Lexical influence on stress processing in a fixed-stress language

Linda Garami[1,2] (garami.linda@ttk.mta.hu, *corresponding author*)

Anett Ragó[1,3] (rago.anett@ppk.elte.hu)

Ferenc Honbolygó[1,3], (honbolygo.ferenc@ttk.mta.hu)

Valéria Csépe[1,4,5] (csepe.valeria@ttk.mta.hu)

[1]MTA RCNS Brain Imaging Centre, Hungary
1519 Budapest, P.O. Box 286., Hungary (*main, affiliation address*)

[2] ELTE FEP, Doctoral School of Psychology, Hungary
1064, Budapest, Izabella u. 64., Hungary

[3] ELTE FEP, Institute of Psychology, Hungary
1064, Budapest, Izabella u. 64., Hungary

[4] BME FNS, Department of Cognitive Science, Hungary
1111, Budapest Egry József utca 1. T. épület, V. emelet 506., Hungary

[5] PU FMPSS, Institute of Hungarian and Applied Linguistics, Hungary
8201 Veszprém, Pf. 158., Hungary

Manuscript of the article that appeared in:

International Journal of Psychophysiology. 2017 Jul;117:10-16.

DOi: 10.1016/j.ijpsycho.2017.03.006.

ABSTRACT

In the present study, we investigate how lexicality affects the processing of suprasegmental features at the word level. In contrast to earlier studies which analyzed the role of either segmental or suprasegmental feature in language processing our aim was to investigate the effect of the lexical status on the processing of violated stress pattern defined by linguistic rules. We have conducted a passive oddball ERP experiment, presenting a frequent CVCV word with legal (familiar) and illegal (unfamiliar) stress patterns. Former results obtained with pseudo-words in a similar paradigm enabled to assess the influence of lexical information on stress processing.

The presence of lexically relevant information resulted in different ERP patterns compared to those obtained with pseudo-words. We obtained two consecutive MMN responses to the illegally stressed words while violating the illegal stress pattern with a legal one the deviant stimulus elicited two consecutive MMN responses as well. In the latter condition lexicality clearly enhanced the comparison of prosodic information between standard and deviant stimuli, as these components very completely missing when presenting pseudo-words.

We interpret the results that lexicality acts as a filter since in the absence of lexical familiarity unfamiliar stress patterns are discriminated better.

Our results highlight that even when stress is fully predictable, it is taken into account during pre-attentive processing of linguistic input.

KEYWORDS

Speech perception
Word stress
ERP
MMN

1 INTRODUCTION

Speech comprehension, particularly the activation of lexical representations of spoken words, relies on both segmental and suprasegmental information. The long-term representation of segmental elements such as phonemes has an extensive literature. According to recent data, adults also use suprasegmental information, i.e. word level prosodic features, relying on long-term prelexical representations when processing linguistic input. In the present study, we investigate how lexicality affects the processing of suprasegmentals at word level.

Word level stress pattern is defined by the order of stressed and unstressed syllables. Languages determine the sequential order and the instantiation of stress itself, individually. In French, for example (cf. Dupoux et al., 2008) F0, duration and intensity are together responsible for the realization of stress pattern. However, the contribution of duration in defining the stressed segment of words varies to a large extent.

In Hungarian, duration is a segmental cue itself that implies a constraint on how much it can contribute to syllabic stress. Earlier results demonstrated no contribution at all (Fónagy, 1958), while more recent, yet controversial phonetic data are suggesting a certain amount contribution (for more details about Hungarian vowel lengths see Mády & Reichel, 2007). Vowel length does not play any role in stress expression in Polish (Domahs, Knaus, Orzechowska, & Wiese, 2012). The other two aspects of forming a language-specific acoustic complex associated with the stress pattern are related to the location and emergence of regular stress. There is a broad range of variations in languages from strictly fixed-stress languages to free stressed ones. In fixed-stress languages, word-internal position for stress is assigned according to a common rule. It is always on the first syllable in Finnish and in Hungarian (Siptár & Törkenczy, 2007), and is always on the last in words (Dupoux, Peperkamp, & Sebastián-Gallés, 2010). Moreover, there are languages with a predominant pattern supplemented with numerous exceptions. Polish words bear stress mostly on the penultimate syllable with a well-defined group of exceptions (Domahs et al., 2012). On the contrary, contrastive languages use lexical stress to convey differences in meaning. Although both Spanish and English have a predominant stress pattern, stress is also a lexical feature in contrast with the aforementioned languages. In contrastive languages, stress contributes to lexical comprehension while in fixed-stress languages word level stress correlates well with word boundaries (Cutler, Dahan, & van Donselaar, 1997). These different functions seem to impact both developing and mature prosodic processing.

Locating word boundaries in fluent speech is not an obvious task since there are no pauses between words like there are clear spaces in written text. In optimal conditions, adults use lexical segmentation strategy relying on known word forms (Norris, 1994). However, suprasegmental features become important when conditions are suboptimal, for instance when lexical cues are not clearly available (Mattys, White, & Melhorn, 2005). The period of early language acquisition is also characterized by the unavailability of lexical cues. According to the literature on early segmentation, prosody helps infants to find word boundaries. However, there are differences between fixed vs. contrastive languages (Friederici, Friedrich, & Christophe, 2007; Höhle, Bijeljac-Babic, Herold, Weissenborn, & Nazzi, 2009; Skoruppa et al., 2009) in regard of the predominant pattern of native language (trochaic, iambic, penultimate, ultimate, etc.).

In contrast to infants, segmentation for adults is based mostly on lexical segmentation, which gives rise to the question: what happens to the exploitation of word level stress? Does independent prosodic analysis operates further as it does in infants, or do prosodically rich lexical representations take over by suppressing the importance of word-stress pattern as a segmentational cue? Or, as Cutler and her colleagues (1997) also puts it: if stress is fully predictable and segmentation is solved, what benefit could be gained from word level stress information?

