meanings (Franchi 2006, p. 97).¹⁰

In the following sections 4 and 5, both the objectives of using eye tracking to improve self-awareness and self-regulation of students of their own reading properties

⁹ Perspective taking is directly relevant to the clause articulation practices discussed in section 2 and also described with examples in sections 4 and 5 of this current article.

¹⁰ “...chamamos de atividade epilinguística a essa prática que opera sobre a própria linguagem, compara as expressões, transforma-as, experimenta novos modos de construção canônicos ou não, brinca com a linguagem, investe as formas linguísticas de novas significações (Franchi 2006, p. 97).

and to trigger their science forming capacity will be exemplified in projects developed in a middle school and at the university level.

4. Psycholinguistics and metacognition at the school

In 2014, my Experimental Psycholinguistics Laboratory (LAPEX/UFRJ) and Aniela Improta França's neuroscience of language laboratory (ACESIN/UFRJ) participated as founding members of the creation of *Rede Nacional de Ciência para a Educação* – a national network of scientists in Brazil intended to discuss and develop means of translating epistemologies and methodologies used in scientific research in all fields to impact all the basic education disciplines at elementary, middle and high school levels. LAPEX and ACESIN then created Laboratory LER to develop a first project with the objective to translate linguistic concepts and methodologies to a public middle school in Rio de Janeiro.¹¹ The project had as inspiration the “triggering science forming capacity” concepts and practical proposals (cf. Honda & O’Neil 1993, 2008), as mentioned above. The fundamental principles of Chomskyan sentence-based linguistics were also assumed (cf. Gallego & Chomsky 2020), specially the innatism hypothesis. Knowledge of language is part of the human nature, a genetic endowment of the species. Therefore, people may have deep intuitions and insights on their languages, including also metacognitive inspections. The project subscribed to active methodologies, problem-solving based education, student protagonist decolonizing pedagogies as used in the *3Grau Indígena project*, and other previous educational experiences.¹² The whole story of the three phases of the project in 8th grade middle school classes in a public school in Rio de Janeiro is presented in Maia (2019b), *Psicolinguística & Metacognição na Escola*, in which the conceptual foundations, the diagnostics, the different workshops and the reassessment phases are fully described and discussed. The project was presented to and approved by the school community, including administrators, teachers, students and parents. In brief, three groups of 20 students each were tested, namely, the workshop group, the middle school control group and the university control group. ANOVAS and t-tests were performed, showing statistically significant differences, as indicated in Graphs 1 and 2. The students in the workshop group took part in weekly extra active, problem-solving based sessions, whereas the students in the middle school control group received only their regular classes at the school.

¹¹ Professor Aniela Improta França (UFRJ) and I founded a new laboratory sharing resources of her Neuroscience of Language EEG Laboratory (Acesin - <http://www.acesin.letas.ufrj.br/>) and the eye tracking psycholinguistics laboratory [LAPEX - [https://pt.wikipedia.org/wiki/Laborat%C3%B3rio_de_Psicolingu%C3%ADstica_Experimental_\(LAPEX/UFRJ\)](https://pt.wikipedia.org/wiki/Laborat%C3%B3rio_de_Psicolingu%C3%ADstica_Experimental_(LAPEX/UFRJ))]. This new laboratory was also joined by laboratories from UERJ, the Rio de Janeiro state university and was called LER (<http://www.ler.letas.ufrj.br/>) and was designed to be dedicated to reading studies using neurolinguistic and psycholinguistic methodologies, such as EEG and eye tracking.

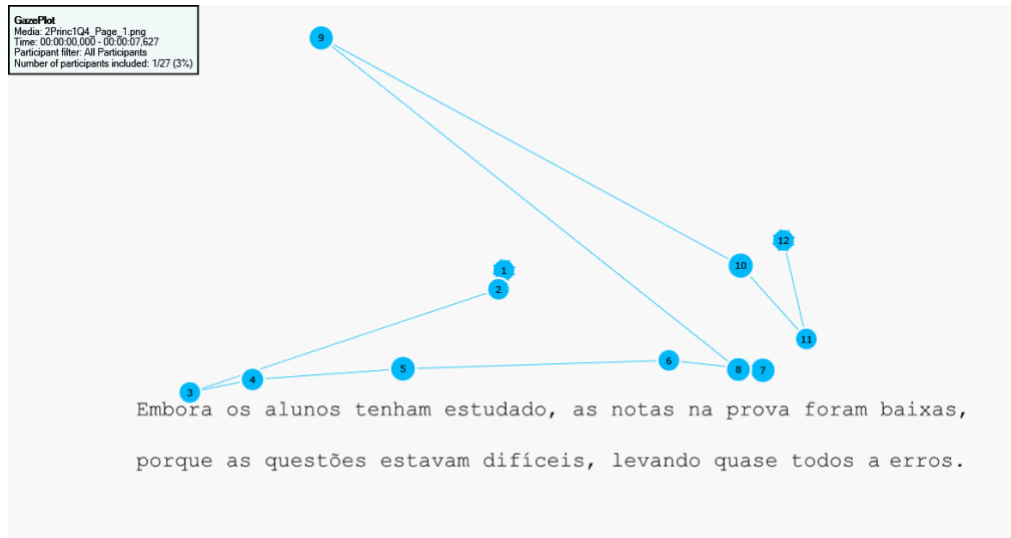
¹² Maia, Franchetto, Storto and Sandalo (2002) present and discuss their proposals to use active decolonizing methodologies and problem-solving based practices to prepare indigenous teachers as researchers when they were consultants and teachers in the 3Grau Indígena Project (https://pt.wikipedia.org/wiki/Faculdade_Ind%C3%ADgena_Intercultural), the first program of higher education of indigenous teachers in Brazil (MEC/UNESCO).

One of the major findings obtained in psycholinguistic and neurolinguistic tests in the diagnostics phase of the project showed the precocious disengagement in the computation of clauses during sentence reading. Full details of methodology and statistical analyses are presented in the Maia (2019b) book, but it is worth mentioning that the disengagement in reading was consistently captured in EEG, eye tracking, self-paced reading and cloze tests carried out by LER laboratory members during the diagnostics semester phase. All tests captured a remarkably strong effect of abandoning the reading to speed up to the interpretation questions in typical reading questionnaire exercises which are common at the schools. As this disengagement effect could also be qualitatively captured and displayed in the form of static and dynamic eye tracking fixation gaze plots or heatmaps, which are very intuitive and user friendly, among the several workshops developed and applied during the treatment year, we decided to explore eye tracking as a metacognitive educational tool, envisaging the future possibility of integrating the technique in school routines, as a reading microscope in school science labs.

Another important finding of the first phase of the project concerned the average fixation latencies and lookback rates on the main clause of the sentences as compared to the subordinate clauses. Proficient university undergraduate students would display higher rates than middle school students in these two on-line measures as well as higher accuracy rates in interpretation questions. The lookback rates found in the diagnostic eye tracking tests run with middle and university students were in line with Hyöna, Lorch and Kaakinen (2002) findings. The authors argue that lookbacks would be indicative of the integrative effort of the information read in order to solve comprehension difficulties. Based on the examination of these second pass refixations in the reading of texts, the authors were able to establish strategies of reading, differing linear readers from structuring selective readers, who are capable to identify the gist in reading more efficiently than the linear readers.

