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The role of prosodic information in silent reading: An eye–tracking study

A century old intuition about the "inner voice" that accompanies silent reading is nowadays formulated as the Implicit Prosody Hypothesis (IPH) emphasizing the role prosody plays in silent reading comprehension. To test the IPH, an eye–tracking corpus was set up and analysed. The corpus consisted of eye–tracking data collected in natural reading, i.e. on text materials not experimentally manipulated. The corpus included a short story that participants, unbalanced Croatian–English bilinguals, read in Croatian and English. The eye–tracking data corroborate the IPH, but only in English, while in Croatian the results are less clear. The participants' gaze was more linked to the content words rather than the prosodic information, but only for fixation durations, not their counts. Arguably, these results reflect differences in stress and grammatical structures between Croatian and English.

1. Introduction

For over a century now, researchers have been focusing on subvocalization, or the "inner voice" experience in silent reading (already Huey 1908/1968 in Ashby and Clifton 2005; for an overview see Breen 2015). There is an impression that phonological information becomes automatically available and covertly utilized, possibly with the purpose of facilitating reading, even when this is not overtly required. Moreover, studies of subvocalization including muscle movement of the speech organs in the course of silent reading have been underway to present the physiological or neurophysiological evidence for this phenomenon (Slowiaczek and Clifton 1980; Orepić 2020). The role of phonological coding defined as the recoding of orthographic information into a sound–based code has been looked into in silent reading to account for the experience of "hearing" segmental (but also suprasegmental) realization of the read text (for a review see Leinenger 2014). The activation of phonology has been suggested to be involved in lexical access, yet its exact timing (pre–lexical, post–lexical, or other) and purpose have remained matters of debate as retrieval of semantic representations derived from the orthographic ones may or may not be aided by the phonological representations of the input (ibid.). Already in 1977 Kosslyn and Matt move beyond the segmental level of processing and report on a series of experiments to unveil a phenomenon they dubbed "person–particular speech recoding". In a nutshell, if the readers read a text they believe has been produced by a fast speaker, they read it more quickly; if, in turn, they believed they are reading a slow speaker's text, they read it more slowly. The mentioned work left no doubt as to the influence of the suprasegmental representation of language in silent reading and in 2002 Fodor takes the issue further building on the work of CUNY's sentence processing research group to put forward the Implicit Prosody Hypothesis (IPH). According to IPH, "(i)n silent reading, a default prosodic contour is projected onto the stimulus, and it may influence syntactic ambiguity resolution. Other things being equal, the parser favors the syntactic analysis associated with the most natural (default) prosodic contour for the construction." (Fodor 2002: 113). Eye–tracking methodology has been used to provide evidence for the effect of the suprasegmental information, overt and implicit. The choice of this methodology is based on a simple fact that implicit prosody cannot be studied directly, i.e. its traces have to be found in some other experimental effects. Therefore, the studies often employ a visual world paradigm to study the effects of overt prosody on language comprehension measured as timely gaze orientation to the target picture while listening to the stimulus sentence. Thus Weber et al. (2006) examined the prosodic facilitation of the referent resolution while listening to adjective – noun pairs where intonation pointed to the focus[1] of the expression. Ito and Speer (2008) obtained anticipatory effects of the suprasegmental information in a similar paradigm (in the presence of the intonational cue the participants fixated the target picture before the corresponding word was encountered in the acoustically presented stimulus sentence). Further on, eye–tracking has been used in studies that included children with autism spectrum disorder (cf. Diehl et al. 2015) to study their sensitivity to the prosodic cues in syntactically ambiguous phrases. The reading studies ranged from the children's ability to match the adult–like prosodic profile in oral reading to text comprehension and word decoding (Schwanenflugel et al. 2004). Implicit prosody in silent reading has also been studied in the developmental context (Veenendaal et al. 2016). The effects of prosody have been documented even in the population of readers with hearing loss (Uetsuki et al. 2020). The eye–tracking reading studies of implicit prosody have been scarce probably because it is unclear whether implicit prosodic contour facilitates comprehension

1 For example: Give me the RED ball vs. Give me the red BALL.

or comprehension process leads to the production of appropriate reading prosody (cf. Kuhn et al. 2010, Webman-Shafran 2017). By tracking the number of fixations in sentences with the number of syllables being manipulated, one could figure out whether stress is a part of the activated phonological representation (for review v. Ashby 2006). The effect that could be traced to the implicit prosody has been found for infrequent words, but not the frequent ones (ibid.). Similarly, the effect of the prosody can be seen as longer fixation times even when the stress is not semantically informative (Ashby and Clifton 2005).