Irrespective of the rich lexical representation, phrase level prosody overlaps with word level stress and holds syntactic structural information that speeds up speech comprehension (Christophe, Peperkamp, Pallier, Block, & Mehler, 2004). Jacobsen argues that both segmental and suprasegmental features are constantly monitored (Jacobsen et al., 2004) in order to identify relevant information in the auditory environment. Evidence for separate processing of phonemes and prosody, the domain to which stress belongs, comes from neurocognitive research. Separable neural mechanisms devoted to aspects of the input that vary over longer or shorter timescales have been identified for the processing of complex auditory signals in general (e.g., Boemio, Fromm, Braun, & Poeppel, 2005), as well as for the processing of speech in particular (e.g., Luo & Poeppel, 2007). These findings integrate into a neurocognitive model of different temporal integration windows according to which speech is analyzed at intervals of approximately 20 to 50 ms appropriate for identifying phonemes, and at intervals of approximately 150–300 ms appropriate for identifying prosody (for review see Hickok & Poeppel, 2007; Poeppel, 2003, 2014) Indeed, electrophysiological studies have demonstrated that stress patterns at word level are processed in adults even in Finnish, Polish and also in Hungarian (Domahs et al., 2012; Honbolygó & Csépe, 2013; Peperkamp, Vendelin, & Dupoux, 2010).

When investigating prosody, analyzing the Mismatch Negativity (MMN) component of event-related brain potentials (ERPs) is a plausible tool, as it is a robust electrophysiological correlate of stimulus discrimination elicited by infrequent stimuli among frequently presented ones. In addition, MMN is independent on attention, and its features, amplitude, latency and scalp distribution, depend on the discriminability of the stimuli used. The MMN component is also influenced by permanent language-specific memory traces. It was shown for speech-sounds (Näätänen, Paavilainen, Rinne, & Alho, 2007), and also consistent with earlier results (Winkler et al., 1999) that the MMN component is sensitive to between- and within category distinctions. The long-term traces of the categories serve as recognition patterns (equivalent of templates, see Honbolygó and Csépe, 2013) parallel to the short-term trace established by the actual standard stimulus in oddball paradigms. This is also confirmed by magnetoencephalography (MEG) measurements showing that auditory and phonological mismatch components stem from somewhat different locations (Winkler et al., 1999). Pulvermüller and colleagues extended this notion to the word level (Pulvermüller et al., 2001). They obtained differences in MMNs for words and nonsense words confirming that the familiarity with a word form also results in different responses. This supports the idea that linguistic information can be assessed pre-attentively connected to different linguistic representations (e.g. phonemes, words).

Beside the familiarity of word form, the familiarity of the word level stress pattern was also investigated. Ylinen and colleagues used a legally stressed CVCV pseudo-word as frequent standard stimulus violating it along the dimension of stress legality (illegal pattern) and/or lexicality (word vs. pseudo-word). Two consecutive MMNs were elicited by the stress violations. Presenting word in an oddball paradigm as a deviant was also accompanied by an MMN that was expected to be delayed when it also violated the legal stress pattern of the standard stimulus. Unfortunately, using the same legally stressed pseudo-word as standard does not allow for a precise distinction between the suprasegmental and lexical processes responsible for the MMNs, and the EEG is lacking the sufficient spatial resolution for testing generators' location in this experiment.

Honbolygó and Csépe (2013) tested different standards along the stress legality dimension by using pseudo-words to control for word familiarity, and found different ERP patterns discriminating language-specific (legal) and violated (illegal) stress patterns, regardless of word familiarity. This means that Hungarian adults are able to discriminate illegal stress pattern as it was shown by the occurrence of two consecutive MMNs for bi-syllabic pseudo-words, while no mismatch response was elicited by the infrequent legal pattern delivered among frequent illegal standards. This strengthens the argument for an existing long-term representation of stress pattern in adults as the ERP responses resulted from processing the complex stress patterns and not just the simple salient acoustic features.

Along the same logic, we tested words with legal and illegal stress patterns using them both in standard and in deviant roles across conditions. Our aim was to examine whether the illegal stress pattern delays the MMN when it plays a deviant role as it did in the study of Ylinen and whether the template-based processing takes place at all when lexical information is easily accessed. We tested Hungarian adults, because Hungarian has a fully predictable stress pattern without exceptions; therefore the results would underpin Jacobsen's proposal of the continuous monitoring of the environment while exploiting full predictability of patterns rather than neglecting them as it was raised by Cutler.

Our recent investigation aimed at monitoring the interplay between word meaning and stress pattern. It seems that using words instead of pseudo-words for following the effect of prosodic violation invites several expectations regarding the mismatch component. According to the lexical trace hypothesis of Pulvermüller (2001), MMN component is more pronounced in case of words than pseudo-words as deviants. This suggests that we might observe larger MMN amplitudes than there was shown in the study of Honbolygó and Csépe (2013). Although in our experiment we presented words in both standard and deviant roles, the lexical trace hypothesis (Jacobsen et al., 2004) proposes that activated lexical representations in addition to acoustic ones affect the change detection. The familiar context hypothesis proposes more elaborate processing of the standard stimulus when it is a familiar one; therefore we can expect higher amplitude responses for words than for pseudo-words in the same paradigm. We also expected that when the standard stimulus is the legally stressed form, the MMN amplitude would be higher compared to the standard stimulus with an illegal stress pattern.

2 MATERIAL AND METHODS

2.1 PARTICIPANTS

Twenty-eight Hungarian native speakers (3 left-handed) participated in the experiment. They have reported no hearing, language and neurological disorders, were recruited from a university course (mean age = 21) and got course credit for participation. Participants provided written informed consent before taking part in the study. The Ethical Review Committee for Research in Psychology (Hungarian Research Fund) approved the whole research project including this particular experiment.

2.2 STIMULI AND PROCEDURE

Hungarian words have stress on the first syllable, which is the only rule regarding word stress for this language (Siptár and Törkenczy, 2007). We used two variants of the word 'baba' (meaning "baby" and "doll" Hungarian). The legal version had stress on the first syllable while the illegal version had stress on the second syllable. The illegal variant was created in Praat (Boersma & Weenink, 2007) by reversing the order of the two constituent syllables of the legal variant. The illegal version had stress on the second syllable and was edited in Praat (Boersma & Weenink, 2007) by reversing the order of the two constituent syllables. The legally stressed word was pronounced by a native female speaker. The stimulus duration was 539 ms. The stressed and unstressed syllables differed in maximum f0 (18.51 Hz) and in maximum intensity (3.49 dB). There were no duration differences between the syllables.

The procedure was a passive oddball paradigm, the same as the one used by Honbolygó and Csépe (2013) with pseudo-words. The probability of the deviant stimuli was 20% (n=200). We presented stimuli in two different conditions to register ERPs for both variants of the stimulus, both as standard and as deviant. In the illegal deviant condition the illegal stress variant was the deviant, and the legal variant was the standard and vice versa in the legal deviant condition (see Table 1).