The eye tracking workshops developed during the treatment phase of the project were restricted to one of the two 8th grade classes (workshop group), as the other class was taken as a control group, not taking part of the workshop sessions, which took place every week during a one-hour recess time for two months. Inspired by problem-solving based teaching methodologies (*cf.* Duch, Groh & Allen 2001), and supported by the intuitive nature of the qualitative eye tracking reading fixations videos and heatmaps, the workshops sought to trigger science forming capacities of systematic observation, comparison, contrast, variables identification, generalization, explanation, hypotheses forming, inference, etc. Students were encouraged to explore all eye tracking parameters without much previous information on eye tracking measures, which were easily discovered by them. For example, in the first session we showed them actual readings of sentences such as below¹³:

¹³ The Brazilian Portuguese four clause sentence displayed in Video 1 could be translated into English as “Even though students had studied, test grades were low because the questions were too hard, leading almost everyone to errors”.



Video 1. Middle school student reading disengagement.
(Click on the image to watch the video)

Workshop participants were very motivated to appreciate and analyze eye-tracking gaze plot videos and heatmaps of readings, collected during the first phase of the project both in the two 8th grade classes at the school, and at the university, with undergraduate students, taken as a second control group. Participants could immediately identify the early disengagement in the reading patterns in Video 1, and could also predict that the interpretation answer would be wrong, as actually illustrated by the heatmap in Figure 1¹⁴:

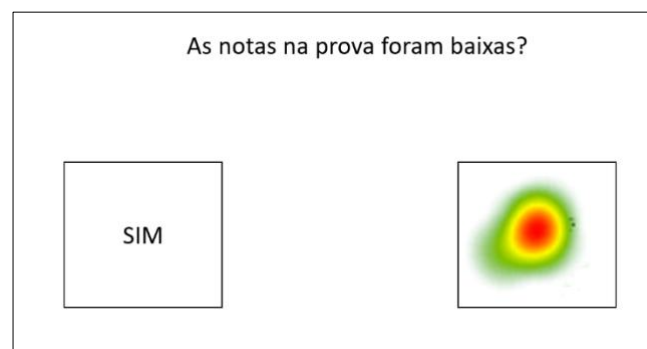
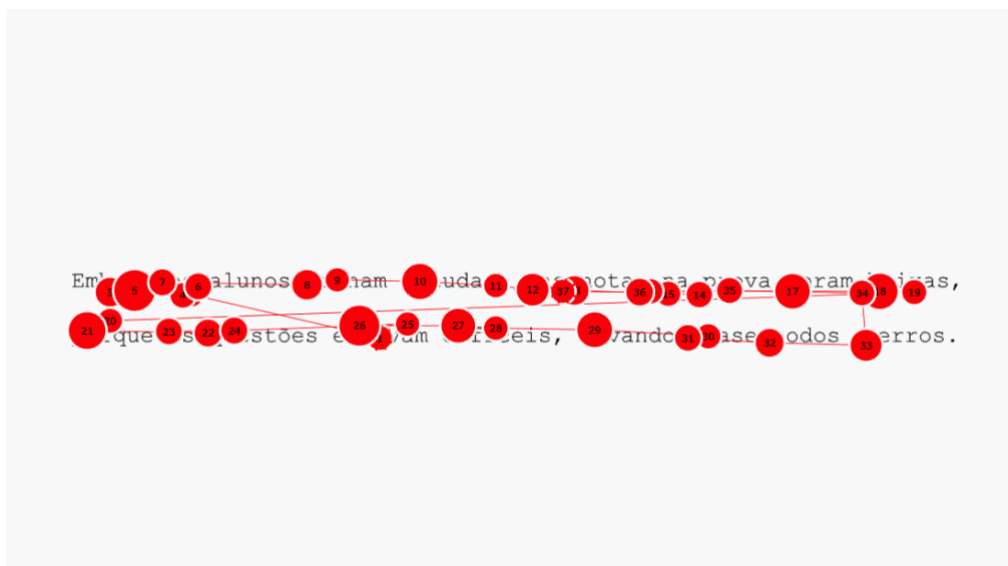


Figure 1. Heatmap of Answer to Interpretation Question of Sentence in Video 1

Exercising innate comparison and contrast capacities, students were usually highly motivated to discover and point out very naturally (and cheerfully) relevant eye tracking parameters in a proficient reading as illustrated in Video 2:

¹⁴ The heatmap shows the answer of the student who read the sentence displayed in Video 1 to the question “were the test grades low?”. The sentence stated in its main clause that the test grades were low (*cf.* footnote 12), but the student incorrectly fixated the square with NÃO “no”, rather than the square with SIM “yes”, making a mistake.



Video 2. University student proficient reading.
(Click on the image to watch the video)

Students could also predict that a proficient reading as in Video 2 would yield a correct answer to its interpretation question, as illustrated in the heatmap in Figure 2:

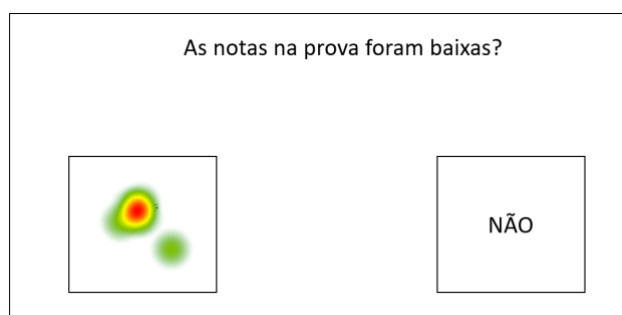
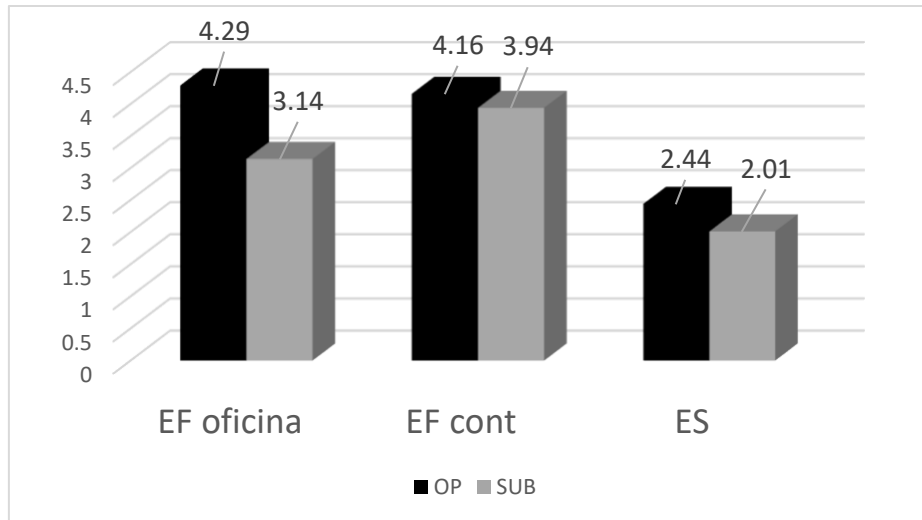


Figure 2. Heatmap of Answer to Interpretation Question of Sentence in Video 2

Finally, in the last semester of the project several post-tests were applied, including eye tracking experiments which found significant improvement in reading patterns in the students of the middle school class which took part in workshops as compared both to control middle class and higher education students, as indicated in Graph 1¹⁵ below and respectively illustrated by prototypical gaze plot videos 3, 4 and 5 in the next section.

¹⁵ Graph 1 displays post-test main clause total fixation durations in black and subordinate clauses in gray for the three groups of subjects, namely, the workshop group, the middle school control group and the university control group.