In general, the experiments have often been set in such a way as to induce a potential garden path effect or the reader's expectation of a certain prosodic contour but proceeded with a prosody–based "surprise" effect affecting semantic or syntactic interpretation of the material and offering an alternative resolution of the input string. This induced longer reading times and longer fixations onto the point in the text that called for reanalysis. In fact, stress seems to be the suprasegmental bit of information that is particularly salient, even in silent reading. Metrical information of a language seems to make an integral and inseparable part of a word's representation (Breen and Clifton 2011). This has been shown in eye–tracking studies where an unexpected stress pattern has been forced onto the participant's interpretation of the text, thus causing processing delays (ibid.; Breen and Clifton 2013). Breen and Clifton (2011, 2013) focus on the effect of the metrical structure of the text and show that metrics affects eye movements during silent reading. They do so by using verb–noun and noun–verb homographs that differ in stress assignment (e.g. *ABstract, abSTRACT*) and portray a reading cost that occurs upon encountering a mismatch between the predicted and actual stress patterns of the word during reading. This is taken to be on–line evidence showing that metrical information is part of the default representation of the word (Breen and Clifton 2011) and is activated even when no spoken realization is necessary in the reading process. Interestingly, the authors find longer fixations on the word that carries the misguiding stress (e.g. The brilliant *abstract*) even before the eye moves on to the word that triggers reanalysis (*was* accepted at the prestigious conference / *the* best ideas from the things they read.). They propose that this is due to the parafoveal vision encompassing the trigger word (was / the) before the eyes move to it thus triggering the reanalysis that is reflected in the greater cognitive processing load and longer fixation times of the focal word. Using a boundary change paradigm Breen and Clifton prove this proposal in their 2013 paper and thus inform further research which can now rest upon the knowledge that metrical information (stress) does play a role in silent reading and is reflected in longer fixations falling upon the stressed syllables. Ashby and Clifton (2005) provide more support to this thesis showing that words with two stressed syllables receive more fixations and thus take longer to read than words with only one stressed syllable. They interpret their results suggesting that appropriate stress assignment presents the completing phase of lexical access. One needs to remark here that the exact point in the lexical processing at which suprasegmental information is activated to aid the completion of (monolingual or bilingual) lexical retrieval seems to remain a matter of debate. An experimenter's curiosity is naturally sparked by the role of stress in the silent reading of two languages as performed by speakers of two languages portraying very different stress patterns (e.g. Croatian and English).

English is a stress–timed language, meaning that is has a regular stress pattern occurring on the lexical words, while the non–stressed syllables are often affected by various phonological processes such as vowel weakening and elision as they allow for the fitting of the unstressed syllables in between the regular metrics of the stressed syllables (Abercrombie 1967). Croatian on the other hand is a syllable–timed language where approximately equal prominence is assigned to all syllables. Therefore, there is no tendency to weaken the vowels at all or as much as in the stress–timed languages. All accent types (rising and falling, long and short) may be placed on the first syllable of a word, rising accents may occur within the word while the last syllable is not stressed (Silić and Pranjković 2007). Unlike Czech, Polish or Macedonian, the position of the stress within a word may shift within a paradigm (Pletikos 2008). This includes prepositions, (e. g. *grâd* 'city', Nom. Sg., but *ȕ grad* 'to the city (Acc. Sg.)' although some studies point to the non–obligatory nature of this shift in contemporary Croatian speech (c.f. Škarić et al. 1987)).

One may observe that in syllable–timed languages syllables are auditorily similar in length, whereas in the stress–timed languages they are not (for an overview see Josipović 1994; 1999). The described differences in the stress of the English and Croatian languages allow for a comparison of silent reading eye–tracking patterns where fixations are expected to occur on the stressed syllables and should very much differ in their distribution dependent on the language–specific stress–assignment.

In written language comprehension, the Lexical Access Hypothesis (cf. Kadota 1987) posits that a phonetic representation of a written word must be fully established before it is recognized and processed; in this process, activation of prosody in silent reading is crucial for the semantic analysis of a natural text. Moreover, the integrative model (ibid.) suggests that, in silent reading, subvocalization plays a relevant role in integrating words into syntactic and semantic relations when organizing them into language chunks necessary for overall comprehension. One may stipulate thus that in the investigation of meaning retrieval in a text as a target unit (as opposed to an isolated word) it is primarily the content words and their stressed syllables that should be focused upon as probably most salient elements of the text to uncover how much they influence meaning retrieval in (silent) reading. The content words also trigger the intra–lexical priming effects affecting the processes of eye–movement planning and, consequently, building the message–level representation (Morris 1994). They receive more visual attention, as reflected in longer dwell times, more regressions or higher number of fixations in comparison to functional words (cf. Schmauder et al. 2000; Krejtz et al. 2016). These findings are documented in numerous eye–tracking studies and it is around them that the theories of eye guidance in reading are built on from the early days of eye–tracking (cf. Rayner and McConkie 1976; Rayner 1998). It is a common practice in experimental work to focus on a narrowly defined category and many studies indeed focus on e.g. emotional words (Wegrzyn et al. 2017) or on errors made by bilingual speakers. English–Chinese bilingual studies are particularly informative due to the similar length of content and functional words in Chinese. Focus is also put on words of both categories manipulated for frequency (Schmauder et al. 2000).

Recently, experimental studies have increasingly been criticized for setting up conditions that do not necessarily reflect natural language use (cf. Sunderman and Kroll 2006). An alternative methodology has been proposed in the field of on–line eye–tracking experimentation. It is based on natural text processing, such as reading a story or a piece of text rather than artificially pre–designed sentences (cf. Denberg and Keller 2019; Hollenstein et al. 2022). This is why the present study employs a narrative, a short story originally written in the English language and its published translation into the Croatian language. The inclusion of texts in two languages that differ in their prosodic structures is envisaged to overcome the shortcomings of text–based eye–tracking studies that, by their nature, lack strict experimental control necessary for the interpretation of the results. Together with the non–invasive eye–tracking methodology and a task in which the participants read the texts silently and at their own pace, this task aims at uncovering the subconscious processes occurring in the course of a natural reading activity in bilingual speakers.

There are different views and definitions of bilingualism, and this paper makes use of the oft cited Grosjean's view. He defines bilingualism as regular (everyday) usage of two languages whereby they do not need to be ambilingually mastered (Grosjean 1994). In line with this, the present paper focuses on the processing of Croatian and English in speakers that correspond to Grosjean's definition of bilinguals, namely speakers of Croatian as mother tongue and English as a second language where English is used on a regular everyday basis for study and leisure purposes. Being a Lingua Franca, English is omnipresent in young people's lives today and, although it is initially learned as a foreign language in Croatia, it has a special status in the participants' everyday routines as they are surrounded by English in their environment.