Conditions ↓ / Stimuli →	Standard (80%)	Deviant (20%)
Illegal deviant condition	ʹ**BA**BA (legal stress)	BAʹ**BA** (illegal stress)
Legal deviant condition	BAʹ**BA** (illegal stress)	ʹ**BA**BA (legal stress)

TABLE 1. CONDITIONS OF THE ODDBALL PARADIGM

2.3 Data collection and analysis

Electroencephalogram (EEG) was recorded from 32 scalp locations according to the international 10-20 system using an electrode cap (BrainAmp amplifier and BrainVision Recorder software, BrainProducts GmbH, EasyCap). The data was recorded with a sampling rate of 500 Hz. The ground electrode was placed between electrodes Fz and Fpz. Impedances were kept below 10 kΩ. Online filtering was between 0.1 and 70 Hz. The reference electrode was Pz and the data was re-referenced offline to the average of all active electrodes: Fp1, Fp2, F9, F7, F3, Fz, F4, F8, F10, FC5, FC1, FC2, FC6, T9, T7, C3, Cz, C4, T8, T10, CP5, CP1, CP2, CP6, P7, P3, P4, P8, O1, O2, P9, and P10. Independent component analysis was applied to remove artifacts of eye-movements (Delorme et al., 2007). The continuous EEG was then band-pass filtered between 0.3 and 30 Hz (12 dB/oct). The data was segmented into 900 ms epochs synchronized to the onset of stimulus including a 100 ms prestimulus baseline (−100 to 800 ms). Remaining artifacts were removed with an automatic artifact rejection algorithm rejecting segments where the activity exceeded ±80 μV. Epochs were than averaged for the four stimuli types (see table 1.). Only the standards preceding the deviants were taken into the grand average balancing the number of trials in all roles (standard and deviant) and to maximize the observable difference between the stimuli.

The stimuli had the same syllabic durational structure as in Honbolygó and Csépe's study (2013) therefore the three latency windows used in that study (320-420 ms, 420-520 ms and 520-620 ms) were used here to evaluate MMN effects. Two additional time windows (100-200 ms, 200-300 ms) were used to assess early ERP effects (P2–N2).

Mismatch responses (discrimination between standard and deviant stimuli) were assessed in both conditions using 3×2 repeated-measures within-subjects analyses of variances (ANOVAs) including frontal Electrodes (F3, Fz, F4) and Role (standard vs. deviant). Further statistical analyses were conducted using 3×2×2 within ANOVAs with the additional factor Legality (legal vs. illegal according to the Hungarian stress on the first syllable rule). This way we could compare the legally and illegally stressed syllables in standard vs. deviant roles across conditions to reveal possible interactions between the Role and Legality factors besides the Legality main effects.

Greenhouse-Geisser (G-G) correction was applied where necessary and ε values are given in the text. Main effects of factors of Role and Legality as well as significant interactions among them including post-hoc comparisons, are reported.

3 Results

Grand average ERP curves for standard and deviant stimuli in both conditions are shown in Figure 1. ERPs are plotted from stimulus onset to 800 ms with 100 ms prestimulus baseline. For graphical display data were filtered with an additional 10-Hz low pass-filter.

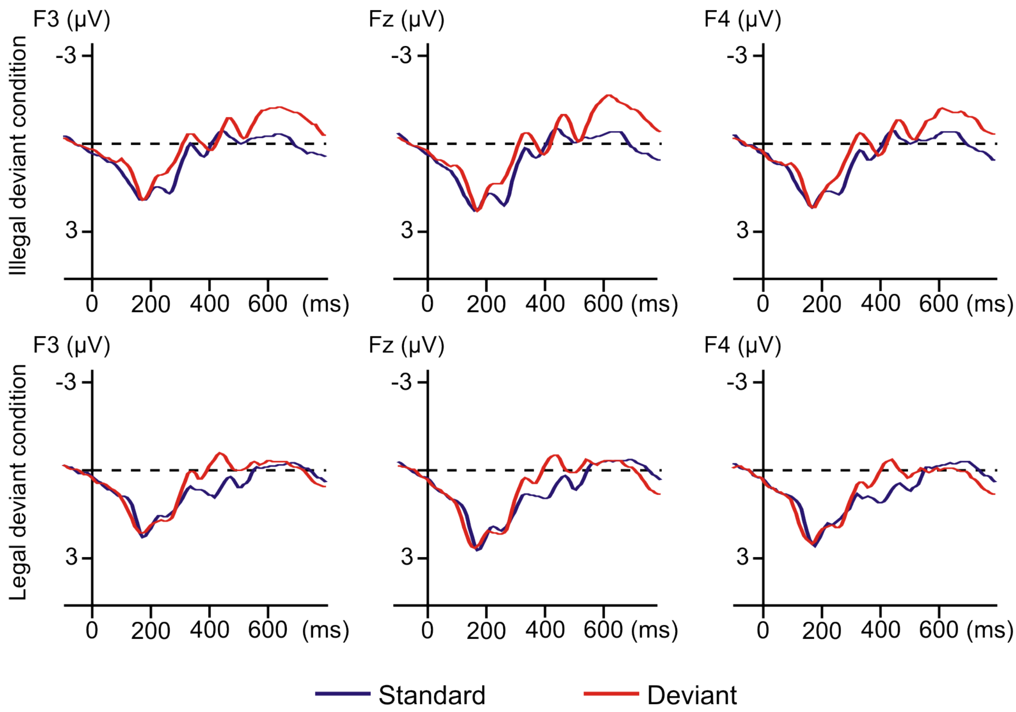

FIGURE 1. GRAND AVERAGE ERPS RECORDED IN ILLEGAL DEVIANT AND LEGAL DEVIANT CONDITIONS FOR WORDS IN ADULTS. RESPONSES ELICITED BY STANDARDS AND DEVIANTS ARE SHOWN WITH BLUE AND RED LINES RESPECTIVELY.

3.1 MISMATCH RESPONSES

We performed a repeated measure of variance (ANOVA), with Electrodes (F3, Fz, F4) and Role (Standard vs. Deviant) as within-subject factors. In the illegal deviant condition it revealed two Role main effects, one in the first (320-420 ms: $F(1,27) = 4.378$, $p = .046$, $\eta_p^2 = .140$) and one in the third (520-620 ms: $F(1,27) = 14.091$, $p = .001$, $\eta_p^2 = .343$) latency window. The first one was significant only on the F4 electrode, while the second one confirmed the presence of a MMN synchronized to the change of the second syllable (see Fig. 2.).

