Influence of Metrical Expectancy on Reading Words: An ERP Study

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Abstract

The purpose of the present study is to investigate to what extent metrical structure in English plays a role in silent word reading. To address this issue, EEG was recorded while participants were visually presented with lists of five bisyllabic words ending with one word that had either the same or different stress pattern as the previous four words. Results revealed that final words that did not match the stress pattern of the previous words elicited distinct ERP components. These results are taken as evidence in favor of automatic processing of speech rhythm even when reading.

Index Terms: speech rhythm, ERP, Reading

1. Introduction

Various studies have suggested that sensitivity to speech rhythm is an important aspect of language processing from infancy through adulthood. In infants, several authors have emphasized the importance of rhythm in infant-directed speech and for language acquisition. For instance, Mehler et al [1], Moon et al [2] and Nazzi et al [3] have shown that young infants, including newborns, can discriminate between utterances from their mother tongue and those from a language from a different rhythmic class, even if the speech was low-pass filtered (400 Hz), thus highlighting the importance of the prosodic parameters. Moreover, 9-month-old American infants showed a preference for listening to words starting with a strong syllable (85-90% of everyday English spoken words according to [4]), compared to weak syllable [5].

In adults, rhythm also seems to be important for the segmentation of the continuous speech stream to isolate words. In particular, several studies have suggested that speech segmentation is guided by information about typical stress patterns (e.g., [6, 7, 8]). Moreover, some results also suggest that a listener does not attend equally to all portions of utterances produced by a speaker. Instead, some segments seem to be more closely attended than others. In particular, attention may be differentially allocated to stressed and unstressed syllables [9, 10, 11, 12].

Recently, several studies have also investigated the neural correlates of speech rhythm using the Event-Related brain Potential (ERP) method. Because of its high temporal resolution (on the order of the millisecond), this method is particularly well-suited for the exploration of the temporal dynamics of language processes. In the auditory modality, ERPs have been utilized to investigate the processing of deviant rhythmic patterns [12, 13, 14], as well as the interactions between meter and semantics [15] and between meter and syntax [16]. Using an auditory oddball paradigm on lists of bisyllabic pseudowords, Wang et al [12] demonstrated that even when listeners are not explicitly paying attention to the speech signal, a positive ERP component (P3a) is elicited by deviant phonemes that occur on stressed syllables. This finding thus supports the view that prosodic salience captures listeners' attention, such that segmentation is achieved by way of increased attention to stressed syllables rather than word onsets. Metrical expectancy in real words was studied by Böcker et al [13], through the use of lists of bisyllabic Dutch words ending with a word that had either the same or different stress pattern as the rest of the list. Results showed that weak-initial words, which are much less common in the Dutch lexicon, elicited several larger negative components than strong initial words; one of these effects, the N325, was also amplified for participants that showed good performance on the metrical discrimination task. The authors therefore suggest that the N325 is a correlate of metrical stress perception, occurring prior to the N400 component, which several decades of literature have now shown to be the brain signature of semantic processing [17]. Indeed, a previous study by Magne et al [15] has highlighted the interrelationship between metrical and semantic expectancies in auditory sentence processing, by demonstrating that the N400 effect, usually evoked by semantic incongruities, is itself modulated by words pronounced with incorrect stress patterns (i.e. lengthening the penultimate syllable instead of the final syllable as expected in French).

These findings point to the importance of stress in lexical access, and are also consistent with behavioral data obtained by Field [18] showing that misplaced stress hinders intelligibility for individuals learning English as a second language. Another explanation for the difficulty in understanding words containing metrical violations has been proposed by Schmidt-Kassow & Kotz [16], who showed that metrical stress is essential for the ongoing speech segmentation process in early latencies in sentence perception. They were also able to demonstrate that meter goes on to interact with syntax in later latencies, as evidenced by lack of additivity of metrical and syntactic violations in the P600 component.

Overall, these studies have revealed that unexpected or incongruous metrical patterns elicit increased negative ERP components in the latency range of the N400. Furthermore, it appears that speech rhythm is processed regardless of the direction of attention and interacts with other levels of linguistic processing.