Studies of bilingual processing using the eye–tracking methodology have often, although not solely, focused on the cross–language influence of phonology and lexis (for an overview see Hayakawa and Marian 2020) and its interrelatedness with orthography (Whitford and Joanisse 2021), employed natural reading tasks for eye–tracking corpus design and associated research (Cop et al. 2015; Whitford and Titone 2012) and compared bilingual speakers of various proficiencies. Rare studies focused on silent bilingual reading. One recent eye–tracking study compared monolingual and bilingual processing of German and Russian in the oral and silent reading modes to show that bilinguals made a higher number of fixations that lasted longer than in the processing of their monolingual peers in both oral and silent reading modes (Krause and Ritter 2022) supporting the notion that silent reading patterns correspond to the oral ones both in monolingual and bilingual processing. To the best of our knowledge, no study has so far investigated the role of metrical information (stress) in bilingual processing of two languages with different stress patterns, utilizing the eye–tracking methodology and focusing on the reading of natural text. This paper aims to fill that gap.

2. Aim and Hypothesis

The present study strives to explain differences in the reading behaviour in two typologically different languages, Croatian and English, that are expected to occur due to the differences in their prosodic structures. If prosodic differences can be used to explain the differences in the bilinguals' reading behaviour when it comes to these two languages, this would corroborate the Implicit Prosody Hypothesis. As mentioned in the introduction, it is quite reasonable to say that implicit prosody in silent reading cannot be tackled directly; therefore, in this study its behavioural outcome will be studied as the attention given to particular elements of the text, as reflected in eye–tracking variables across two languages, English and Croatian. One predicts that the participant's gaze will adhere to the metrical structure of the presented language, i.e. that the fixation pattern will reflect the metrical structure of the text. As the stress carries salient information, the participants' fixations are expected to linger on the stressed syllables in both languages, following their language–specific varied stress distribution yielding differences in eye–tracking measures (fixation durations and counts) between the languages. Thus in 'natural reading' (i. e. reading a text that is not manipulated experimentally) the experimental effect of implicit prosody is expected to be obtained as a difference between the amount of attention given to the stressed syllabi in English and Croatian whereby this difference in attention follows the differences in metrical structures between the languages. Both in English and in Croatian stressed syllables are parts of the content words – this is more prominent in English (as mentioned in the Introduction, in Croatian the stress can relocate to the preposition as in *grâd – ȕ‿grad (town – to the town)*. In order to check whether the reader's gaze follows the pattern of content and function words, the amount of time spent on each will be measured as well.

The simple logic of this study is, however, complicated by a number of factors. Differences in orthography lead to the syllables of different sizes (in letters) in English and Croatian. This is measured as the *orthographic depth* (Gontijo et al. 2003) calculated as a total number of grapheme–phoneme correspondences (GPC) divided by the total number of graphemes, *g*. In Croatian this *GPC/g* ratio is 1.1 (only phonemes /ǯ/, /ļ/ and /ń/ are written as digraphs *dž*, *lj* and *nj*), while in English *GPC/g* = 2.4 (ibid.). In addition, generally more Croatian words are multisyllabic simply due to the morphological markings which very often consist of (or at least contain) a vowel thus adding a syllable to a word. In the analysed portion of the texts the English text consisted of 429 syllables (183 stressed). Croatian translation of the same portion of the text contained 593 syllables with 210 stressed. In other words, the English text contained 43% of the stressed syllabi while the Croatian text contained 35%. These two differences between English and Croatian put forward the prediction that English stressed syllables will be fixated more.

Finally, typological differences between Croatian and English yield differences in the number of words in the Croatian translation of the English text. Thus 309 English words were translated into 273 Croatian words. While the English text analysed for this study contained 150 content words (48%), the Croatian text contained 167 (61%). This is due to the analytic nature of English and more morphological markings in Croatian as a fusional language. If the attentional processes reflected in fixation times orient the gaze towards the content words, this allows for the prediction that the Croatian content words will be fixated more. In general, this means that various factors act in opposite directions and that the final results as obtained in the eye–tracking measurements will be a product of their 'tug of war'.

This study has been envisaged as an exploratory one rather than confirmatory. We hope to make a point in establishing whether we may have a case in believing that the stress guides a reader's gaze. Should this be found relevant, this study is hoped to incite further investigation in this direction.

3. Methodology

This study employed a reading paradigm in a natural reading experiment, i.e. the participants read a text that was not experimentally manipulated. They were asked to read silently, and at their own pace, a story presented in English and Croatian while their eye movements were being recorded. They read a short story entitled "Storyteller" by Hector Hugh Munro Saki (The Complete Stories of Saki, 1993, first published 1914). The original English version and the published translation into Croatian (Munro Saki 1984) were used to ensure content similarity in both languages. The participants read this story in English and Croatian in two balanced sessions that took place at least three weeks apart where one half of the participants was first exposed to the text in Croatian followed by the text in English and for the second half of the participants this order of the presentation was reversed. The story was presented on six successive slides, each containing 17 rows of text. Double spacing was used with the Ariel font size 24. The participants were positioned at a 50 cm distance from the screen on which the text was presented. To ensure the participants' careful focus, they were informed that, once they had read the text, there would be a multiple–choice test. The first page of the text was analysed for the purposes of this publication as this yielded abundancy of data to test the research hypothesis. The participants signed a consent and the study was carried out in line with the ethical prerequisites.