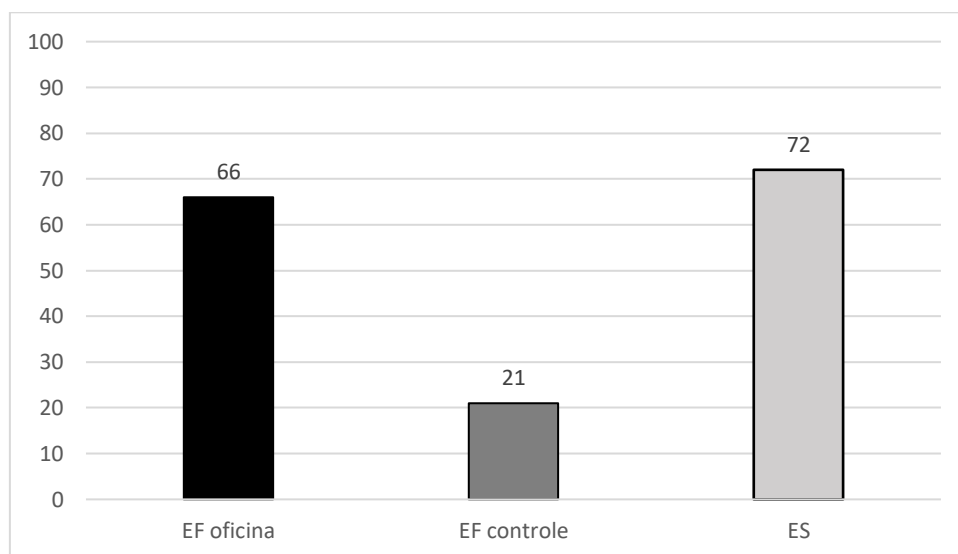


Graph 1. Post-test Total Fixation Durations (ms) in Main and Subordinate Clauses in Three Groups of subjects: the workshop group (EF oficina), the middle school control group (EF cont) and the university control group (ES).

Fonte: Maia (2019b, p. 92).

Graph 1 shows that the middle school group who took the workshops now displayed significantly longer latencies on main clauses than on the average of subordinate clauses, in contrast with the middle school control group who did not show significant differences in fixation between main and subordinate clauses. The last two columns in Graph 1 shows that university students read sentences faster but display significant differences in their reading of main and subordinate clauses.

Graph 2 displays accuracy rates in the interpretation questions, demonstrating how gist identification significantly improved for the workshop group who are now closer to the higher education group, having significantly improved accuracy rates in relation to the 8th grade class who did not take the workshops.



Graph 2. % of gist identification in workshop (EF oficina), middle (EF) and university (ES) control groups.

Fonte: Maia (2019b, p. 98).

In the next section, prototypical comparative videos 3, 4 and 5 are illustrative of the fixation and saccadic movement patterns across the three group of subjects. As they were also used in Linguistics classes at the university they will be shown in the next section of the article.

5. Eye tracking in the teaching of linguistics

The objective of this section is to demonstrate and discuss the use of eye tracking examples in the reading of different constructions in undergraduate and graduate linguistics classes I have taught at the Federal University of Rio de Janeiro in 2020 and 2021. The practices allowed classes with active participation of the groups, under the hypothesis that the study of syntactic theory, experimental syntax and sentence processing, including, in addition to syntactic issues, epistemological and methodological issues, would benefit significantly from quali-quantitative analyses of prototypical gaze plots and heatmaps from sentences in our eye tracking corpora, which were examined in group discussions during the courses.

In these classes not only quantitative data were discussed, but classes would generally start with the display of videos showing qualitative data, such as gaze plots and heatmaps from several studies in Psycholinguistics and Experimental Syntax that we had already developed in our laboratory.¹⁶ The videos usually triggered discussions with students about linguistic and psycholinguistic issues, such as the reading of sentences for gist task used in the project described in the previous section, but also included garden-path sentences, syntactic and semantic anomalies, the filled-gap effect, island effects, direct and indirect cause, and recursive constructions, among other topics.

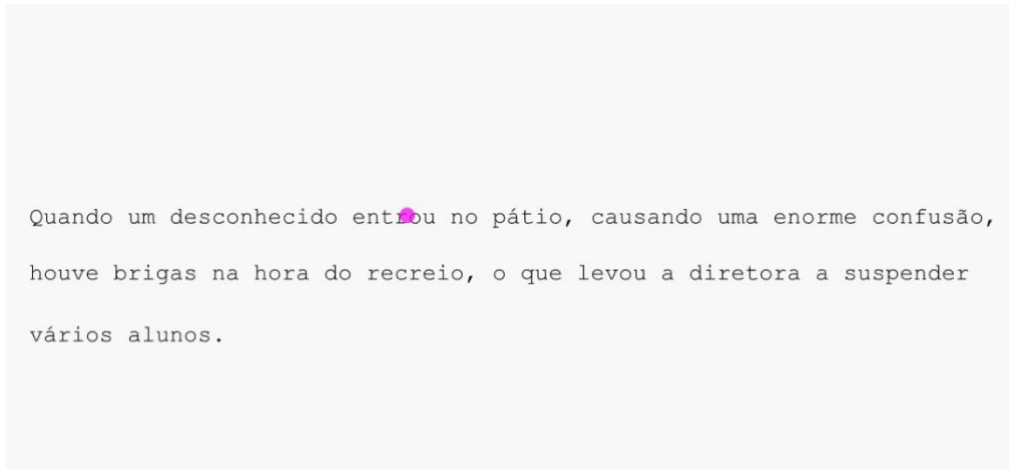
If the reader of the present article would like to experience how these problem-solving based classes would happen, let me suggest that the gaze plots and heatmaps illustrating each section be comparatively inspected before the analyses proposed in the text are read. Examine the fixation patterns as well as the progressive and regressive saccadic movements and try to make hypotheses concerning representation and processing issues for each construction. We will offer short briefings of the grammar and processing questions at stake and the analytical threads explored in usually cheerful 'think aloud in group' sessions, which would usually include many replays of the videos during discussions to compare observations and analyses.

5.1. Gist identification data

Let us start with the post-test gaze plots illustrative of the graphs which end section 4 above. Video 3 is a prototypical middle school control group sentence reading; Video 4

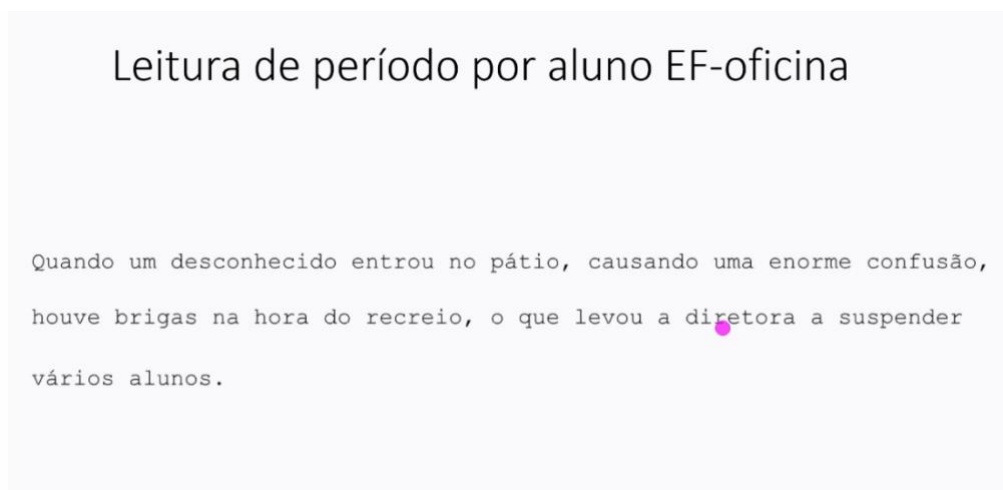
¹⁶ The Laboratory of Experimental Psycholinguistics (LAPEX) at the Federal University of Rio de Janeiro has been running eye tracking experiments since 2007. During the years of 2020 and 2021, due to the pandemic, no new eye tracking tests could be implemented and run, but we could still resort to our existing eye tracking data and make active use of them in classes. These were exploratory sessions which usually yielded lively participation and enthusiastic approval from students, but at this point they have not been thoroughly evaluated yet, as suggested they should be by an anonymous Diacrítica reviewer.

is a prototypical middle school workshop group reading and Video 5 is a prototypical Higher Education sentence reading.