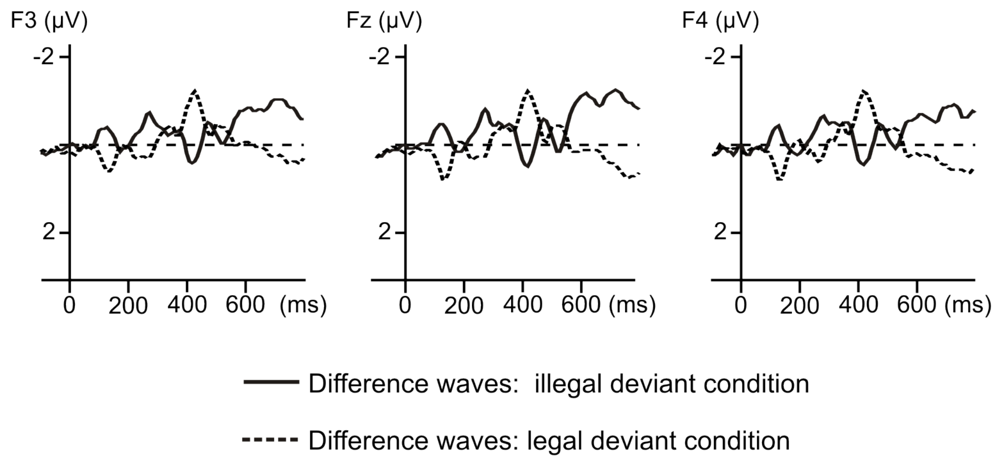

FIGURE 2. DIFFERENCE WAVE ERPS FOR WORDS IN ADULTS IN THE TWO CONDITIONS ARE SHOWN FOR THREE FRONTAL (F3, FZ AND F4) ELECTRODE SITES.

For the same ANOVA but in the legal deviant condition we obtained two MMN responses. The first in the 320-420 ms latency window ($F(1,27) = 13.796$, $p = .001$, $\eta_p^2 = .338$), the second for the legally stressed deviant was in the 420-520 ms window ($F(1,27) = 10.959$, $p = .003$, $\eta_p^2 = .289$) , earlier than the one found for illegally stressed deviant one in the other condition.

3.2 EFFECTS OF LEGALITY

To compare the physically identical stimuli in different roles we have performed a 3×2×2 Electrodes (F3, Fz, F4) × Role (standard vs. deviant) × Legality (legal vs. illegal stress) within-subjects ANOVA.

In the first early time-window (100- 200 ms) we obtained a Legality main effect ($F(1,27) = 13.630$, $p = .001$, $\eta_p^2 = .335$) and an interaction for Legality and Role ($F(1,27) = 21.322$, $p = .000$, $\eta_p^2 = .441$). Post hoc analyses showed that legally stressed deviants elicited higher ERP amplitudes than standards ($F(1,33) = 9.489$, $p = .005$, $\eta_p^2 = .26$), and just the very opposite was observed for the illegally stressed stimuli ($F(1,33) = 10.388$, $p = .003$, $\eta_p^2 = .278$; see Fig. 3.). Moreover familiar deviants (i.e. deviants with legal stress pattern) elicited more positive ERPs than unfamiliar deviants (i.e. deviants with illegal stress pattern) ($F(1,33) = 27.214$, $p = .000$, $\eta_p^2 = .502$; see Fig. 3.).

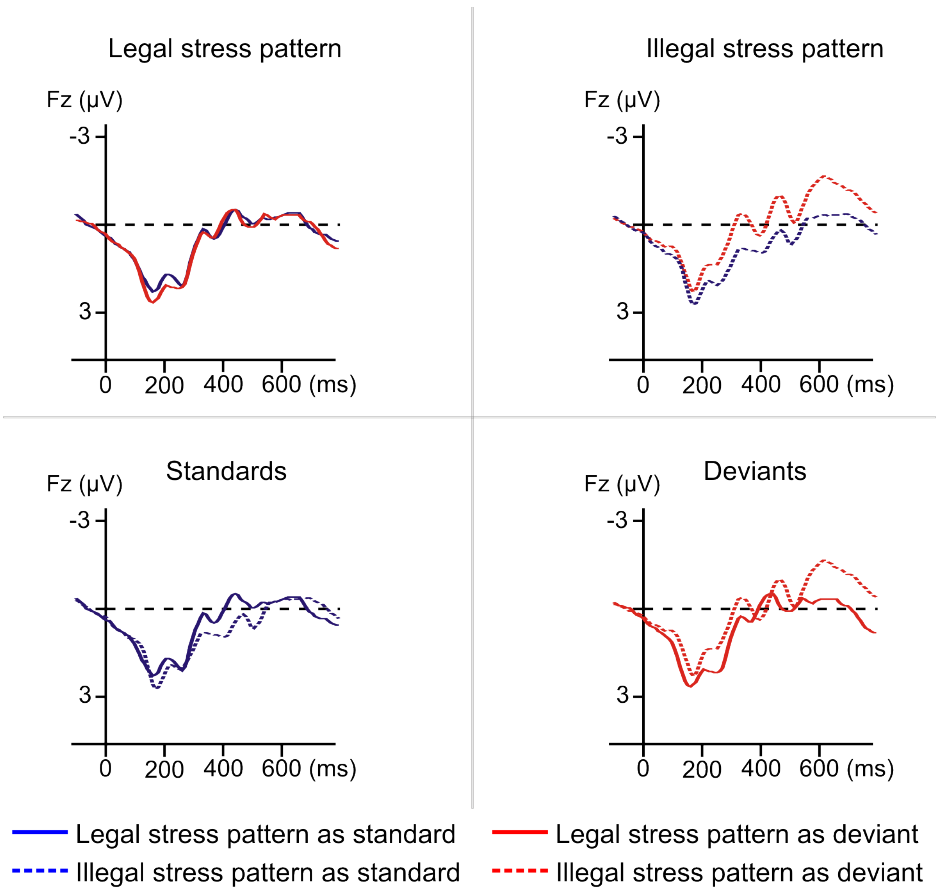

FIGURE 3. GRAND AVERGAE ERPS ELICITED BY WORDS WITH LEGAL AND ILLEGAL STRESS PATTERN IN ADULTS, DEVIDED BY THE ROLE OF THE PRESENTATION (DEVIANT / STANDARD) AND THE LEGALITY OF THE STIMULI (LEGAL / ILLEGAL).