In all of the aforementioned studies, metrical stress was expressed through variations of acoustical cues. However, several studies suggest that implicit prosodic information may also influence reading (e.g., [19]) and furthermore propose a link between speech rhythm sensitivity in young children and later reading performance (e.g. [20]). Only a few studies have looked at the influences of prosodic information on the neuro-cognitive processes involved in reading. Steinhauer and Friederici [21] demonstrated that the closure positive shift (CPS), typically elicited by intonational phrase boundaries during spoken sentences, was also elicited during silent reading when implicit intonational phrase boundaries were indicated by commas. In a recent study in Chinese, Luo and Zhou [22] investigated the impact of the rhythmic patterns of the verb-object noun combination on cognitive processes during silent sentence reading. In Chinese, rhythm is expressed through the combination of words with different numbers of syllables. When a verb and an object noun are combined, they must have the same number of syllables, so it is not acceptable to combine a monosyllabic verb with a bisyllabic object noun, or a bisyllabic verb with a monosyllabic object noun. Unacceptable rhythmic patterns elicited an N400 followed by a late positivity, suggesting that rhythmic constraints influence semantic processing during Chinese sentence reading.

The purpose of the present experiment was to further investigate the impact of rhythm on reading. We manipulated the metrical expectancies of lists of 6 written words. The first four words of each list had the same stress pattern (trochaic or iambic), while the fifth word had either the same or different stress pattern as the previous words of the list. If the regular metric pattern of the list does indeed generate expectancies about the metrical structure of upcoming words, even in the written domain, we would expect words with different stress patterns to elicit N400 components.

2. Methods

2.1. Participants

Eight Psychology students (3 males and 5 females; mean age: 23 years old) received course credits for their participation in the experiment, which lasted about one hour. This study was approved by the Institutional Review Board Committee at Middle Tennessee State University, and all participants gave their written informed consent to participate. All were right-handed, had normal hearing and vision and were native speakers of English. Two participants were discarded because of excessive ocular artifacts.

2.2. Stimuli

Each trial consisted of a sequence of five bisyllabic words presented in succession on a computer screen. The first four words were either all trochaic (i.e., stressed on the first syllable) or all iambic (i.e., stressed on the second syllable). Metrical expectancy was manipulated by varying the stress pattern of the fifth word. In the metrically expected condition, the fifth word had a similar stress pattern as the previous four words. In the metrically unexpected condition, the fifth word had a different stress pattern. The written word frequency was controlled so that all words within a given list had similar frequencies [23]. After each list, an additional word was presented and used as a target for a memorization task. In half the list, the target word was new while in the other half, it was a repetition of one of the five previous words. No list was repeated. Examples of stimuli in each experimental condition are presented in Table 1.

2.3. Procedure

During the experimental session, participants were presented with two blocks of fifty word lists each. Block order was counterbalanced across the participants, and word lists were randomized within each block. Participants were asked to pay attention to each word in the lists and to press a button if they thought the target word was new or another button if they thought it was a repetition of one of the previous words. The task was designed to ensure that participants pay attention to each word of the list without having any explicit knowledge about the rhythmic manipulation on the fifth word.

Table 1: *Examples of stimuli used in the four experimental conditions*

Condition	Word 1	Word 2	Word 3	Word 4	**Word 5**	Metrical Expectancy
1	SW Body	SW Level	SW Study	SW Woman	**SW** **Table**	Expected
2	WS Result	WS Today	WS effect	WS control	**WS** **Idea**	Expected
3	SW Body	SW Level	SW Study	SW Woman	**WS** **Idea**	Unexpected
4	WS Result	WS Today	WS effect	WS control	**SW** **Table**	Unexpected

Note: SW= Strong-Weak stress pattern (trochaic), WS=Weak-Strong stress pattern (iambic)