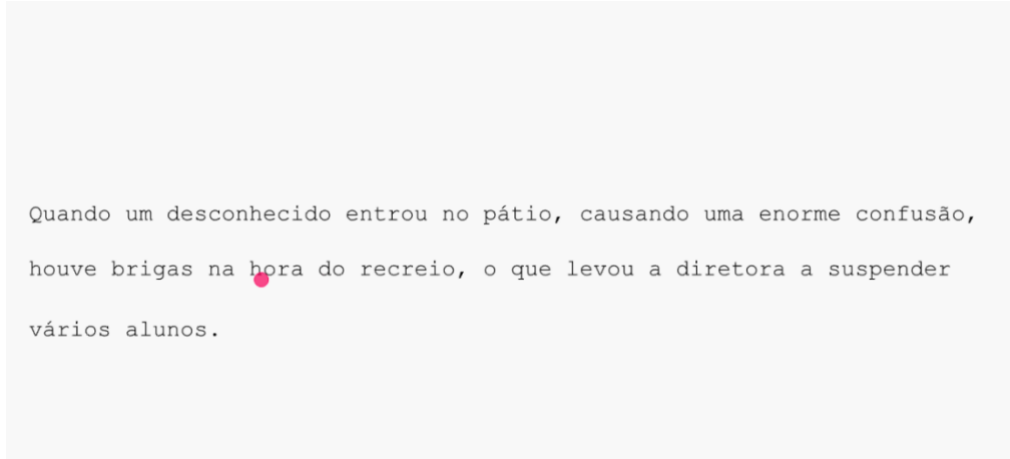
Video 3. Middle school control group reading.
(Click on the image to watch the video)

Students would evaluate the reading patterns of the dynamic gaze plot in Video 3 and would generally infer low proficiency in gist identification, as there was early disengagement during sentence reading. Even though the first clause was reread, reading was abandoned right after the first pass reading of the second clause. On the other hand, Video 4 illustrates the reading of a middle student who took part in the eye tracking workshops and of other activities in the project treatment phase. Linguistics students could easily detect a selective structural reader (*cf.* Hyöna *et al.* 2002) who looks back to the critical gist clause both during first and second pass readings:



Video 4. Middle school workshop group reading.
(Click on the image to watch the video)

Finally, the comparison of the same sentence read by a university student reveals that her overall reading speed is faster than the average middle school student, as indicated in Graph 1, in section 4. Higher Education subjects in average also proficiently return to previously read critical materials in their search for the gist, as illustrated in Video 5, below:



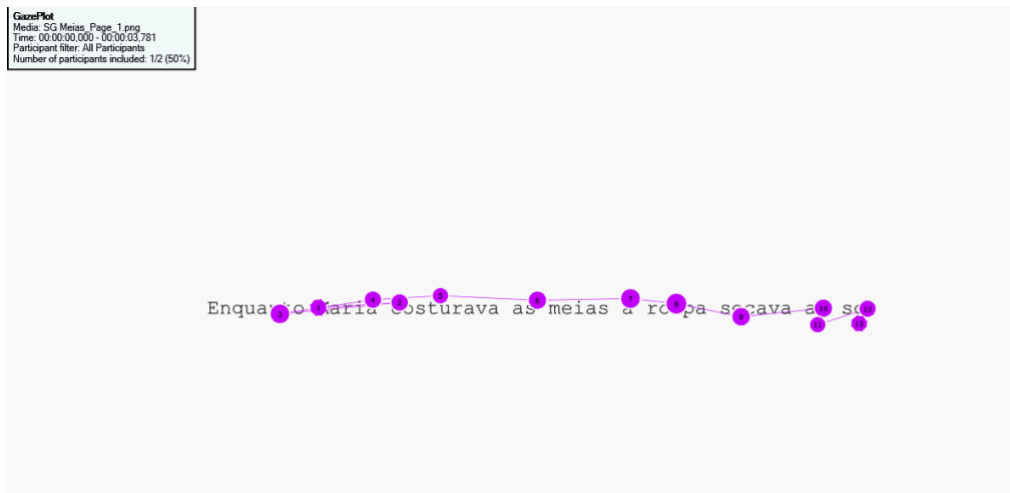
Video 5. Higher Education control group.
(Click on the image to watch the video)

5.2. Sentence processing data: late closure

Sentence Processing principles such as Late Closure – LC (Frazier & Rayner 1982; Ribeiro 2012) were also presented and discussed with the active participation of undergraduate and graduate students, based on the visualization of typical garden-path readings which violate the LC principle, in contrast to readings which do not violate it.¹⁷ The discussion about the psychological reality of punctuation as a cue to separate syntactic constituents could also benefit from the presentation of the eye tracking gaze plots. Let us, first, look at the relevant qualitative eye tracking data, comparing videos 6, 7 and 8¹⁸:

¹⁷ These gaze plots were prototypical examples of a study reported in Ribeiro (2012).

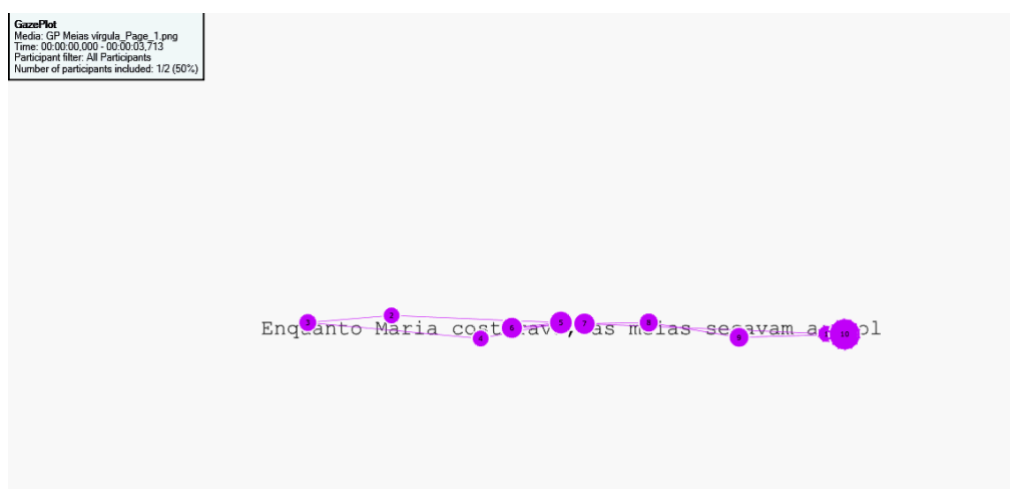
¹⁸ Video 6 sentence displays the BP equivalent to the English sentence While Maria sewed her socks the clothes dried in the sun; video 7 BP garden path sentence can be translated as While Maria sewed her clothes dried in the sun; video 8 BP sentence includes a comma which avoids the garden path in the sentence in video 7 and can be translated as While Maria sewed, her clothes dried in the sun.



