Searching for behavioral correlates of text complexity in reading

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1. Reading modality: voice and eyes as source for cognitive processes

Reading processes have been studied in a psycho and neurolinguistic perspective and a lot is known about what is involved (Perfetti, 1999). Interrelated processes and behaviors in reading have been separately studied in silent reading and reading aloud. The data dependent on reading modality inform us in different ways about online linguistic processing, comprehension and fluency.

Reading aloud provide data from reading speech, where speed, hesitations and prosody constitute a rich source for inferring and interpreting ongoing linguistic integration. The required speech articulation creates a lag between visual input perception and its production (Benjamin & Schwanenflugel , 2010).

In silent reading, eyes can be a good window to capture cognitive processes. Fixations, progressive and regressive saccades, that is, the eye movements patterns can inform us about processing costs when dealing with materials with different textual and linguistic properties (Rayner, Juhasz & Pollatsek, 2005).

What about combined reading data from voice and eyes? Will they be more informative than when isolated?

Eye-voice span (EVS) is a construct that has been exploited tentatively from Buswell to today (Inhoff et al., 2011; Laubrock & Kliegl, 2016, a.o.). Its purpose is to grasp the dynamic cognitive labor involving linguistic representations, perceptive and cognitive processes required for comprehension when reading aloud.

EVS means the distance between eyes and voice, knowing that when the production of a given word begins, the eyes are ahead 2 to 3 words or around 500ms. The EVS amplitude is variable considering the reader experience and processing troubles triggered for local linguistic properties of print input, such as lexical properties.

Our previous research on reading

Costa, Falé and Luegi are developing a set of experiments: on oral reading *per se* with speech analysis (Costa, 1992); on silent reading with eyetracking (Luegi, 2006; Costa, Matos & Luegi, 2009); and more recently reading aloud with simultaneous register of speech and eye movements (Falé, Costa & Luegi, 2016). We aim to study the impact of lexical, syntactic and textual properties in processing costs. Considering the data from speech reading and from eyetracking, we found that eye movements are more sensitive to linguistic properties and text complexity than reading speech: sometimes the eyes respond to linguistic properties that voice apparently ignores.

Current research question:

To what extent can the lexical complexity affect the EVS?

Hypothesis

Considering that lexical properties, such as word length, syllable structure, word stress and frequency, impact on visual word recognition and lexical access, and assuming that EVS should be sensitive to lexical properties, we predict that:

- phonological complex words, as a result of number and syllable type and word stress, should have an effect on EVS, shortening it;
- less frequent phonological complex words should reduce more the EVS amplitude.

3. Experiment

Design and materials

Two texts, each one with 30 target words, avoiding positions in the end of the line, punctuation marks, and contiguity between targets. The 60 words, with 3 or 4 syllables, were distributed over three levels of complexity (around 20 per each level), taking into account:

- phonological properties, such as number and syllable type, and stress type, following the hierarchy based on syllable types frequency in European Portuguese (Vigário & Falé, 1994; Vigário et al., 2006).

  CV < V < CVC < VC < CCV

  (split nucleus with glides and vowel nasality features contribute to add more steps in the hierarchy)

- word frequency, according the *Multifunctional Computational Lexicon of Contemporary Portuguese* (CLUL)

	COMPLEXITY LEVEL	TARGET WORD	SYLLABLE		WORD STRESS	FREQUENCY LEVEL (log10/2)	PHONETIC TRANSCRIPTION
			NUMBER	STRUCTURE			
PHONOLOGICAL COMPLEXITY	C1	CIDADE *city*	CI.DA.DE	CV.CV.CV	PAROXYTONE		[si'dadɨ]
	C2	GARANTIR *assure*	GARANTIR	CV.CVn.CVC	OXYTONE		[gɐrɐ̃'tiɾ]
	C3	FAMÍLIAS *families*	FA.MÍ.LIAS	CV.CV.CGVC	PROPAROXYTONE		[fɐ'miljɐʃ]
PHONOLOGICAL AND FREQUENCY COMPLEXITY	C1	GARANTIR *assure*	GA.RAN.TIR	CV.CVn.CVC	OXYTONE	3163 - 10000	[gɐrɐ̃'tir]
	C2	FAMÍLIAS *families*	FA.MÍ.LIAS	CV.CV.CGVC	PROPAROXYTONE	1001 - 3162	[fɐ'miljɐʃ]
	C3	ABSORÇÃO *absorption*	A.BSOR.ÇÃO	V.CCVC.CVGn	OXYTONE	101 - 316	[ɐbsɔɾ'sɐ̃w̃]

Participants

17 European Portuguese adult native female speakers, university students, proficient readers.

Procedure

Participants read two texts and were asked to read aloud at their own pace, trying to understand. After reading each text, participants answered a multiple-choice questionnaire, thus ensuring a reading comprehension task.