In the second early time-window (200-300 ms) we obtained Legality ($F(1,27) = 8.976$, $p = .006$, $\eta_p^2 = .249$) and Role main effects ($F(1,27) = 7.081$, $p < .013$, $\eta_p^2 = .208$) and an interaction for Legality and Role ($F(1,27) = 24.645$, $p < .0000$, $\eta_p^2 = .477$). Post hoc analyses revealed higher amplitudes for standards than for deviants for illegally stressed words ($F(1,27) = 21.833$, $p < .000$, $\eta_p^2 = .447$; Fig. 3.), and higher amplitudes for stimuli with familiar than for stimuli with unfamiliar stress pattern in the deviant role ($F(1,27) = 28.778$, $p < .000$, $\eta_p^2 = .516$; Fig. 3.).

In the first MMN latency window (320-420 ms) Role main effect (F(1,27) = 21.829, p < .000, η_p^2 = .447) and Legality × Role interaction was obtained (F(1,27) = 16.751, p < .000, η_p^2 = .383). The illegal stress pattern as standard elicited higher amplitudes than as deviant (F(1,27) = 33.144, p < .000, η_p^2 = .551; Fig. 3.), while stimuli with legal stress pattern as standard elicited higher amplitudes than stimuli with illegal stress pattern (F(1,27) = 13.404, p = .001, η_p^2 = .332; Fig. 3.).

In the second MMN window (420-520) also a Role main effect (F(1,27) = 15.167, p < .001, η_p^2 = .360) and a Legality × Role interaction was obtained (F(1,27) = 24.299, p = .000, η_p^2 = .474). Again, stimuli with the illegal stress pattern as standard elicited a higher amplitudes in brain responses than as deviant (F(1,27) = 21.988, p < .000, η_p^2 = .449; Fig. 3.), while a word with illegal stress pattern as standard elicited more positive amplitudes than with legal stress pattern (F(1,27) = 18.828, p = .000, η_p^2 = .411; Fig. 3.).

In the third MMN window (520-620 ms) we obtained a Role main effect (F(1,27) = 13.435, p = .001, η_p^2 = .332) and an interaction for Legality and Role (F(1,27) = 14.573, p = .001, η_p^2 = .351) as well. Post hoc analyses revealed higher negative amplitudes for illegally stressed words as deviants than as standards (illegals: F(1,27) = 21.833, p < .000, η_p^2 = .447; Fig. 3.), and more negative amplitudes for stimuli with unfamiliar than with familiar stress pattern now in deviant role (14.079, p = .001, η_p^2 = .343; Fig. 3.). All significant main effects are presented in Figure 4.

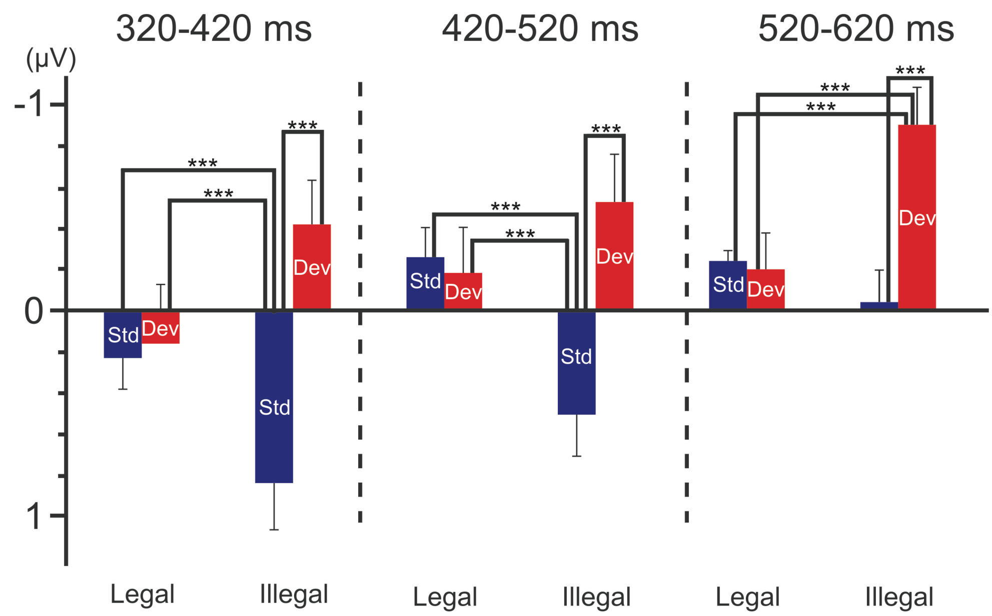

FIGURE 4. GRAPHICAL ILLUSTRATION OF THE SIGNIFICANT ERP AMPLITUDE DIFFERENCES FOR WORDS IN ADULTS AT THE FRONTAL ELECTRODE SITES.

Significant brain responses were characterized by a frontal modulation of voltages and polarity reversal synchronized to the syllables of the stimulus, thus showing the typical latency and scalp distribution of an MMN component even in the case of physically identical stimuli (see Fig. 5.).