Video 6. Sentence without a garden-path.
(Click on the image to watch the video)



Video 7. Garden-path sentence.
(Click on the image to watch the video)



Video 8. Garden-path avoided by comma.
(Click on the image to watch the video)

The videos posed interesting problems to be solved by the students. While video 6 was quickly read requiring only progressive fixations, video 7 had several regressions to the critical area of the garden-path, namely the region in which the *NP as meias* “the socks” is initially attached as the object of the verb *costurava* “sewed” and needed to be reanalyzed as the subject of the verb *secavam* “dried”. In video 8, the comma avoided the garden-path. Even undergraduate students who had had no previous classes about the garden-path theory or the late closure principle were able not only to establish the facts comparing the readings of the three sentences but could also deduce the basic tenets of garden-path theory and elaborate about the usage of commas as syntactic markers.

5.3. Sentence processing and experimental syntax data: filled gap effect data

Maia (2014b) investigated Filled Gap Effect (FGE) constructions (*cf.* Stowe 1986) such as in Example 1 in comparison with controls as in Example 2 in Brazilian Portuguese, through eye-tracking and self-paced reading experiments:

(1)

Que livro o professor escreveu a tese sem ler antes?

Which book the teacher wrote the thesis without reading before

“Which book_i did the teacher write the thesis without reading t_i before?”

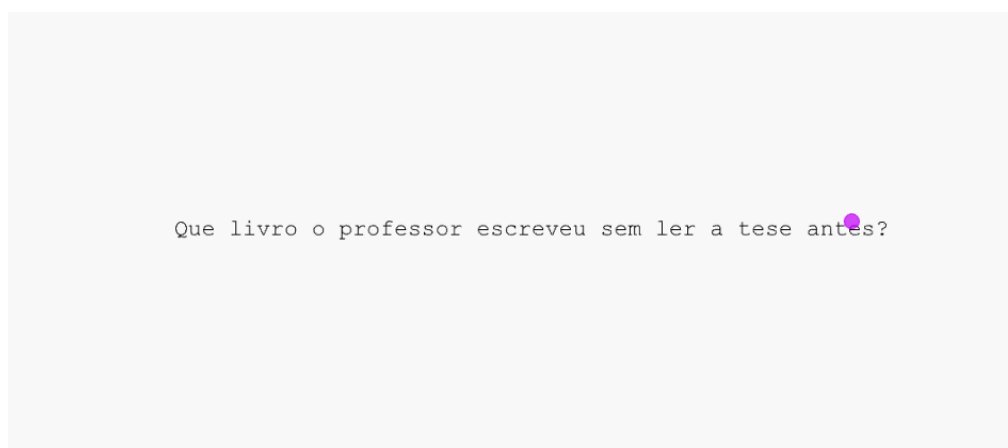
(2)

Que livro o professor escreveu sem ler a tese antes?

Which book the teacher wrote without reading the thesis before

“Which book_i did the teacher write t_i without reading the thesis before?”

Typical non-discrepant qualitative data of the eye tracking readings of sentences in these two conditions, such as videos 9 and 10 below, obtained in the study reported in Maia (2014b), were showed, and discussed in graduate Experimental Syntax and Sentence Processing classes in 2020 and in 2021. As proposed above, the readers of this present article are also invited to inspect and try to comparatively analyze the gaze plots:



Video 9. Sentence without an FGE.
(Click on the image to watch the video)



Que livro o professor escreveu a tese sem ler antes?

Video 10. FGE sentence.
 (Click on the image to watch the video)

As the reader may have observed in Video 9, the fixation point is in the center of the screen when the sentence first appears, and then immediately moves to the left to start the reading of the sentence. Fixations then move forward along the sentence up to the end when there is a selective regressive movement to the WH-phrase *que livro* “which book”, in the beginning of the sentence. In Video 10, on the other hand, the fixation point also starts at the center of the screen and moves left to start reading the sentence. However, the sentence reading pattern is more costly now. There is a long fixation in first pass reading on the NP *a tese* “the thesis”, and there are also second pass regressive movements to this same NP, during the reading of the sentence. These patterns were actively established by the students early in the class and explanatory hypotheses were advanced along two lines: (i) the Filled Gap Effect sentence processing principle and (ii) the immediate satisfaction of grammatical conditions in the experimental syntax framework. As indicated in the introduction of the current paper, the Sentence Processing and the Experimental Syntax specialties are related but should not be properly taken as isomorphic. The examination of quantitative and qualitative data on the Filled Gap Effect was a relevant point of departure to substantiate the epistemological discussion concerning these two levels of analyses, namely the parsing algorithm and the grammatical assignment of theta-role to the WH-Phrase *que livro* “which book”, in an A-bar position (*cf.* Wagers & Phillips 2009), which would require the postulation of a gap as a first resort, which would be trivial in Example 1, but costly in Example 2, since there is an NP (*a tese*) filling the object position where the Wh-Phrase could be interpreted as first resort.

5.4. Syntactic and semantic anomalies data

Data as the dynamic eye tracking gaze plots¹⁹ in videos 11 and 12 below were used to trigger discussions in a graduate course about syntactic and semantic anomalies and their detection in reading comprehension.



Motorcycles can easily swerves around the police barrier.

Video 11. Syntactic anomaly.
(Click on the image to watch the video)



Motorcycles can easily swim around the police barrier.

Video 12. Semantic anomaly.
(Click on the image to watch the video)

Maia & Nascimento (2020) investigated to what extent the reading of sentences in Brazilian Portuguese may differ in relation to grammatical and semantic anomalies and how these sentences are evaluated for their good formation, taking as control syntactically and semantically well-formed sentences. The analyses of the on-line data suggested that sentences that present anomalous number agreement features in the object noun phrase are more costly in terms of fixation and re-fixation patterns than the semantic anomalous sentences, even though they may be better accepted by educated speakers in the off-line

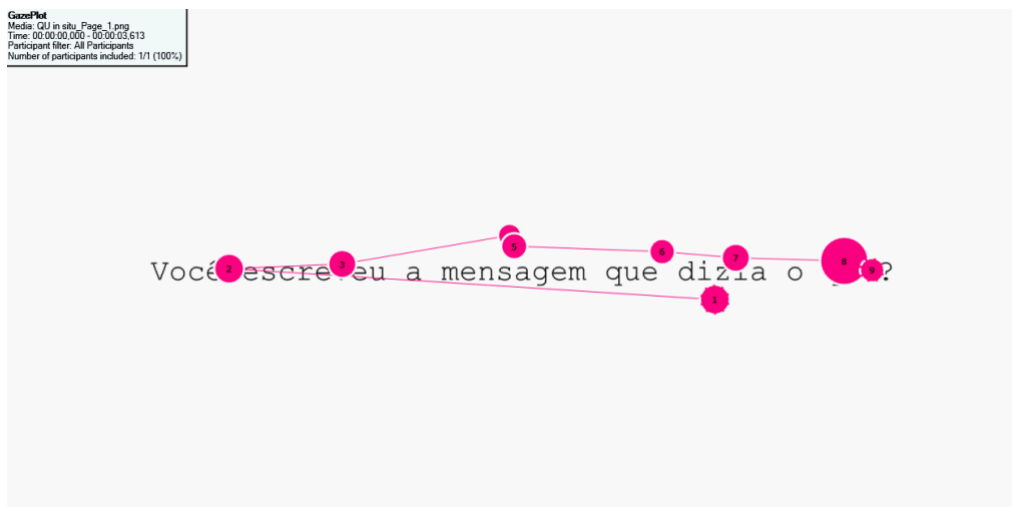
¹⁹ These English gazeplot data are part of a pilot study carried out with native New Zealand English speakers in the Laboratory of Experimental Psycholinguistics (LAPEX/UFRJ) in 2019. The data go in the same direction as the BP data collected in 2019 and analyzed and published in Maia and Nascimento (2020) in which syntactic anomalies were shown to trigger first pass regressions in contrast with semantic anomalies which trigger second pass regressions.

measure than sentences with semantic anomalies. It was argued that the results provide evidence in favor of structural models of sentence processing. These issues were discussed both in relation to the BP and the English data, offering an interesting opportunity to explore the syntax/semantics interface in terms of language architecture. In the English data in video 11, it is clearly noticeable that the subject-verb agreement anomaly triggered first pass regressions to the anomaly area, whereas the semantic anomaly in video 12 only triggered second pass regressions to the anomalous s-selection area.