Eye movements were recorded with a SMI IVIEW X™ HI-SPEED system, at a 1250Hz speed, and sound was recorded with a Logitech® Webcam Pro 9000.

Stimuli were divided, for presentation, into two blocks of text, font in size 22, Courier New, with two paragraphs spacing between rows, in a 17-inch screen.

Independent variables

- Phonological complexity at three levels: C1 < C2 < C3
- Phonological complexity plus frequency at three levels: C1 < C2 < C3

Dependent variables

Eye movement analysis

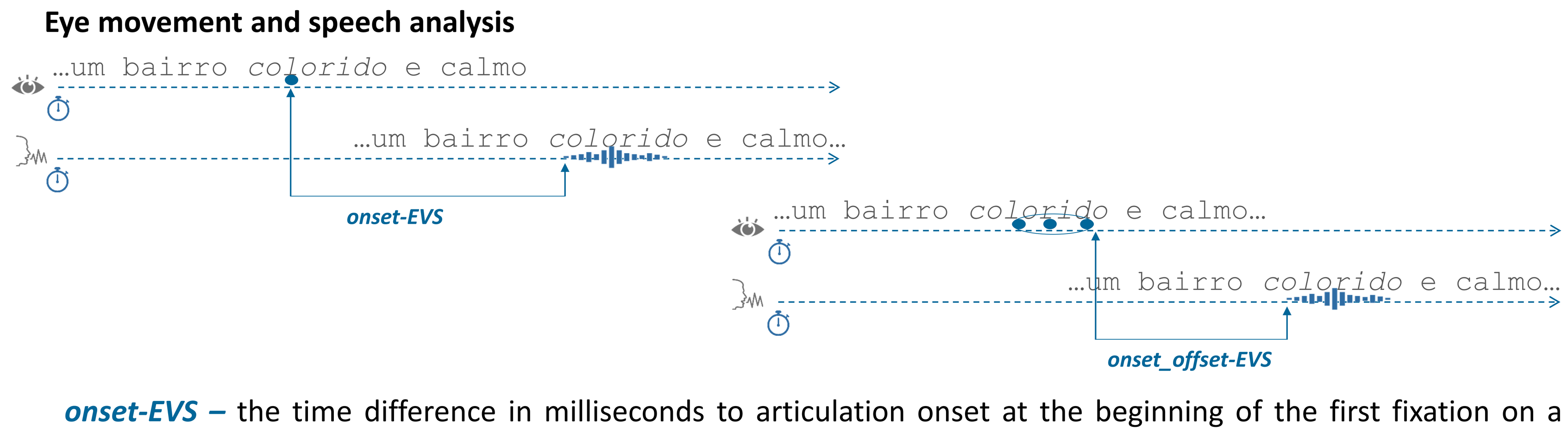
First fixation (FF) – first time a word is fixated regardless if it is fixated one or more times; reveals specific processes of visual word recognition (VWR).

First pass (FP) – all the time spent in the fixation of a word before moving the eyes to right or left regions; reveals aspects involved in VWR and lexical access.

Speech analysis

Word Production Duration (WPD) – the time spent on the production of a word; should reveal lexical access and any disturbance coming from word recognition, phonological mapping, lexical access and possible articulatory problems

Eye movement and speech analysis

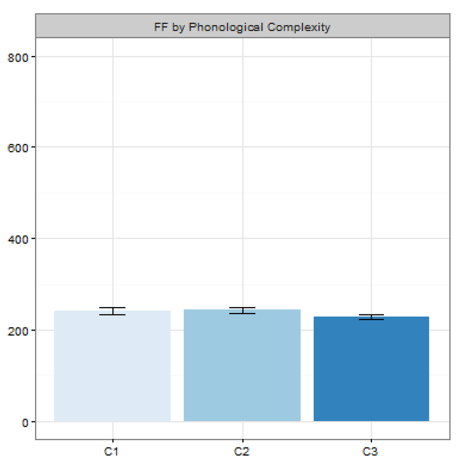


onset-EVS – the time difference in milliseconds to articulation onset at the beginning of the first fixation on a word.

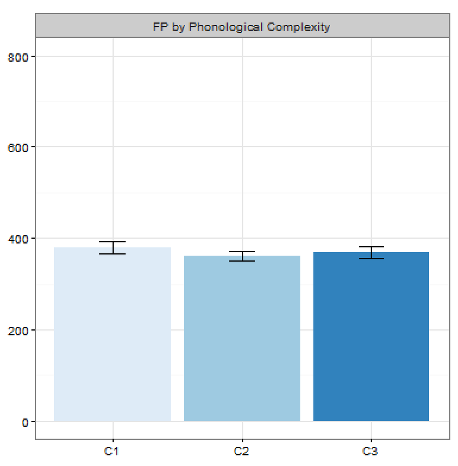
onset_offset-EVS – the time difference in milliseconds to articulation onset at the end of the last fixation on a word.