The eye–tracking data were collected in the eye–tracking laboratory, on an SMI iView HiSpeed 500 device with the sampling rate of 500Hz. This device uses a chin–rest and a forehead–rest for stabilizing the head while recording. First, each participant's gaze was calibrated on 9 points and once a participant had completed the reading task, subsequent validation was carried out on four points (a built–in option of the device) to ensure that the participant's gaze had remained calibrated throughout. Only the data collected from the participants whose gaze had remained calibrated throughout the session and with a successful tracking rate of >95% as well as the validation data of >90% were included into the analysis. The tracking rate and validation data are incorporated into the output of the measurements for each participant. After calibration, the participants were asked to read a short text (two short Aesop Fables, three lines of text each, occupying the top and bottom of the screen) to ensure the precision of the measurements on the top and on the bottom of the pages where the eye–trackers are typically less precise. The built–in software (SMI Experiment Centre was used for the experimental control and the SMI BeGaze2 was used for data pre–processing, visualization and exporting of the data).

The analysis was based on the general or 'global' measure of reading per participant. Instead of just taking the Reading Times as the variable provided by the eye–tracking system, for this study a sum of fixations in the Areas of Interest (AOIs) was calculated. Therefore, fixations on the white space between the lines of text were excluded from the analysis. The motivation for this is both practical and substantive: the built–in automatic creation of AOIs around the words could thus be employed for at least one category of predictors (content and function words) but, more importantly, this new derived measure reflects the attentional processes related to the predictors better than just the raw reading times which is the measure of total cognitive effort put to the comprehension of the text and which contains a degree of randomness due to the way the SMI eye–tracker software creates the AOIs narrowly around the words (v. Figure 1). In addition to the word AOIs, the stressed syllables AOIs were created manually. Their position was based on the position of the stress in standard Croatian and English varieties.

Average fixation durations were taken into the analysis, as well, since this measure reflects the local lexical processes (Clifton et al. 2007; Holmqvist et al. 2011), i. e. the cognitive effort invested into the lexical retrieval.

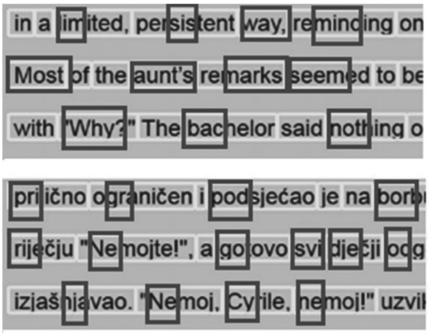

Figure 1. AOIs tagged for stress (black) and words (white) on English (above) and Croatian text (below). Word AOIs were automatically generated by SMI software and renamed for parts of speech manually.

Raw data was pre–processed using the SMI BeGaze2 software (removal of the blinks, definition of the AOIs) and exported to the .csv file. The data export was based on fixations, i. e. all fixations per participant with the relevant attributes were exported for further analysis. This ensured that the fixations falling into two areas of interest were counted only once (with the 'advantage' given to the manually created AOIs). The .csv file was further filtered in Microsoft Excel in order to obtain average values of the relevant variables per participant (mean values, sums) suitable for final statistical analysis performed in R (2021). Multiple regression was performed using the lme4 package (Bates et al. 2015).

3.1. Participants

The participants can be described as unbalanced bilinguals[2]. They were 2nd and 3rd year students (age 19–22) at the University of Zagreb who use English every day for study purposes and leisure. To enrol in their studies, they needed to achieve level B2 or higher at their high school leaving exam; therefore, the participants were fluent in English. However, as their L2 was not specifically tested for the purposes of the study, and therefore, their proficiency could have been varied, the participants were taken as the random effect in the regression model. The students came from various Croatian regions and their dialects sometimes varied regarding the position of the stress (for example, the word *lopata* 'shovel' is pronounced as *lòpata* in standard Croatian, i. e. in Štokavian dialects, but as *lopȁta* in e.g. Kajkavian dialects, cf. Kapović 2015). The inconsistencies in stress placement and its quality (falling or raising, long and short) has been noticed even in professional TV anchors who speak standard Croatian (Buzina 1987), therefore no additional check of the participants' native accent was done. Also, such a check could have revealed the participants the aim of the study and could have influenced the data. In total 89 students participated in reading the Croatian text, while 83 participated in reading the English text. For this study 65 of them were analysed. Their eye–tracking data were of good quality in both languages.

4. Results and Discussion

The present analysis takes fixations as primary events of interest and makes use of their counts and durations. These, together with the language of presentation and the type of the AOIs (content words, functional words or stressed syllables), constituted the fixed effects of the model. As previously explained, the participants' language skills were not specifically tested for experiment purposes so they were included into the model as a random effect. The participants took longer to read the English text than the Croatian one ($\bar{x}$ENG= 143808 ms (2.4 minutes), σENG = 40081 ms; $\bar{x}$HRV= 77140 ms (1.29 minutes), σHRV = 20740 ms). The av-

2 for definition cf. APA Dictionary of Psychology, https://dictionary.apa.org/unbalanced–bilingual

erage difference between reading the page of the Saki's story in Croatian and English is thus 1.11 minutes and this difference is significant ($t(63) = -11.67$, $p < 0.001$). This is not surprising as English is the participants' less dominant language. Similarly, statistically significant differences were found in average fixation durations ($t(63) = -3.02$, $p = 0.004$) and fixation counts ($t(63) = 4.58$, $p < 0.001$), although, the participants made more shorter fixations on the Croatian text, i. e. the difference in reading times arose as the fixation durations accumulate. On the other hand, the larger number of (shorter) fixations in Croatian may reflect the larger 'reading depth' in Croatian. The reading depth may be defined as a ratio between the duration of fixations and the number of words, i.e. as average fixation durations per word (Holmqvist et al. 2011, p. 527). Overall larger reading depth was obtained on the English text (229.37 ms in comparison to 218.75 ms obtained for the Croatian text)[3]. In accordance to their typical interpretation these values would suggest that the participants invested more cognitive effort in reading the English text, which is not surprising.