5.5. Subjacent and in situ WH

Maia, Moura and Souza (2016) report an eye tracking experiment investigating the filled gap effect (FGE) in subjacent and non-subjacent constructions²⁰ in Brazilian Portuguese in a 2x2 design in which the plausibility of the verb complement s-selection is also tested. The results suggest that relative clause syntactic island configurations are quickly perceived by the parser, preventing both the postulation of the FGE, and the plausibility evaluation of the verb complement s-selection. In non-subjacent conditions, the FGE is instantiated, and the semantic evaluation occurs only subsequent to parsing decisions, not avoiding the FGE, as predicted by syntax-first processing models.

Videos 13 and 14 were shown to students in a graduate course in Experimental Syntax before Maia *et al.* (2016) was read and discussed in class.



Video 13. Wh-phrase in situ.
(Click on the image to watch the video)

²⁰ According to Chomsky (1973, 1977) subjacency is a locality constraint to movement. For example, a relative clause is an island, that is a syntactic context which blocks movement.



Video 14. Wh-phrased moved out of Relative Clause Island.
(Click on the image to watch the video)

Video 13 shows the reading of a BP sentence in which a wh-phrase is in situ:

- (3)
 Você escreveu a mensagem que dizia o quê?
 You wrote the message that said what
 “Did you write the message that said what?”

In Video 14, the wh-phrase was moved to the left periphery of the same sentence:

- (4)
 O que você escreveu a mensagem que dizia?
 What you wrote the message that said
 “What did you write the message that said?”

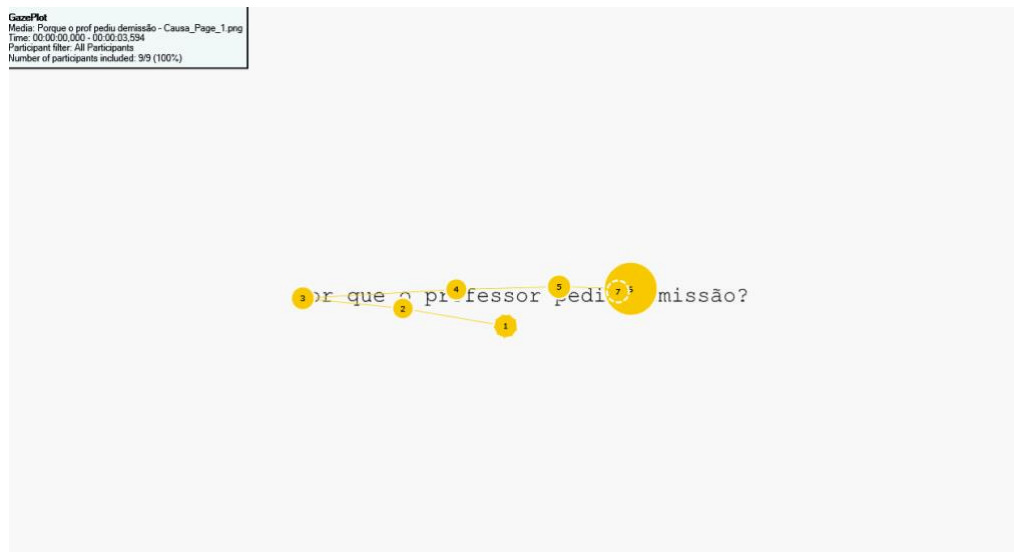
Students readily noticed that while the sentence in video 13 was read with only 9 fixations and no regressions, sentence in video 14 required 23 fixations and many second pass refixations. These striking differences motivated the active participation of the students in interesting discussions concerning the relative clause island constraint.

5.6. Inference data

As discussed in the introduction and in section 2 of the current paper, the case for the sentence proposed in Scott (2009) should also be considered in Brazilian education, where the sentential level has not been so explored as higher levels of the textual organization, which seem to be the mainstream topic in school textbooks. In this subsection of section 5 in which we explore the qualitative use of eye tracking gaze plots at the university level, we would like to argue that even macrostructural processes such as presuppositional and inferential analyses are already available at the sentential level

and can be productively assessed and discussed in terms of problem-solving methodologies in classes.

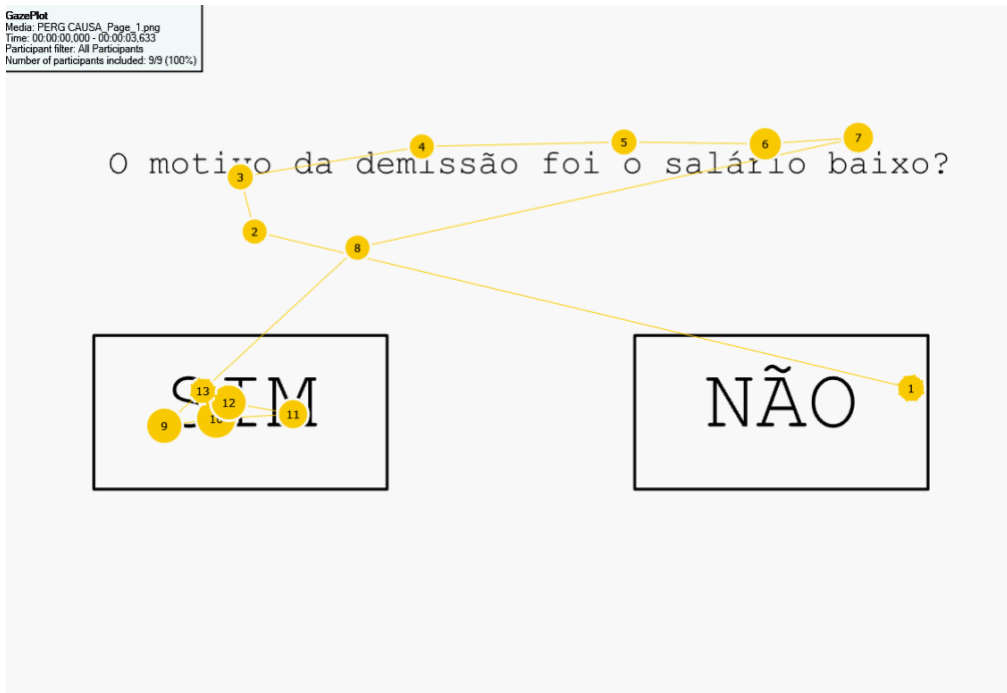
Let us start with the relevant data, involving direct and indirect causality.