4. Analysis and Results

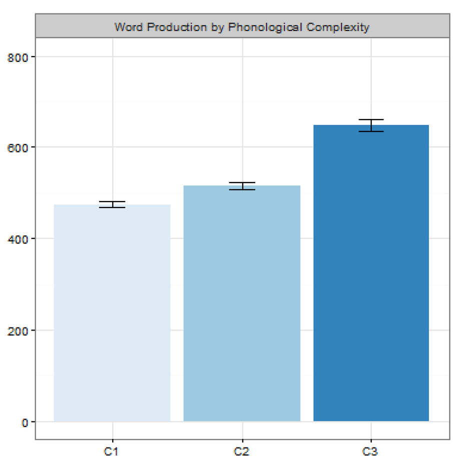
Target words and phonological complexity



Graph 1 – First Fixation by Phonological Complexity.



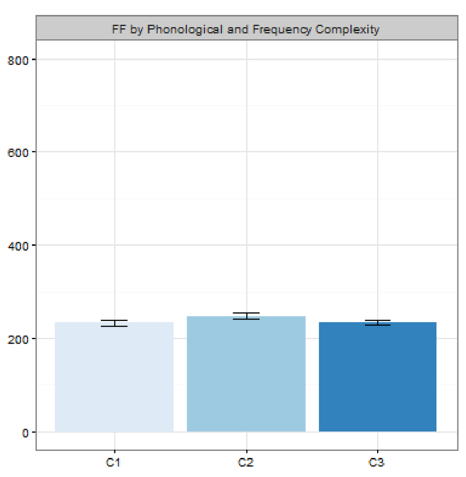
Graph 2 – First Pass by Phonological Complexity.



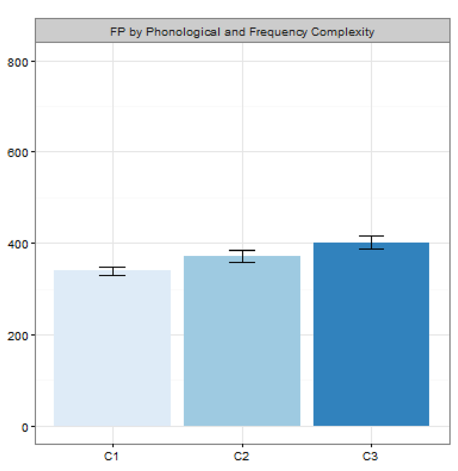
Graph 3 – Word Production time by Phonological Complexity.

- Neither **First Fixation** nor **First Pass** discriminate between degrees of phonological complexity;
- **Word Production Duration** distinguishes between C1 and C2 (Est. = 40.949; SE = 13.479; t = 3.038; $\boldsymbol{p = 0.002}$), and between C1 and C3 (Est. = 175.429; SE = 14.088; t = 12.452; $\boldsymbol{p < 0.001}$).

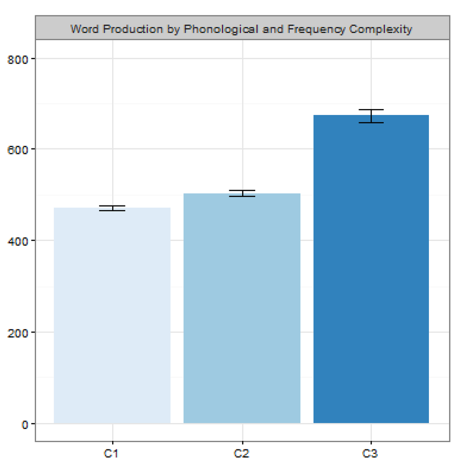
Target words, phonological complexity and frequency



Graph 4 – First Fixation by Phonological and Frequency Complexity.



Graph 5 – First Pass by Phonological and Frequency Complexity.



Graph 6 – Word Production Duration by Phonological and Frequency Complexity.

- **First Fixation** does not distinguish between complexity levels;
- **First Pass** allows to discriminate between C1 and C2 (Est. = 31.735; SE = 17.143; t = 1.851; $\boldsymbol{p = 0.064^*}$), and between C1 and C3 (Est. = 60.392; SE = 16.815; t = 3.591; $\boldsymbol{p < 0.001}$);
- **Word Production Duration** variable distinguishes C1 from C2 (Est. = 31.919; SE = 12.914; t = 2.472; $\boldsymbol{p = 0.013}$) and C1 from C3 (Est. = 202.069; SE = 12.722; t = 15.884; $\boldsymbol{p < 0.001}$).