The overview of the reading data is represented in Figure 2.

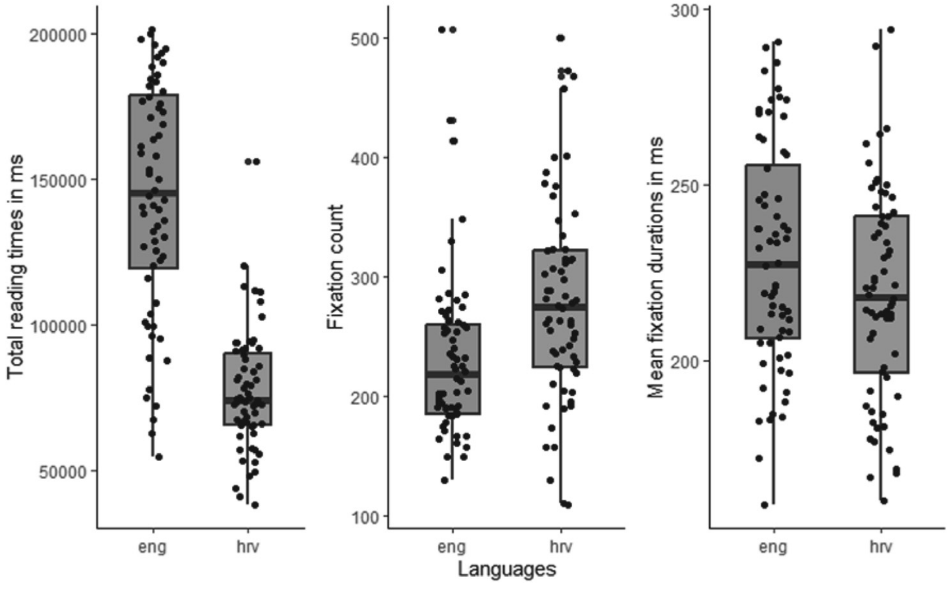

Figure 2. The "global" differences in reading the English and Croatian text

The difference in the total reading times and mean fixation duration reflects the difference in language proficiency; the participants needed more time to read the text in English and they needed more time to retrieve the words. However, they

3 If one takes a different way of calculating reading depth, e. g. based on fixation counts (cf. Holmqvist et al. 2011), the values would be larger for Croatian due to a smaller denominator, the number of words and a larger number of fixations the participants had on the Croatian text. Holmqvist et al. (2011) mention five different ways of measuring reading depth.

made less fixations on the English than on the Croatian text (Figure 2). On average, the participants included in this study fixated English words on average 10 ms longer, but made 48 fixations more on the Croatian page.

A multiple regression model was used in order to test whether it was the metrical information (i.e. the position of the stress) that guided readers' attention through the text reflecting their inner speech in silent reading or their gaze directions could be explained by more common factors, such as the distinction between content and functional words (cf. Schmauder et al. 2000) and whether the languages differed in this respect. Therefore, the model took the sum of all fixation durations as a dependent variable and language (English or Croatian) and AOI type (stressed syllabi, content or functional words areas of interest) as predictors. The participants were taken as a random effect, i.e. the model formula was:

$$Sum\ of\ Fixation\ Durations \sim AOI\ type + language + (1 \mid Participant)$$

One needs to remark here that only the fixations onto the AOIs (the stressed syllabi) were included in the analysis, mostly due to technical reasons outlined in the text above). Out of these, the number of fixations onto the stressed syllabi were looked into (which fell either on the content or the functional words). The number of fixations onto the content words that did not fall onto the stressed syllabi and the number of functional words that did not fall onto the stressed syllabi were looked into as separate variables. This was done to show that, within these categories, the stressed syllables attract the gaze. This action, in turn, was performed so as to defend the study reasoning as it could be argued that mostly content words are stressed so that what we counted were the fixations upon the content words rather than onto the stressed syllables. However, by showing that the fixations onto the content words (and functional words for that matter) fall onto the stressed syllables within those words, we hope to show that it is not just any syllable within the content words the participants are fixating but it is the stressed syllables within those words. This should yield a rather firm conclusion that the readers' gaze in both languages falls onto the stressed part of the word meaning that stress guides the gaze. At the same time, the number of fixations onto the AOIs was telling as the stressed syllables greatly surpassed the number of fixations outside the AOIs.