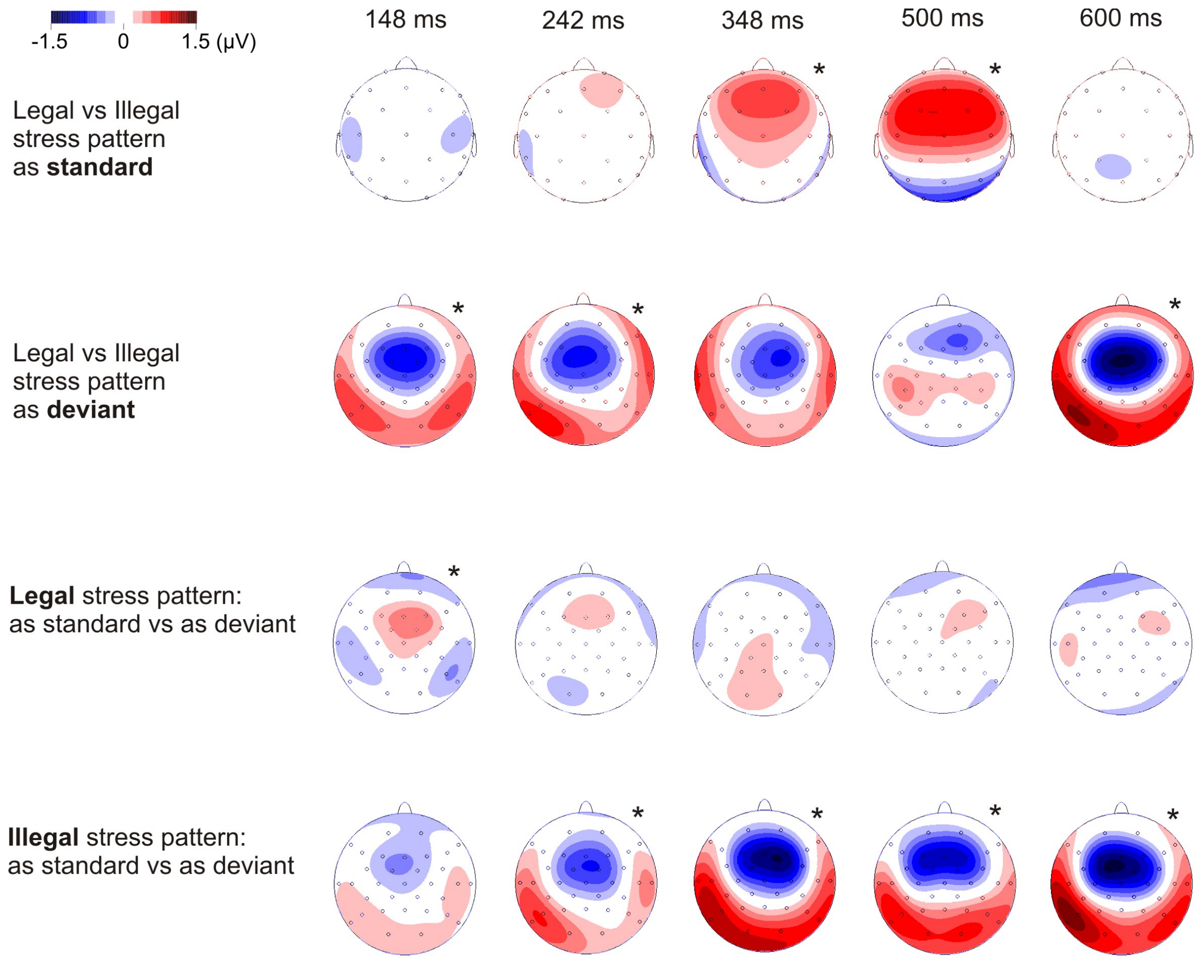

FIGURE 5. TOPOGRAPHIC MAPS FOR THE DIFFERENCE VOLTAGES WHEN PROCESSING DIFFERENT STRESS PATTERNS PRESENTED IN THE SAME ROLE AND PHYSICALLY IDENTICAL STIMULI IN DIFFERENT ROLES OF THE ODDBALL OARADIGM. THE MAPS IN THAT SIGNIFICANT RESPONSES OCCURRED ARE MARKED.

4 Discussion

We have conducted an ERP experiment presenting frequent CVCV words with legal (familiar) and illegal (unfamiliar) stress patterns in a passive oddball paradigm. We utilized the rule-based nature of Hungarian, a fixed-stress language that uses stress only on the first syllable without an exception. Our study was designed to overcome the limitations of two earlier studies by applying specific conditions. Ylinen and colleagues used only legally stressed pseudo-words as standards and observed delayed MMN responses for word deviants with illegal stress pattern so that dividing the lexical and prosodic levels of processing is ambiguous (Ylinen, Strelnikov, Huotilainen, & Näätänen, 2009). Honbolygó and Csépe (2013) using only pseudo-words of different stress patterns (legal and illegal) suggested template-based processing for prosody for meaningless phonotactically legal stimuli. The main objective of our recent study was to shed light on the effect of prosodic information in the presence of lexical access in a fixed-stress language.

Hungarian adults responded with one genuine MMN to illegally stressed words in the same third latency window (520-620 ms) as it was obtained for pseudo-words (Honbolygó & Csépe, 2013) synchronized to the second syllable. It could reflect the additional stress on this syllable or the reversed stress pattern as a whole. For pseudo-word standards, both Honbolygó & Csépe (2013) and Ylinen et al. (2009) found an earlier MMN for the lack of stress on the first syllable in the first latency window. This effect was significant only on the F4 electrode for word (320-420 ms), so this component of discrimination was missing or masked for words.

When words of illegal stress pattern were interspersed with legal ones, the familiar patterned deviant word elicited two consecutive MMN responses. For pseudo-words no MMN was found for the legally stressed deviant. The MMNs were synchronized to the syllables with additional stress (320-420) and lack of stress (420-520 ms). In this condition lexicality clearly enhanced the comparison of prosodic information between standard and deviant stimuli, contrary to the other condition (see Fig. 6.).

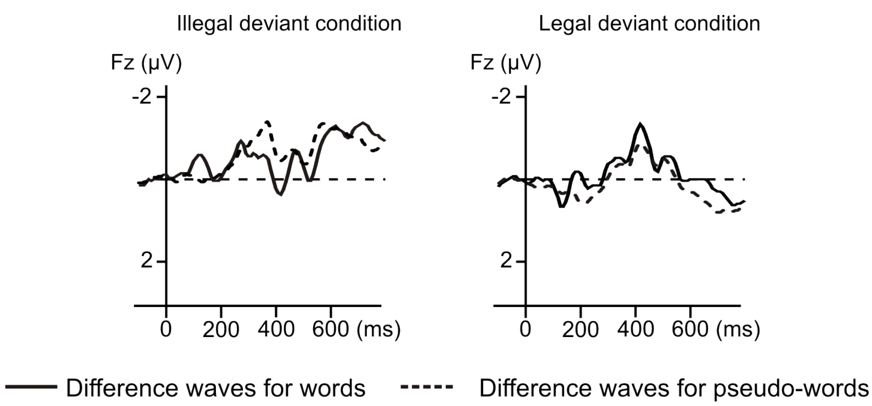

FIGURE 6. DIFFERENCE WAVES (DEVIANT MINUS STANDARD) ERPS RECORDED FOR WORDS IN THIS EXEPRIMENT AND PSEUDO-WORDS IN ADULTS RECORDED BY HONBOLYGÓ AND CSÉPE (2013).

According to these results, lexicality acts as a filter: in the absence of lexical familiarity unfamiliar stress patterns are discriminated better. In the presence of lexical familiarity other cues indicating the perfect match with lexically rich representations are exploited. To conclude, even though stress is fully predictable in Hungarian, it is taken into account during pre-attentive processing of linguistic input.

Regarding linguistic representations introducing the concept of filters is not a new idea. Studying phrasal prosody and transitional probability Shukla and his colleagues concluded that phrasal prosodic information acts as a filter to transitional probabilities in their behavioral paradigm (Shukla, Nespor, & Mehler, 2007). When phrasal prosody and transitional probability indicated different boundaries, unfamiliar transitional cues are suppressed. Such as unfamiliar stress pattern had less effect on amplitudes when presenting words instead of pseudo-words (Fig. 6.).