Complexity level on a word was previously assigned as a function of intrinsic phonological features and lexical information about frequency from a large corpus in EP. Physiological information coming from eyes and speech confirms partially linguistic categorization.

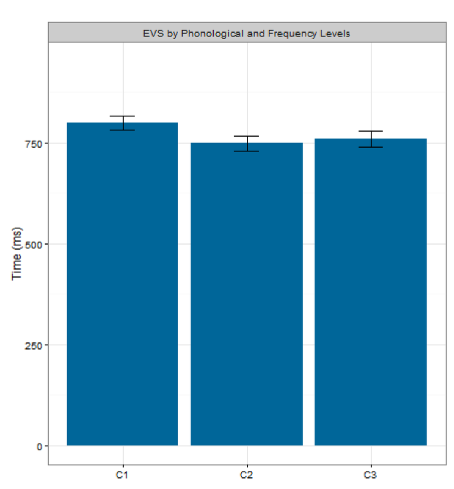
WPD mirrors the growing complexity from C1 to C3, with simpler words using significant less production time than more complex words. This is an expected result because C3 groups mostly long words and, particularly, with heavy syllables. It is worth saying that C2 and C3 also include short complex words (*e.g.*, eleição/*election* or atrito/*attrition*).

In what concerns the eyes, FF is insensitive to phonological and frequency properties, whereas FP works as a measure that distinguishes levels of complexity but only when frequency information is incorporated in the classification.

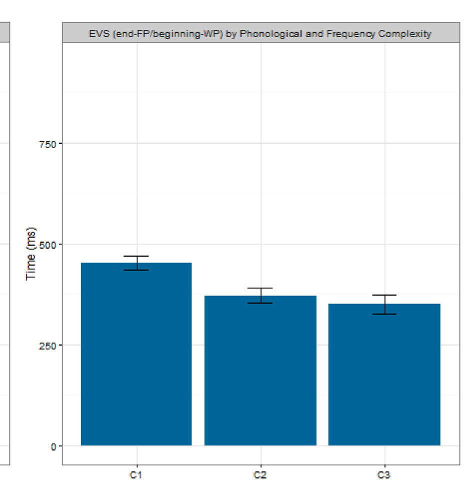
WPD and FP are good indicators to distinguish between our target words

EVS considering phonological complexity and frequency

Considering the results from eye movements and word production, statistical analysis was performed only on target words classified in 3 levels of complexity as a result of phonological and frequency properties.



Graph 7 – Onset-EVS by Phonological and Frequency Complexity.



Graph 8 – Onset_offset-EVS by Phonological and Frequency Complexity.

Onset-EVS

- EVS1 is higher in C1 than in C2 (Est. = -50.953; SE = 24.020; t = -2.121; $\boldsymbol{p = 0.034}$);
- There are no differences between C1 and C3 (Est. = -40.867; SE = 23.524; t = -1.737; p = 0.082).

Onset_offset-EVS

- EVS2 is higher in C1 than in C2 (Est. = -78.586; SE = 27.482; t = -2.860; $\boldsymbol{p = 0.004}$);
- EVS2 is higher in C1 than in C3 (Est. = -100.414; SE = 26.914; t = -3.731; $\boldsymbol{p < 0.001}$).

5. Conclusions and next step

The temporal lag we obtained in *onset-EVS* can show the effect of some formal lexical properties. The eyes, in a first fixation, perceive quickly visual information that trigger neuro and cognitive processes in specific cortex visual areas, the mapping between letters and sounds, and the planning of the motor processes that lead to the articulatory word phonetic form.

The temporal lag obtained by *onset_offset-EVS* must integrate and be reactive to all the formal lexical information, including meaning and frequency of the word, and even its relations with the mental text model that is being built during reading. When the articulation begins, it is informed by all lexical properties of the previous fixated word.

Results show a *quasi* non effect of *onset-EVS* derived from complexity: simpler words allow a large EVS than C2, and not different from C3. Comparing C1 and C2, we can say that as the complexity increases, lag decreases.

When the voice is informed by eyes over all the lexical information and if the word is complex, voice holds the eyes and does not let them move forward, otherwise the working memory goes into overload and there will be loss of crucial information for understanding. In turn, to wait for the voice, eyes must do longer fixations and refixations. To slow the eyes, the voice commits disfluencies such as vowel lengthening ([ɐbsɔːɾ'sɐ̃w̃]) or truncations ([ɐb/ɐbsɔːɾ'sɐ̃w̃]).

And here is our next step in research: deepen what we know about cognitive processes in reading shown by the prosody and the dynamics of eye patterns.

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