The analysis showed that both language and the type of the area of interest were statistically significant predictors (the comprehensive output of the statistical programme is given in Table 1 and Table 2)

	F	Num df	Den df	p
AOI_type	20.05	2	189	< .001
language	4.79	1	189	0.030
AOI_type * language	59.11	2	189	< .001

Note. Satterthwaite method for degrees of freedom

Table 1. The model results (with *AOI type* levels: stressed, content words., function words and *language* levels: hrv (Croatian) and eng (English) Fixed Effect Omnibus tests

				95% Confidence Interval				
Names	Effect	Estimate	SE	Lower	Upper	df	t	p
(Intercept)	(Intercept)	18646	718	17192	20175	189	25.95	< .001
AOI_type1	funct – cont	–6421	1760	–10246	–2887	189	–3.65	< .001
AOI_type2	stressed – cont	4677	1760	1653	8075	189	2.66	0.009
language1	hrv – eng	2437	1114	187	4535	189	2.19	0.030
AOI_type1 * language1	funct – cont * hrv – eng	–14333	2728	–19638	–8085	189	–5.25	< .001
AOI_type2 * language1	stressed – cont * hrv – eng	–29654	2728	–35284	–23587	189	–10,87	< .001

Table 2. The Fixed Effects Parameter Estimates

The analysis also confirmed interaction between the language and the type of the area of interest; in other words, that the switch between the languages had a different effect on the durations of the fixation positions as captured by the three areas of interest (stressed syllabi, content and function words), which is illustrated in Figure 3.

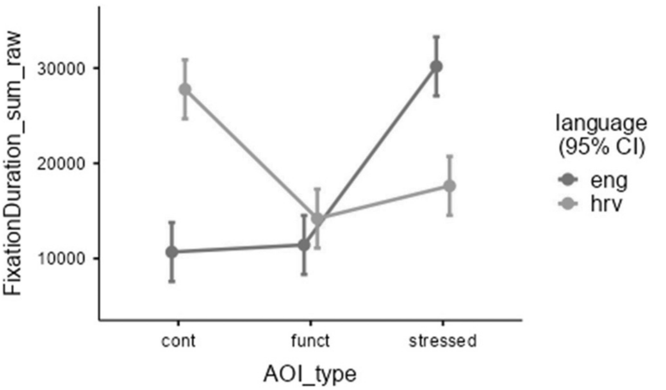

Figure 3. The Effects plot. The sums of all fixation durations per participant per AOI type are plotted on y–axis. The vertical bars represent the 95% confidence interval (CI).

Likelihood Ratio Test (LRT) for the random effect also proved to be significant (LRT = 12.2, $p<0.001$). This means that the model with the random effect is better than the model without it (in terms of likelihood). The conditional R2 is 0.453, i.e. the model explains around 45% of the variance. The marginal R^2 is 0.271 (the variance explained just by the fixed effects). These results point to the large individual differences even among a relatively compact group of successive bilinguals selected from the student population.

Finally, since the number of areas of interest is three, the post–hoc comparisons have been made (Bonferroni) to assess which AOI type predicted the fixations to the largest extent. Overall, all three comparisons proved to be statistically significant (cont–funct: $p=0.001$, cont–stressed: $p=0.026$, funct–stressed $p<0.001$).

Further on, the comparisons were made for each AOI type for both languages. In both languages differences were found between content words and stressed syllables ($p<0.001$). In English the difference was found significant between function words and stressed syllables as well ($p<0.001$). However, the same difference was not found to be significant in Croatian. Similarly, the difference between content and function words was found significant in Croatian ($p<0.001$), but not in English. Finally, both stressed syllables and content words differed significantly across languages, but the function words did not. These results are illustrated in Figure 3.

This model shows, first, that there are differences in the attentional processes in reading English and Croatian texts. These differences at least partly arise from the differences in the prosodic structures of the two languages; the language proved to be a significant predictor in the model predicting the total time different AOIs were fixated during reading in the two languages. Second, the participants, the successive bilinguals, spent more time fixating the stressed syllables in English. The tiny differences in the fixation positions and their durations accumulated during reading and were clearly visible in the sums of fixations taken as the variable explained by the AOI type and language in the model. Duration itself, i.e. the mean fixation duration per participant per AOI type does not point to this interpretation probably because this measure does not account for the number of fixations to any of the AOI types a participant might have had. This is in accordance to the already mentioned literature which takes fixation duration as a measure of local lexical processes (Clifton et al. 2007, Holmqvist et al. 2011). It is indeed common to take the fixation duration as a measure of lexical retrieval: "there is now a fair amount of evidence to indicate that some of the variability [in fixation durations] is due to systematic differences in the ease of processing the words in the text" (Rayner and Duffy 1986: 191). Therefore, the second model served as some sort of control. If the same predictors explain mean durations of the fixations, then it just might be that the reasoning behind the first model is simply an instance of the more general and uninformative statement that people read differently in different languages. Therefore, the second model formula

$$\textit{Mean Fixation Durations} \sim \textit{AOI type} + \textit{language} + (1 \mid \textit{Participant})$$

was examined. The overall results are shown in Table 3.

Fixed Effect Omnibus tests				
	F	Num df	Den df	p
AOI_type	0.982	2	189	0.377
language	19.133	1	189	< .001
AOI_type * language	0.345	2	189	0.708

Note. Satterthwaite method for degrees of freedom

Table 3. The second model results

As Table 3 shows, language seems to be the statistically significant predictor of the mean fixation durations (per participant and per AOI type). Similarly, all other fixed effects parameter estimates were not significant (Table 4). In other words, the mean durations are shorter for Croatian than for English text. It is only logical to assume that this just reflects the greater language proficiency in the first language of the participants. This finding is illustrated in Figure 4.