Video 15. Initial question in direct causality condition.
(Click on the image to watch the video)

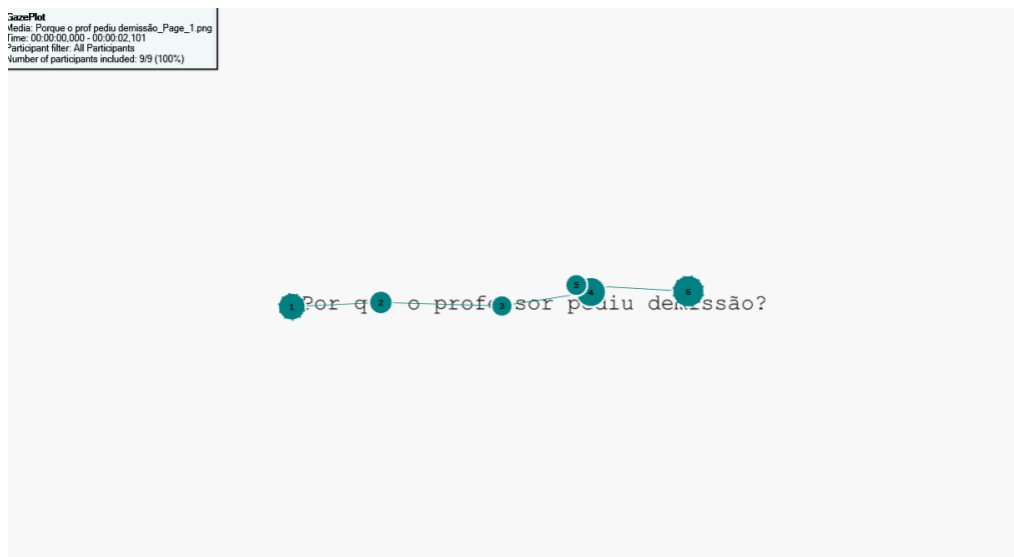


Video 16. Direct causality sentence.
(Click on the image to watch the video)

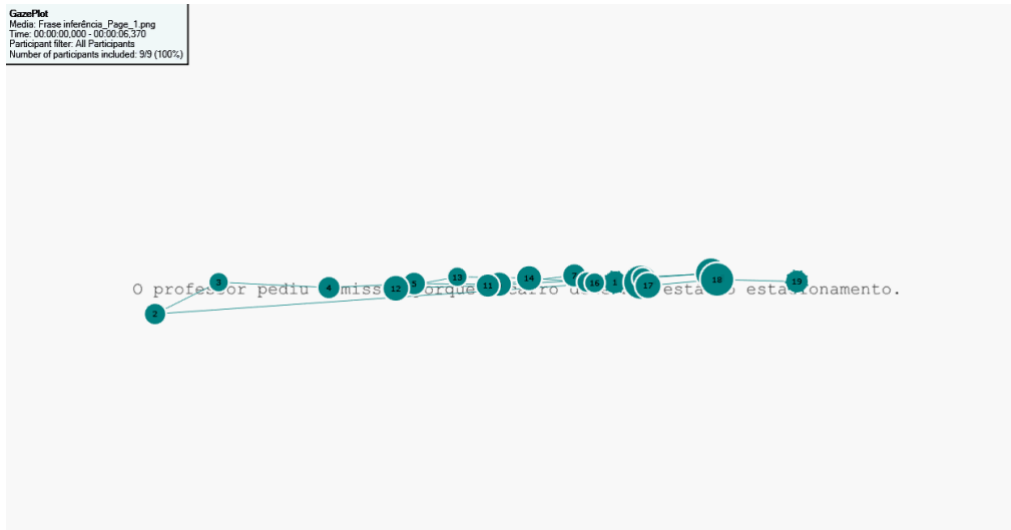


Video 17. Final question in direct causality condition.
 (Click on the image to watch the video)

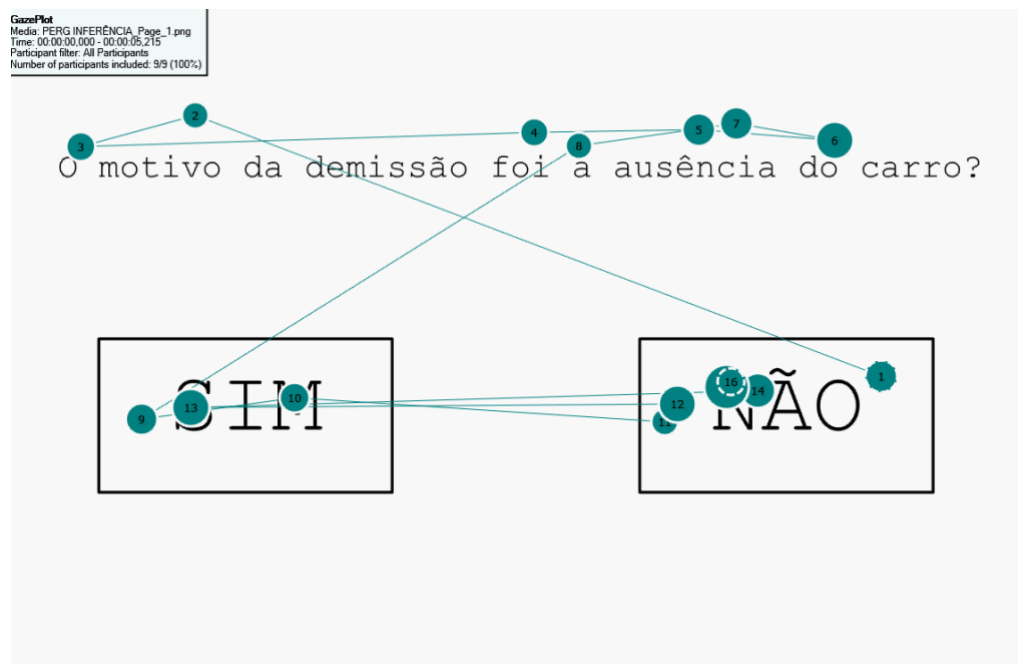
As discussed in Santos (2019) and in Roeper, Maia and Pilati (2020), direct or explicit causality, as illustrated above, seem to be processed more easily than indirect or implicit causality, which requires the establishment of presuppositions and inference. If we compare the three gaze plots above with the three gaze plots below, as we have done in undergraduate and graduate classes at UFRJ, we find a very rich material to discuss a wide variety of theoretical and methodological issues with a clear impact on the development of science forming capacity.



Video 18. Initial question in indirect causality condition.
 (Click on the image to watch the video)



Video 19. Indirect causality sentence.
 (Click on the image to watch the video)



Video 20. Final question in indirect causality condition.
 (Click on the image to watch the video)

The comparison of the initial question in both the direct and indirect causality conditions does not yield any significant difference, as expected, since they are exactly the same stimulus in both direct and indirect causality conditions and have no previous context:

(5)

Por que o professor pediu demissão?

Why the teacher quit

“Why did the teacher quit?”

However, the readings of sentences with direct and indirect causality clearly show differences in fixation numbers and latencies, as well as in regression patterns, as students usually very accurately pointed out.

(6)

O professor pediu demissão porque o salário dele não dava para as despesas.

The teacher quit because the salary of him not enough for the expenses

“The teacher quit because his salary was not enough for the expenses”

(7)

O professor pediu demissão porque o carro dele não está no estacionamento.

The teacher quit because the car of him not is in the parking lot

“The teacher quit because his car is not in the parking lot”

In Example 6, there is a very direct cause relation between the main clause idea of quitting a job and the fact that the salary was not enough. In Example 7, on the other hand, there is only indirect causation requiring inferential reasoning in a series of presuppositional steps, which students would formulate, for instance, as:

- The teacher would probably drive to work every day.
- The teacher would usually park his car at the parking lot.
- The teacher would never miss a day.
- The fact that his car is not in the parking lot suggests that he might have quit.