2.4. EEG data acquisition and analysis

The electroencephalogram (EEG) was recorded continuously from 64 Ag/AgCl sensors in the GSN Hydrocel (EGI, Eugene, OR) placed on the scalp with Cz at the vertex, connected to a NetAmps 300 amplifier, using a MacBook Pro computer. Data was referenced online to Cz. The frequency of acquisition was 500Hz, and impedances were kept below 50 kOhm. EEG preprocessing was carried out with NetStation Viewer and Waveform tools. The EEG data was filtered offline with a bandpass of 0.1 to 100 Hz. The data was then rereferenced offline to the algebraic average of the left and right mastoid sensors. In order to detect the blinks and vertical eye movements, the vertical and horizontal electrooculograms (EOG) were also recorded. Data time-locked to the fifth word of each list was segmented into epochs of 1150ms, starting with a 150ms baseline prior to the onset of the words and continuing 1000ms post-word-onset. Trials containing movements, ocular artifacts or amplifier saturation were discarded. Individually for each subject, ERPs were computed by averaging together the EEG segments for each condition at each electrode site. For the statistical analysis, electrodes were grouped into eight regions of interest on the scalp, each including six electrodes (left frontal: 10, 11, 13, 17, 18, 19; right frontal: 1, 2, 5, 56, 58, 59; left centro-frontal: 7, 9, 12, 14, 15, 16; right centro-frontal: 3, 51, 53, 54, 57, 60; left temporal: 22, 23, 24, 25, 27, 30; right temporal: 44, 45, 48, 49, 52, 55; left parieto-occipital: 21, 26, 28, 31, 33, 35; right parieto-occipital: 38, 39, 40, 41, 42, 46).

ERPs were analyzed by computing mean amplitudes in selected latency ranges (250-400 ms, 350-450 ms, and 450-600 ms) relative to a 150 ms pre-stimulus baseline, and based on the visual inspected of the data. Analyses of Variance (ANOVAs) were used to compare the mean amplitude across the four experimental conditions. Meter (trochaic versus iambic), Expectancy (expected versus unexpected), Hemisphere (left versus right) and Region (frontal, centro-frontal, temporal, parieto-occipital) were used as within-subject factors. All p values reported below were adjusted with the Greenhouse-Geisser epsilon correction for non-sphericity.

3. Results

Between 250 and 400 ms, there was no significant main effects of Expectancy or Meter, but there was a significant Expectancy x Region interaction [F(3,15)=6.22, p=0.018]. Planned comparisons in separate regions revealed that metrically unexpected fifth words elicited larger negative components than metrically expected fifth words in frontal [F(1,5)=43.38, p=0.001; difference=-1.22µV] and centro-frontal [F(1,5)=7.21, p=0.043; difference=-0.90µV] regions, while no significant difference was found in the temporal and parieto-occipital regions (see Figure 1). There were no significant effects in the 400-600ms latency range.

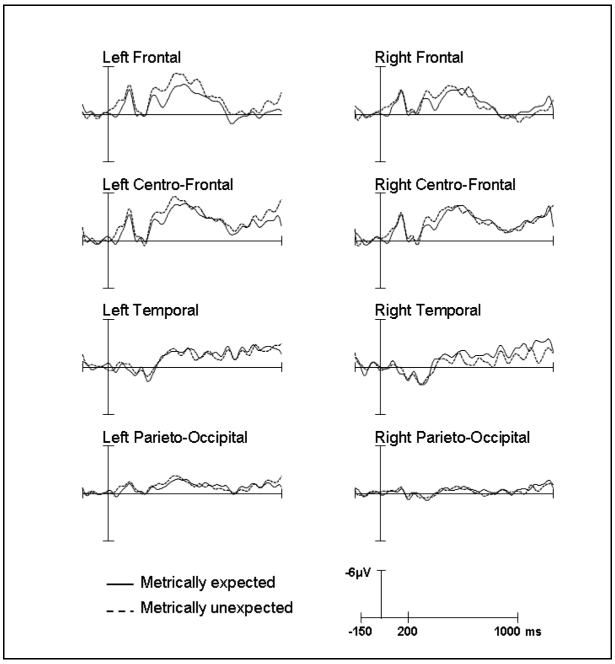

Figure 1: *Metrical expectancy effect. Waveforms show the ERPs for metrically expected final words (solid) and metrically unexpected final words (dashed), from 150 ms before word onset to 1000 ms after word onset. Data are presented for each region of interest.*

Though the main effect of Meter was not significant between 250 and 400 ms, further analysis in a smaller latency range revealed a marginally significant main effect of Meter between 350 and 450 ms [F(1,5)=6.00, p=0.058; difference=-0.51µV], suggesting that trochaic words elicited somewhat larger negative components than iambic words. No other main effect or interaction was significant in this latency range (see Figure 2). No significant effect was found in the 450-600 ms latency range.