Fixed Effects Parameter Estimates								
				95% Confidence Interval				
Names	Effect	Estimate	SE	Lower	Upper	df	t	p
(Intercept)	(Intercept)	224.061	2.13	219.76	227.62	189	105.0454	< .001
AOI_type1	funct – cont	–6.393	5.22	–17.00	5.57	189	–1.2236	0.223
AOI_type2	stressed – cont	–0.107	5.22	–10.29	11.06	189	–0.0205	0.984
language1	hrv – eng	–10.615	2.43	–14.89	–5.72	189	–4.3742	< .001
AOI_type1 * language1	funct – cont * hrv – eng	4.772	5.94	–5.82	16.55	189	0.8028	0.423
AOI_type2 * language1	stressed – cont * hrv – eng	1.277	5.94	–10.36	13.18	189	0.2148	0.830

Table 4. The Fixed Effects Parameter Estimates for the second model

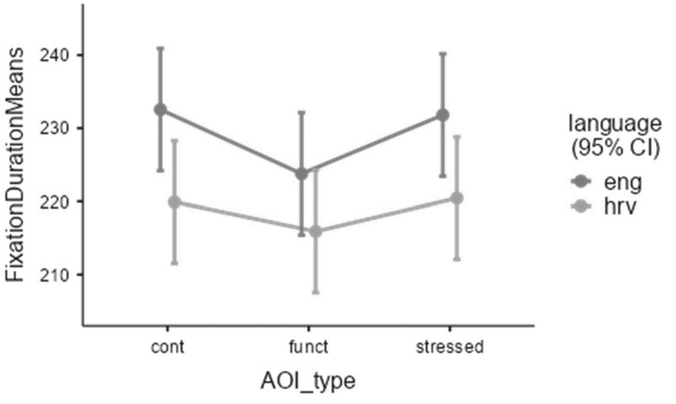

Figure 4. The Effects plot. The means of all fixation durations per participant per AOI type are plotted on y–axis. The vertical bars represent the 95% confidence interval (CI).

Marginal R2 = 0.032 while the conditional R2 = 0.52. Likelihood Ratio Test (LRT) for the random effect was significant (LRT = 57.2, $p<0.001$). These results may again point to the large individual differences between the participants. The post–hoc comparisons did not reveal any significant differences that would point to a particular level of the predictors in the model. The parallel lines of Croatian and

English means in Figure 4 illustrate the greater ease with which the Croatian–English successive bilinguals read the Croatian text.

The third analysis was based on the fixation counts. The model was defined by the formula:

$$Fixation\ counts \sim AOI\ type + language + (1 \mid Participant)$$

and the overall results are shown in Table 5 and Table 6.

Fixed Effect Omnibus				
	F	Num df	Den df	p
language	24.7	1	315	< .001
type	494.4	2	315	< .001
Language * type	299.1	2	315	< .001

Note. Satterthwaite method for degrees of freedom

Table 5. The third model results

Fixed Effects Parameter Estimates								
				95% Confidence Interval				
Names	Effect	Estimate	SE	Lower	Upper	df	t	p
(Intercept)	(Intercept)	81.46	2.41	76.73	86.2	63.0	3.77	< .001
language1	hrv – eng	9.92	2.00	6.01	13.8	315.0	4.97	< .001
type1	funct – cont	–43.72	2.45	–48.51	–38.9	315.0	–17.88	< .001
type2	stressed – cont	32.91	2.45	28.12	37.7	315.0	13.46	< .001
language1 * type1	hrv – eng * funct – cont	–101.44	4.89	–111.02	–91.9	315.0	–20.74	< .001
language1 * type2	hrv – eng * stressed – cont	–105.61	4.89	–115.19	–96.0	315.0	–21.60	< .001

Table 6. The Fixed Effects Parameter Estimates for the third model

The post–hoc tests revealed statistically significant differences between English content words and stressed syllabi, but not between content and functional words (the difference between English functional words and stressed syllables is also significant). In Croatian all paired comparisons turned out to be statistically significant. This is clearly represented in Figure 5.

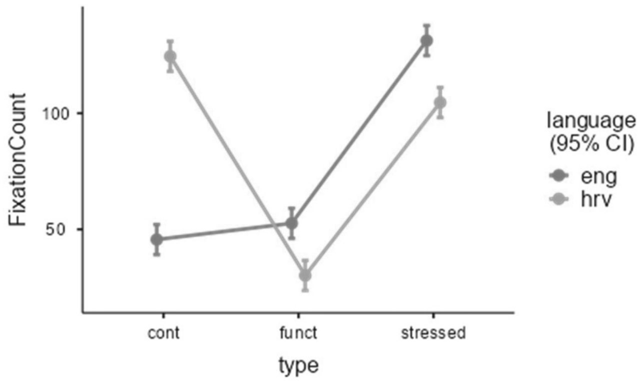

Figure 5. The Effects plot. The fixation counts per participant per AOI type are plotted on y–axis. The vertical bars represent the 95% confidence interval (CI).

The Likelihood Ratio Test (LRT) for the random effect was significant (LRT = 112, $p<0.001$) which indicates large individual differences between subjects. However, marginal R2 = 0.7 while conditional R2 = 0.83, both being very high with a smaller difference between them which points to the relevance of fixation counts in assessing the role of implicit prosody in silent reading.

Generally, studying eye movements during reading involves a complex bundle of multiple concepts at various levels of cognitive processing, from sensorimotor control to visual attention and language processing. These concepts are typically included into the reading models such as E–Z model (Reichle et al. 1998, 2003) and usually relate the fixation landing positions and their durations to word recognition processes. Factors such as word frequency, word length or its predictability/surprisal are the psycholinguistic elements of these models. Most eye–tracking research into the psycholinguistic processing deals with words (cf. Rayner and Pollatsek 2006). Even if some phonological or morphological effect is studied, the effects are measured on whole words as a facilitation effect measured usually in fixation durations. The research that went into the fixation positions within one point in the word generally studied low–level processes related to oculomotor control (McConkie et al. 1989) and deal with optimal or preferred viewing positions for word identification (around the word centre). The minimal contribution of the present study is in that is hopes to show that a linguistic process, i. e. the position of the stress can influence where the fixation will land within a word.