Based on our results it is evident that the reversed stress pattern contributes to different processes seen in changes of the MMN responses. However, a traditional comparison, e.g. the analysis of the difference waves, did not answer the question whether the ERP responses were related to stress violation of a specific syllable or to detected changes of the whole word's stress pattern. We resolved it by comparing the physically identical stimuli. The strongest evidence, confirming different patterns are not processed in the same way, is that the familiar pattern (legal stress pattern) elicits ERPs regardless of its actual role in conditions. Conversely, the processing of the unfamiliar pattern is adjusted to roles. This is in line with the results of pseudo-words. We can conclude that legal words' stress pattern is processed based on long-term, pre-lexical, language-specific representations. Moreover, the early ERP, N2 showed an expressed sensitivity both to frequency and to familiarity. It was larger for the illegal deviant than for the legal deviant words, similar to those observed in the two pseudo-word studies discussed above.

The main advantage of the stimulus chosen for our study was the balanced acoustic structure (same syllables of different stress assignment). Moreover, the words used allowed us to investigate a crucial component of speech processing that is the lexical access where the auditory input is matched onto lexical representation (MacGregor, Pulvermüller, van Casteren, & Shtyrov, 2012). We used familiar (legal) and unfamiliar (illegal) stress patterns with a frequent word, and this allowed us to compare our data with those for pseudo-words of same syllabic characteristics investigated in our earlier study (Honbolygó and Csépe, 2013). Although the role of lexical stress information in word recognition received considerable attention (see Cutler, 2005, 2012 for review), less is known about the impact of stress information on this process in languages not using lexical stress. Several psycholinguistic models aimed at explaining the auditory-lexical matching process, such as the Cohort, Trace and Shortlist models (Cutler, 2012; Luce & Mclennan, 2005; Weber & Scharenborg, 2012). Although these models are different in several aspects, all commonly assume that recognition is an incremental process. The observed responses more resistant to violated stress assignment for words as compared to pseudo-words (see Figures 6.) are in agreement with this prediction. Moreover, our finding is in agreement with the TRACE model as an elaborate processing of the familiar standards is seen and this is predicted by the model. This could be well seen in the 1st and 2nd MMN window (320-420 ms; 420-520 ms), where the standards of legal stress assignment elicited higher amplitudes than those of illegal stress pattern. This may also support the notion of template-based word stress processing, but to gain confidence results should be replicated in one session for both words and pseudo-words. This, however, is not surprising as to our best knowledge neither of the spoken word models were successful in incorporating the suprasegmental structure information as argued by Cutler (2012).

Regarding the redundancy of word level prosody in fixed stressed languages, our results can be well explained as the consequence of continuous monitoring (Jacobsen et al., 2004) enabling the interplay of different aspects of a linguistic stimulus. However, the neurocognitive models of speech processing do not provide a well applicable frame for explaining the lexical-prosodic processing. Our results support strongly the interaction of different representations including those associated with prosodic processing activated by single words without context. Our findings indicate that the processes recruited for words differ from those for pseudo-words and the neural response elicited is correlated with the lexical specification. Using the terms of Strelnikov, the MMN modulations can be seen as the result of two different predictions, one served by an inductive (parallel/top-down) and one by a deductive (sequential/bottom-up) processes (Strelnikov, 2008). As opposed to pseudo-words, semantic information can overrule the effect of violated stress in a single word paradigm by acting as a top-down influence, so that a meaning first process compensate for the prediction error. This assumption is based on the neurophysiological results proposing fast recognition of familiar word forms and lexical category decision (word vs. pseudo- word), in the region of anterior to Heschl's gyrus in the left superior temporal gyrus (STG), and an acoustic analysis in the primary auditory cortex (Friederici, 2012). However, a better view on the contributing network can only be gained by imaging studies contributing a neurocognitive model of the lexical specification of prosodic information.

5 CONCLUSION

In conclusion, the results strengthen the view that adults rely on long-term representation of prosodic information. Based on our ERP data stress information is taken into account during pre-attentive processing even in fixed-stress languages, when stress pattern is fully predictable, and only one stress rule exist. However, this process is influenced by lexical information as meaning operates over the stress pattern of the word. In case of adults using lexical segmentation strategy, lexicality acts as a filter as it facilitates familiar stress pattern processing but not unfamiliar one. This, however, is valid only for this paradigm, as we do not know how lexicality and prosody interact on sentence level.

6 ACKNOWLEDGEMENTS

The authors wish to thank Kinga Kreif and Gabriella Baliga for their help in the data acquisition and Orsolya Kolozsvári for her valuable comments.

This study was supported by the Hungarian Scientific Research Fund (NKFIH-OTKA-NK 101 087, Principal Investigator: Valéria Csépe).

References

Boemio, A., Fromm, S., Braun, A., & Poeppel, D. (2005). Hierarchical and asymmetric temporal sensitivity in human auditory cortices. *Nature Neuroscience*, *8*(3), 389–395. http://doi.org/10.1038/nn1409

Boersma, P., & Weenink, D. (2007). Praat: doing phonetics by computer. Retrieved from http://www.fon.hum.uva.nl/praat/

Christophe, A., Peperkamp, S., Pallier, C., Block, E., & Mehler, J. (2004). Phonological phrase boundaries constrain lexical access I. Adult data. *Journal of Memory and Language*, *51*(4), 523–547. http://doi.org/10.1016/j.jml.2004.07.001

Cutler, A. (2005). Lexical Stress. In D. B. Pisoni & R. E. Remez (Eds.), *The Handbook of Speech Perception* (pp. 264–289). Oxford: Blackwell Publishing. http://doi.org/10.1111/b.9780631229278.2004.00014.x

Cutler, A. (2012). *Native listening: Language experience and the recognition of spoken words*. MIT Press.

Cutler, A., Dahan, D., & van Donselaar, W. (1997). Prosody in the comprehension of spoken language: a literature review. *Language and Speech*, *40*(2), 141–201. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9509577

Domahs, U., Knaus, J., Orzechowska, P., & Wiese, R. (2012). Stress "deafness" in a Language with Fixed Word Stress: An ERP Study on Polish. *Frontiers in Psychology*, *3*(November), 439. http://doi.org/10.3389/fpsyg.2012.00439

Dupoux, E., Peperkamp, S., & Sebastián-Gallés, N. (2010). Limits on bilingualism revisited: stress "deafness" in simultaneous French-Spanish bilinguals. *Cognition*, *114*(2), 266–75. http://doi.org/10.1016/j.cognition.2009.10.001

Dupoux, E., Sebastián-Gallés, N., Navarrete, E., & Peperkamp, S. (2008). Persistent stress "deafness": the case of French learners of Spanish. *Cognition*, *106*(2), 682–706. http://doi.org/10.1016/j.cognition.2007.04.001

Fónagy, I. (1958). A hangsúlyról (On stress). *Nyelvtudományi Értekezések*, *18*.

