



Rhythm's gonna get you: Regular meter facilitates semantic sentence processing

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ABSTRACT

Rhythm is a phenomenon that fundamentally affects the perception of events unfolding in time. In language, we define 'rhythm' as the temporal structure that underlies the perception and production of utterances, whereas 'meter' is defined as the regular occurrence of beats (i.e. stressed syllables). In stress-timed languages such as German, this regularity functions as a powerful temporal and structural cue in speech comprehension. Recent evidence shows that it also interacts with higher level linguistic faculties such as syntax (Schmidt-Kassow & Kotz, 2009a). The current ERP experiment investigated the impact of metric structure on lexico-semantic processing, comparing the effects of semantic and metric expectancy in regular and irregular metric sentence contexts. We predicted that (1) semantically unexpected words would result in an increased N400 amplitude and (2) metric context modulates the N400 amplitude. Our results confirm these predictions: semantically unexpected words elicit an N400 that is significantly smaller in a metrically regular than a metrically irregular sentence context. The current findings support the idea that metric regularity enhances the prediction of stress locations in a sentence context, which in turn facilitates lexico-semantic integration.

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1. Introduction

The role of rhythm in human behavior has long been subject to elaborate experimentation and theory building. This is not surprising as rhythm is a fundamental phenomenon affecting a range of behaviors such as motor, music, and language. In language, we define *rhythm* as the temporally regular or irregular structure that underlies the perception and production of utterances. Conversely, *meter* is defined as the regular occurrence of *beats* (Lehrdahl & Jackendoff, 1983). In languages such as German or English, beats may be realized as stressed syllables in a sentence (Cummins & Port, 1998; Lee & Todd, 2004; Schmidt-Kassow & Kotz, 2009a; Slowiczek, 1990). In speech, the alternation of stressed and unstressed syllables may provide a temporal cue that allows to predict when the next stressed syllable is likely to occur ("When next?" see Large & Kolen, 1994).

In speech perception listeners focus their attention on particular points in time at which salient stressed syllables are expected to occur (e.g. Mattys, 1997), thereby allowing the listener to entrain to the speech signal (e.g. Arantes & Barbosa, 2010). This assumption is consistent with the "attentional bounce hypothesis" (Pitt & Samuel, 1990), in which attention is thought to move from one

stressed syllable to the next enhancing a listener's perception of strong and weak syllables in the speech. Moreover, it is also well known that the auditory system continuously searches for regularities in the acoustic signal and, once detected, allows the listener to form predictions about upcoming events (Winkler, Denham, & Nelken, 2009). Similarly, linguistic context makes it easier for listeners to predict a likely continuation of a sentence and informs the comprehension system of incoming words (e.g. Groppe et al., 2010). We therefore consider that default metric stress patterns and characteristic accent distributions are used to form predictions about when the next stressed syllable should occur regardless of the fact that speech contains dynamic variations (i.e. pauses, intonation, and loudness) and constantly changes over time.

Such an account is in line with the rapid comprehension and the robust interpretation of ambiguous and noisy input (Pickering & Garrod, 2006). Consequently, we consider that the ongoing speech signal is not completely unpredictable but encompasses perceptual regularities that lead to facilitated information processing. It is therefore no coincidence that metric stress plays a significant role in language acquisition (Jusczyk, 1999), speech segmentation (Mattys & Samuel, 1997), lexical grouping (Dilley & McAuley, 2008), and syntactic processing (Schmidt-Kassow & Kotz, 2009a). Based on this evidence, the question arises whether regular metric structure impacts other higher order linguistic faculties such as semantics.

We address this question by using EEG and are looking more closely at the N400 component which has been associated with lexical information processing and contextual integration (for reviews, see Federmeier, 2007; Kutas & Federmeier, 2000, 2011;

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Lau, Phillips, & Poeppel, 2008). The N400 is a good index of lexico-semantic integration and can provide information about contextual factors that influence lexico-semantic information processing. Furthermore, it has been claimed that the N400 amplitude is modulated by expectancy (Lau et al., 2008), reflects the ease with which meaning is integrated into a sentence context (e.g. Boulenger, Hoen, Jacquier, & Meunier, 2011; van den Brink, Brown, & Hagoort, 2006), and is affected by the extent to which properties of incoming words are pre-activated by the contextual information available (see DeLong, Urbach, & Kutas, 2005; Federmeier, 2007).