5. Conclusion

Being the first bilingual eye–tracking natural reading corpus study in Croatian, this research into the implicit prosody in silent reading has a limited goal: to demonstrate that the implicit prosody may be used to account for at least a portion of the difference in the reading patterns in L1 and in L2 by unbalanced Croatian–English bilinguals. While the results do corroborate the Implicit Prosody Hypothesis (IPH) in English, the interpretation of the reading patterns in Croatian is more problematic with only one variable (fixation counts) pointing to this direction. The results obtained for Croatian might have been the product of the mentioned 'tug of war' between the factors that dragged to the opposite directions with Croatian transparent orthography and its greater ratio of content words taking the victory. This finding may be in line with the eye–tracking Provo Corpus with its predictability norms (Luke and Christianson 2018) with low average predictability for content words in a monolingual English corpus. The sum of fixation durations on content words – as they accumulate during reading – being larger for the Croatian text may indeed point to the role of predictability, therefore, mainly semantic processes as dominant in L1 Croatian readers. But this inference is rather speculative without some further empirical research. Nevertheless, these results, different in English and Croatian might point to the processing differences that result from the typological differences between languages, both in terms of their prosodic structures and their morphological mechanisms.

Finally, a simple general measure of average fixation times proved to be a good check: the difference between L1 and L2 may be interpreted as the differences in proficiency among the bilingual participants included into the study. The obtained results simply suggest longer times required for local lexical retrieval in a language in which the participants are less proficient.

6. Limitations and future prospects

Although natural reading methodology has the advantage of an easily obtainable large data set and high ecological validity, it has some limitations. With the abandoning of the experimental control the selection of an adequate text becomes very important. The current trend is to include texts of different genres into the corpora, which was not the case in this study (based on the idea to use a text suitable for future inclusion of various participants, including children). The available eye–tracking equipment also laid some limitations in terms of study design (poor automatic definition of the AOIs) and available variables related to reading. This imposed some serious limitations on the statistical analysis. The equipment that allows for multiple layers of user–defined automatically generated AOIs – a necessity in corpus–based eye–tracking – will allow for better factorial designs, let alone the analysis based on the Bayesian statistics where the priors might be calculated on variables that reflect linguistic structures while the posterior distributions would be the values measured by the eye–tracker. Finally, the corpus based 'natural reading' eye–tracking should be viewed only as a method complementary to the psycholinguistic experiments with full experimental stimuli control; the corresponding experiment should therefore be one of the next steps in examining the role of prosody in the reading comprehension.

Finally, to suggestions for future research we add working with participants from a single dialect, possibly such which corresponds the standard Croatian stress–assignment most. This would help avoid concerns about various stress assignments in the implicit prosody realization process presumably affecting fixation loci.

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Uloga prozodije pri čitanju u sebi: mjerenje pokreta oka

Više od stoljeća stara intuicija o »unutarnjem glasu« koji prati čitanje u sebi danas se formulira kao Hipoteza implicitne prozodije (IPH) koja naglašava ulogu prozodije u razumijevanju čitanja, točnije kao tvrdnja da prozodija implicitna nekoj sintaktičkoj strukturi određuje kako govornik (čitatelj) tu strukturu tumači. Budući da se radi o prozodiji koja prati čitanje u sebi, dakle budući da se hipoteza ne može provjeriti izravno, odabrana je metoda mjerenja pokreta očiju koja hipotezu može neizravno potkrijepiti, istraživanjem razlika u tekstovima različitih prozodijskih struktura. Tako je prikupljen mali paralelni hrvatsko–engleski korpus označen podacima mjerenja pokreta oka i to na tekstu kojim se nije eksperimentalno manipuliralo, u tzv. paradigmi prirodnog čitanja (*natural reading*). Korpus je uključivao kratku priču koju su sudionici, nebalansirani dvojezični govornici hrvatskoga i engleskoga, pročitali na hrvatskome i engleskom. Izmjereni podaci pokreta očiju analizirali su se s obzirom na područja interesa koja su obuhvaćala naglašene slogove i značenjske ili funkcijske riječi. Provedeno višestruko regresijsko modeliranje pokazalo je različite prediktore duljine čitanja (kao zbroja trajanja svih fiksacija) u hrvatskome i engleskom. Dok su duljine fiksacija na naglašene slogove dobri prediktori duljine čitanja u engleskome, u hrvatskome se broj fiksacija na naglašene slogove pokazao kao bolji prediktor duljine čitanja, a ne njihova duljina. Tako je Hipoteza implicitne prozodije potvrđena za L2, ali samo djelomično za L1. Rezultati se tumače s obzirom na razlike u tipologiji ritmičkih sustava u hrvatskome engleskom (naglasni i slogovni ritam), razlikama u ortografiji, ali i razlikama u jezičnim strukturama između dvaju jezika (odnos funkcijskih i sadržajnih riječi). Isto tako, pokazale su se značajne individualne razlike među sudionicima kao i njihova razlika u stupnju ovladanosti u L1 i L2, što se pokazalo na varijabli prosječne duljine fiksacija kao kronometrijske mjere leksičkog priziva.

Keywords: eye–tracking, reading comprehension, psycholinguistics, Implicit Prosody Hypothesis, prosody, bilingualism, English, Croatian

Ključne riječi: mjerenje pokreta oka, razumijevanje čitanja, psiholingvistika, hipoteza implicitne prozodije, prozodija, dvojezičnost, engleski jezik, hrvatski jezik