4. Discussion

The present study aimed to further investigate the impact of rhythmic constraints on silent word reading in English. The results suggested that even during reading, word lists with a regular stress pattern elicit expectancies about the stress pattern of upcoming words. This was demonstrated by the presence of a larger negative component, elicited by metrically unexpected words. Moreover, the fact that trochaic words were associated with somewhat larger negative components than iambic words, regardless of the expectancy and despite the fact that trochaic and iambic words were controlled for

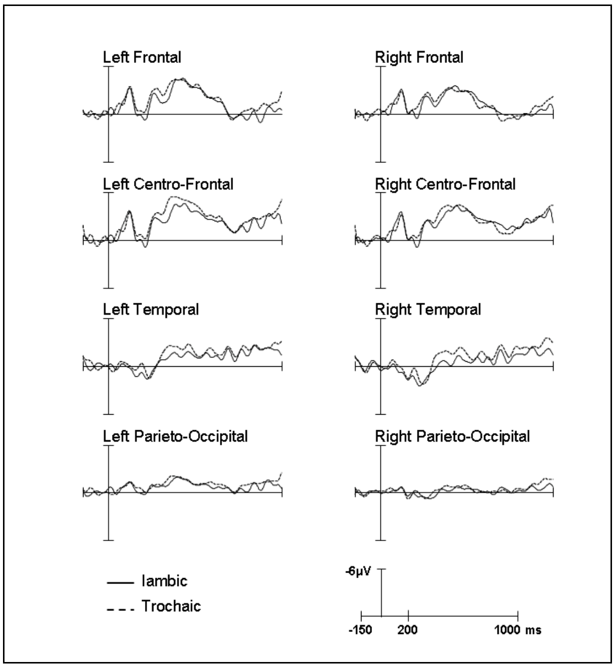

Figure 2: *Stress pattern effect. Waveforms show the ERPs for iambic final words (solid) and trochaic final words (dashed), from 150 ms before word onset to 1000 ms after word onset. Data are presented for each region of interest.*

word frequency, also suggests that the metrical structure of a word influences its processing during reading.

The increased negative ERP component elicited by metrically unexpected words shares a similar latency range (250-400ms) and scalp distribution (central and frontal regions of the scalp) as the N400 component described extensively in the literature (see [24] for a review). Typically, regardless of the modality (visual or auditory), this component is elicited by words that are not semantically expected in the context of a word, sentence or discourse [25]. Larger N400 components have been interpreted as reflecting difficulties in either integrating semantic information or generating semantic expectancies [24].

The present results are in line with previous studies showing that incorrect rhythmic patterns may hinder semantic processing not only in the auditory modality [15, 16], but also in the visual modality [22]. Moreover, because the words did not contain any rhythmic incongruities, and only the contextual regularity of the stress patterns within a given list was manipulated, the results also extend the previous findings by showing that even a more subtle manipulation is enough to perturb semantic processes.

Regardless of the expectancies, trochaic words also elicited a slightly larger N400 component than iambic words. At first look, this finding may be surprising, since for bisyllabic words in English, the trochaic stress pattern is known to be more frequent than the iambic stress pattern [4]. Thus one may have expected the iambic stress pattern to elicit larger N400 component than the trochaic stress pattern as reported for spoken words in Dutch [13]. However, because words were presented visually as a whole, it was not possible to time-lock the ERP recording to the second syllable in the present study. Thus the larger N400 to trochaic words may reflect a better time-locking of the N400 component to each individual trochaic word, compared to iambic words, for which the timing of the processing of the second syllable may have varied across the different words. This is currently being investigated in an auditory version of the present study in which ERP recordings are time-locked to either the first or the second syllable of each word. In any case, the difference between the N400 elicited by trochaic and iambic words further highlights the automatic processing of the metrical structure of the words during silent reading.

Finally, it is worth noting that during the experimental session, participants were engaged in a memorization task, thereby not explicitly focusing on the stress pattern of the words. Thus, in line with previous studies (e.g., [15]), the N400 elicited by metrically unexpected words cannot be solely attributed to controlled processes such as attentional focus and task demands, and probably reflects more automatic aspects of lexico-semantic processing of the words.

5. Conclusions

These results coincide with the previous literature showing that rhythmic information is processed early during language processing, and that it modulates semantic processing. Moreover, they also suggest that metrical structure guides sentence comprehension regardless of the modality of input, auditory (i.e., speech) or visual (i.e., reading). Taken together, the recent ERP literature on speech rhythm could have potential implications for models of reading and may provide a better understanding of the neurocognitive processes involved in language acquisition.

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