Friederici, A. D. (2012). The cortical language circuit: From auditory perception to sentence comprehension. *Trends in Cognitive Sciences*, *16*(5), 262–268. http://doi.org/10.1016/j.tics.2012.04.001

Friederici, A. D., Friedrich, M., & Christophe, A. (2007). Brain responses in 4-month-old infants are already language specific. *Current Biology*, *17*, 1208–1211. http://doi.org/10.1016/j.cub.2007.06.011

Hickok, G., & Poeppel, D. (2007). The cortical organization of speech processing.

Neuroscience, *8*(May), 393–403.

Höhle, B., Bijeljac-Babic, R., Herold, B., Weissenborn, J., & Nazzi, T. (2009). Language specific prosodic preferences during the first half year of life: evidence from German and French infants. *Infant Behavior and Development*, *32*, 262–74. http://doi.org/10.1016/j.infbeh.2009.03.004

Honbolygó, F., & Csépe, V. (2013). Saliency or template? ERP evidence for long-term representation of word stress. *International Journal of Psychophysiology*, *87*(2), 165–72. http://doi.org/10.1016/j.ijpsycho.2012.12.005

Jacobsen, T., Horváth, J., Schröger, E., Lattner, S., Widmann, A., & Winkler, I. (2004). Pre-attentive auditory processing of lexicality. *Brain and Language*, *88*, 54–67. http://doi.org/10.1016/S0093-934X(03)00156-1

Luce, P. A., & Mclennan, C. T. (2005). Spoken Word Recognition: The Challenge of Variation. In D. B. Pisoni & R. E. Remez (Eds.), *The Handbook of Speech Perception* (pp. 590–609). Blackwell Publishing. http://doi.org/10.1002/9780470757024.ch24

Luo, H., & Poeppel, D. (2007). Phase patterns of neuronal responses reliably discriminate speech in human auditory cortex. *Neuron*, *54*(6), 1001–10. http://doi.org/10.1016/j.neuron.2007.06.004

MacGregor, L. J., Pulvermüller, F., van Casteren, M., & Shtyrov, Y. (2012). Ultra-rapid access to words in the brain. *Nature Communications*, *3*, 711. http://doi.org/10.1038/ncomms1715

Mády, K., & Reichel, U. D. (2007). Quantity distinction in the Hungarian vowel system--just theory or also reality? *Proc. 15th ICPhS, Saarbrücken*.

Mattys, S. L., White, L., & Melhorn, J. F. (2005). Integration of multiple speech segmentation cues: a hierarchical framework. *Journal of Experimental Psychology. General*, *134*(4), 477–500. http://doi.org/10.1037/0096-3445.134.4.477

Näätänen, R., Paavilainen, P., Rinne, T., & Alho, K. (2007). The mismatch negativity (MMN) in basic research of central auditory processing: a review. *Clinical Neurophysiology : Official Journal of the International Federation of Clinical Neurophysiology*, *118*(12), 2544–90. http://doi.org/10.1016/j.clinph.2007.04.026

Norris, D. (1994). Shortlist - a Connectionist Model of Continuous Speech Recognition. *Cognition*, *52*, 189–234. http://doi.org/10.1016/0010-0277(94)90043-4

Peperkamp, S., Vendelin, I., & Dupoux, E. (2010). Perception of predictable stress: A cross-linguistic investigation. *Journal of Phonetics*, *38*(3), 422–430.

http://doi.org/10.1016/j.wocn.2010.04.001

Poeppel, D. (2003). The analysis of speech in different temporal integration windows: cerebral lateralization as "asymmetric sampling in time." *Speech Communication*, *41*(1), 245–255. http://doi.org/10.1016/S0167-6393(02)00107-3

Poeppel, D. (2014). The neuroanatomic and neurophysiological infrastructure for speech and language. *Current Opinion in Neurobiology*, *28*, 142–149. http://doi.org/10.1016/j.conb.2014.07.005

Pulvermüller, F., Kujala, T., Shtyrov, Y., Simola, J., Tiitinen, H., Alku, P., … Näätänen, R. (2001). Memory traces for words as revealed by the mismatch negativity. *NeuroImage*, *14*(3), 607–616. http://doi.org/10.1006/nimg.2001.0864

Shukla, M., Nespor, M., & Mehler, J. (2007). An interaction between prosody and statistics in the segmentation of fluent speech. *Cognitive Psychology*, *54*(1), 1–32. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/16782083

Siptár, P., & Törkenczy, M. (2007). *The Phonology of Hungarian*. *The Phonology of the World's Languages*.

Skoruppa, K., Pons, F., Christophe, A., Bosch, L., Dupoux, E., Sebastián-Gallés, N., … Peperkamp, S. (2009). Language-specific stress perception by 9-month-old French and Spanish infants. *Developmental Science*, *12*(6), 914–919. http://doi.org/10.1111/j.1467-7687.2009.00835.x

Strelnikov, K. (2008). Activation-verification in continuous speech processing: Interaction of cognitive strategies as a possible theoretical approach. *Journal of Neurolinguistics*, *21*(1), 1–17. http://doi.org/10.1016/j.jneuroling.2007.06.001

Weber, A., & Scharenborg, O. (2012). Models of spoken-word recognition. *Wiley Interdisciplinary Reviews: Cognitive Science*, *3*(3), 387–401. http://doi.org/10.1002/wcs.1178

Winkler, I., Lehtokoski, A., Alku, P., Vainio, M., Czigler, I., Csépe, V., … Näätänen, R. (1999). Pre-attentive detection of vowel contrasts utilizes both phonetic and auditory memory representations. *Cognitive Brain Research*, *7*, 357–369. http://doi.org/10.1016/S0926-6410(98)00039-1

Ylinen, S., Strelnikov, K., Huotilainen, M., & Näätänen, R. (2009). Effects of prosodic familiarity on the automatic processing of words in the human brain. *International Journal of Psychophysiology*, *73*(3), 362–8. http://doi.org/10.1016/j.ijpsycho.2009.05.013