Accordingly, requiring more reasoning steps than direct causality, the indirect causality gaze plot displays about 50% more fixations, also requiring second pass regressions to be properly processed. Interestingly, the final question also yields differences. While the direct causality sentence question is answered in a very straightforward fashion, the indirect causality sentence question is answered with gaze patterns which suggest doubt, as the gaze moves back and forth, scanning both answer possibilities, before finally deciding for the right answer.

5.7. PP direct recursion vs. PP indirect recursion

Finally, we would like to give an illustration of the use of heatmaps in graduate classes exploring the recursive embedding and juxtaposition of Prepositional Phrases in BP. Maia (2016) reported an eye-tracking sentence picture matching experiment comparing the processing of coordination (direct recursion) and embedding (indirect recursion) of PPs in BP, predicting that self-embedding would be more costly than conjoining. Results confirmed the prediction. Before reading and discussing this paper in class, students were shown heatmaps as illustrated in Figures 3 and 4, obtained in the study:

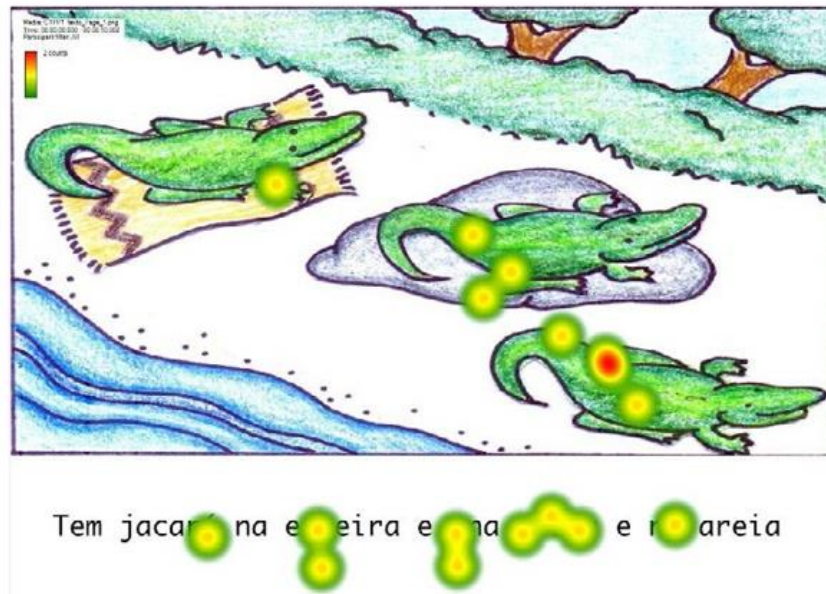


Figure 3. Heatmap of PP conjoined sentence *Tem jacaré na esteira e na pedra e na areia* “There is an alligator on the mat and on the rock and on the sand”

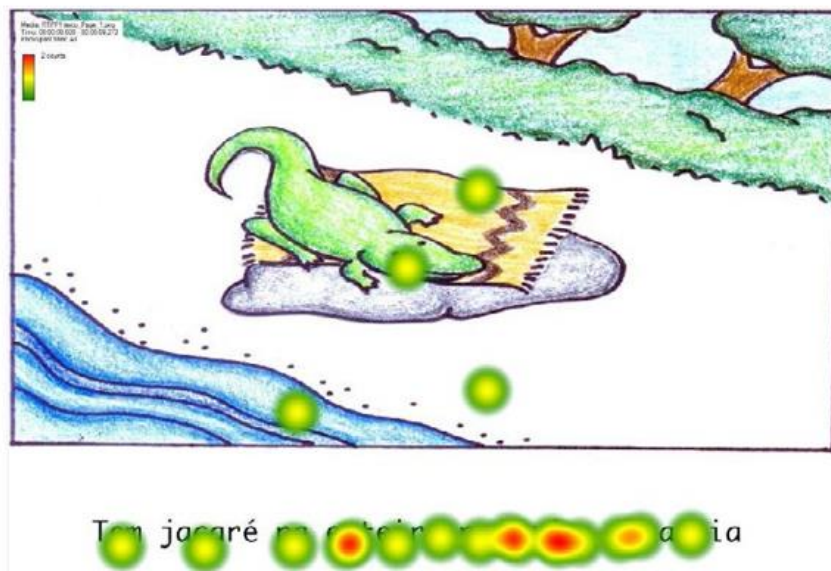


Figure 4. Heatmap of PP embedded sentence *Tem jacaré na esteira na pedra na areia* “There is an alligator on the mat on the rock on the sand”

The students very intuitively identified that the green areas in the heatmaps indicated less fixation durations, the yellow areas had less fixation durations than the red areas, which had the highest fixation durations in reading. Students also concluded that fixation patterns in the reading of the PP conjoining condition illustrated in Figure 3 tended to be less costly than the reading of the PP embedding condition in Figure 4, in which the red areas indicated higher fixation durations than in Figure 3. These observations led to interesting discussions about juxtaposition as being a flatter process than hierarchical embedding. The class analyzed these patterns as an indication of the difficulty inherent to the embedding process, which would not be the default process, if compared to the conjoining process.

6. Final remarks

As we have reviewed in the present paper, a metacognitive ability which came to be known as ‘theory of mind’ has been initially assessed as having first appeared in non-human primates to become later highly developed in humans, allowing individuals to infer others’ mental states and emotions. However, these earlier findings that other non-human animals would have metacognition were later ruled out as mere contingency effects (*cf.* Metcalfe 2008).

If, on the one hand, the appearance of a unique metacognitive ability would have allowed the first hominids to transcend the limits of environmental stimuli, developing consciousness of others’ mental states and self-reflexivity to become aware of themselves, on the other hand, a new challenge would have been posed: How reliable are others as sources of information? According to Sperber *et al.* (2010), to try to avoid being misinformed and deceived, humans must develop epistemic vigilance. If metacognition can be thought of as a secondary level of representation which could be fully established through hierarchical structuring made possible by language, epistemic vigilance on metacognition would be even recursively more complex, adding a third level of representation to cognition. This multilayered view of human cognition would be related to what Chomsky (2016) has called the basic property of language – the recursive capacity that allows the generation of an infinite array of hierarchically structured expressions. That being true, the question of how to develop epistemic vigilance in an infodemic world would be properly tackled through language reasoning which could then be thought of in terms of educational metacognitive exercises of recursion and inference, in addition to other structures, as we have sought to demonstrate in the paper.

Finally, we have made a case here that the sentence is the proper “small object” to start developing fundamental microstructural abilities and we have also presented our initial attempts to explore eye tracking as a metacognitive tool in education, in order to develop students’ language awareness and science forming capacity in lively active classes which may offer breakthroughs to counter infodemics, to be further explored in a post-pandemic new normal at the schools and universities.

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Thanks: The ideas presented in this paper have benefitted from many interesting discussions in live talks during several remote events the author has participated, in 2020 and 2021. Taking the risk of unintended omissions, I would like to mention the 36 Encontro da Associação Portuguesa de Linguística – APL, the ABRALIN Linguists on-line event, the Third Experimental Portuguese Linguistics Workshop (University of Toronto), the III and IV Encontro Nacional sobre o Ensino de Língua Portuguesa (ENELP), the 73 Reunião Anual da Sociedade Brasileira para o Progresso da Ciência (SBPC), the 68 Seminário do Grupo de Estudos Linguísticos do Estado de São Paulo (GEL), Maia & Gomes 2020 presentation at the Language Acquisition Research Center (LARC-UMass) and the 12th International Society of Applied Psycholinguistics Congress (ISAPL).

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