How can eye movements and prosody jointly inform us about linguistic processing?

**Reading** is firstly a visual process that feeds a complex bundle of cognitive operations leading to comprehension. The reader has to deal with multiple linguistic sources to decode, categorize, parse and interpret sequences of words. Visual word recognition (VWR) can proceed more or less easily depending on lexical properties, such as length, frequency and familiarity. Phonological structure including syllable type and stress. Isolated words need to be organized in structures by imposition of working memory and the need to build interpretative syntactic units. For that, grammar and intonation play a crucial role, not neglecting the help of punctuation (Perfetti 1999; Hortin et al. 2006).

**Reading aloud** involves all the representations and processes intervening in silent reading, more the planning and production of speech. Therefore it is as an extremely informative communicative task about the cognitive processes it implies, (Ashby et al. 2012; Benjamini & Schwanenflugel 2010).

**Eye movements and reading speech** can provide important indicators to the study of written language processing. Scan paths reveal patterns of saccadic movements, several measures of fixation time in a word region minor lexical and prosodic operations on the print input (Rayner et al. 2005). In reading speech, prosodic strategies such as intonation, speech rate or hesitations point out the same cognitive processes than eye movements, however they are expressed in a delayed temporal line (eye-speech space) (Roth et al. 2011; Frazier et al. 2006; Clifton et al. 2005). In a modular and sequential perspective, after VWR, building structure takes place. For that reason, the reader has to pay attention to lexical information and to graphic cues to construct syntactic units and to establish boundaries between these units, i.e. to parse. We can expect that the reader needs to spend more time in setting a word that holds the periphery of a XP than when it occupies the position in its core; in the same way, we can expect that the reader will spend more time in setting a word that holds the periphery of a clause or sentence. The supposed time increase could be justified because there is a progressive accumulation of information to be processed: from the word itself, to its integration in a syntactic unit (XP), and to their incorporation into a discursive structure. This must be visible in eye movements and speech, by themselves and in combination.

**Hypotheses**

- **H1** Boundaries at syntactic and discursive positions, as loci for structural building and information integration, should be marked by visible prosodic markers and longer eye fixations, when compared with non-boundaries.
- **H2** Discursive boundaries, as loci for wrap-up effects in the context of a complex text and under the influence of punctuation, must trigger higher fixation time (gaze and regressive fixations), and strong prosodic indicators of an intonational phrase boundary with significant decrease of FS in declarative sentences.
- **H3** At a head phrase, as no a boundary position, we do not expect important variation of prosodic or eye movements variables comparing with boundary positions.

**Independent variables**

- **Position**: Syntactic boundary (SB) vs. Discursive boundary (DB).
- **No Boundary (NB)**.

**Aims**

- Identify processes of linguistic information integration undergoing in oral reading for understanding.
- Verify the effect of linguistic and discursive structure on speech and eye movements at specific loci in the text.
- Understand how prosody and eye movements can be related to reveal cognitive operations of structure building.

**Dependent variables**

**Eye movements analysis**

As sensitive measures to catch the processing of target structures, we selected 3 variables (Rayner et al. 2005):

- **First fixation (FF)** – average duration of the first fixation in a word; must reflect specific processes to visual word recognition, regardless the lexical complexity of the word.
- **First pass (FP)** – which includes FF and other fixations before moving the eyes to right or left region; could tap the processes involved in lexical access, required for their integration in a larger meaning or structural unit.
- **Total time of word fixation (TWF)** – including all fixations in a word; must reflect word integration in a semantic-discursive mental representation, and can reveal wrap-up effects.

**Speech acoustic analysis**

To identify prosodic boundaries we consider two acoustic parameters (Gussenhoven & Fietkau 1992):

- **Stressed vowel length (SVL)** – as a marker indicating the proximity of a high level prosodic boundary: the longer the time word duration is, the higher the boundary is expected.
- **Fundamental frequency of the stressed vowel (F0)** – as an indicator of the syntactic position of the word: the more the word occupies the right periphery of a phrase or sentence, lower is F0 on the stressed vowel.

**Experiment**

**Participants**

17 European Portuguese native female speakers, proficient readers.

**Experimental material for reading**

Following previous studies on reading aloud and linguistic processing (Falk, Costs & Lueg, 2015, 2016), we assume that the high level of text complexity creates leading to a less automatized behavior in reading for comprehension, triggering a greater reliance on structures, in a more likely boundedly processing mode. So, in order to identify behavioral indicators of linguistic processing and information integration for reading aloud, we prepared a text with a specialized topic - speech-acoustic insulation - adapted from an engineering journal.

A text of around 200 words was considered controlling phonological and lexical properties, namely: prevalence of words of 3 or more syllables, presence of words with complex syllable types (CVC, VCC, CCV), low frequency words in the language (Graph 1). To control for these features we used Frep and CRPC, tools for computational analysis of EP databases.

**Results**

**Results for Syntactic and Discursive positions**

**Eye Movements**

- A Position effect in FF (F(2,16)=7.729; p<0.001) is clear when comparing SN and DB (p=0.018) and SB and DB (p=0.016), with longer reading times for DB. A Position effect is also registered in TWF (F(2,16)=7.952; p<0.001), when comparing NB and DB (p=0.051) and SB and DB (p=0.001), with longer reading times for DB (Graph 2).

- The lack of Position effect in FF (F(2,16)=0.932; p=0.679) sustain the assumption that word targets in all positions are equivalent in terms of lexical properties.

**Reading Speech**

**Conclusions**

Conjoint effects of eye movements and prosody are clear along the studied positions, however it is in Discursive boundary that this effect is stronger:

- The increase of fixation time in both FF and TWF occurs simultaneously with a decrease of FS values. This means that, at the locus where processes related with structural building and prosodic phrasing occur, eyes take later to complete the structure and possibly to resume prior information while speech indicates they are working towards closure with less F0.

- Unexpectedly, the head of a XP, that we considered a no boundary position, seems to be in competition with a syntactic boundary, showing similar values in FF and even higher values in TWF.

- This result can be interpreted as a correlate of syntactic operations required by the projection of a bare syntactic category in a larger unit (X = XP).

- The higher duration of the stressed vowel in NB compared to boundary positions reinforce the hint that the nucleus of a syntactic phrase is time consuming for purpose of structure building.

**References**


A resolution 364x364 of this problem, typical of actual forms of rural life, focuses on the existence of technical resources acting in the opposition the propagation of noise.

**Procedures**

Eye movements were recorded with a SMI RED250 Hi-SPEED system, at a 125Hz speed, and sound was recorded with a Logitech® Webcam Pro 9000.

For presentation, the text was divided in two blocks, font in size 22, Courier New, with two paragraphs spacing between rows, in a 17-inch screen.

Subjects were asked to read at their own pace trying to understand. After the reading aloud, participants answered a multiple-choice questionnaire, thus ensuring a reading comprehension task.