At first glance, semantic and metric information processing may not have much in common, but both seem to rely on a form of prediction. However, in semantic processing, the orientation towards future events seems to be based on expectancy rather than prediction as it involves a restricted number of potential word candidates (DeLong et al., 2005). As for metric processing, predictions arise at a more structural, form-dependent level (Dohmas, Wiese, Bornkessel-Schlesewsky, & Schlesewsky, 2008; Magne, Gordon, & Midha, 2010; Rothermich, Schmidt-Kassow, Schwartz, & Kotz, 2010). In particular, stress-timed languages such as English or German allow predictions about the position of stressed syllables in a sentence context based on the perceived rhythmic flow of the preceding sentence context. These predictions may occur even if the distribution of stressed syllables does not include precise temporal information.

It is important to note that in the present study, regularity is not achieved through temporal regularity, i.e. having a constant stimulus onset asynchrony (see for example, Quené & Port, 2005; Schmidt-Kassow & Kotz, 2008), but by the regular distribution of stressed and unstressed syllables. We assume that this regular metric structure may provide a context that leads to prediction and facilitated processing in speech comprehension (Gow & Gordon, 1993). Consequently, lexico-semantic information should be more easily processed in a regular than an irregular metric sentence context. Based on this assumption, we directly compared the effects of metrically regular and irregular sentence context on lexico-semantic processing. We hypothesized that lexico-semantic integration of unexpected words (indexed by an N400 amplitude rise) into the sentence context is facilitated by the precedence of a metrically regular sentence context.

However, the exact nature of the N400 is still unclear: on the one hand, it is thought to reflect ease of access due to priming or pre-activation (Federmeier, 2007; Kutas & Federmeier, 2000). Conversely, it is also considered to reflect the level of integration difficulty of a word into a given sentence context (Brown & Hagoort, 1993; Hagoort, 2008; Osterhout & Holcomb, 1992). While the current study will not ultimately clarify this issue, it aims to more closely examine the nature of the N400 response by investigating a potential modulation as a function of metrically predictable (regular) and irregular sentence context.

In the N400 literature, the idea that the amplitude of the N400 is inversely proportional to the ease of contextual integration is well-established (Bentin & McCarthy, 1994; Chwilla, Brown, & Hagoort, 1995; Kutas, Van Petten, & Kluender, 2005; Rugg & Doyle, 1994). The modulation of the N400 is thought to reflect the semantic processing of a word in relation to its preceding context, whereby a larger N400 amplitude reflects an increased effort in semantic processing (Holcomb, 1993; Kutas & Federmeier, 2000; Kutas & Hillyard, 1980). Thus, the more easily a word can be integrated into a sentence context, the smaller the amplitude of the N400 should be (Kutas & Hillyard, 1984). Findings supporting the influence of a metrically regular sentence context on the N400 would extend previous research which suggests that language comprehension can be highly predictive, as long as linguistic (or non-linguistic) context supports such predictions (Pickering & Garrod, 2006).

The purpose of the present study was to examine the interaction of metric and semantic processing, and in particular, the influence of the metric structure of a sentence on lexico-semantic integration. Previously, Magne et al. (2007) investigated the interaction of meter and semantics in French and reported an N400 in response to semantically unexpected words. Furthermore, they reported a biphasic pattern consisting of a P600 and an early negativity (labeled N400) for metrically incongruous sentence-final words. The authors suggested that this early negativity reflects incorrect stress assignment during lexical access, as the encountered metric structure interferes with lexical access to word meaning. They concluded that the negativity may be considered as a part of the N400 family due to its similar latency and scalp distribution.

However, our previous findings provide an alternative account. We have shown that an early negativity in response to metrically unexpected (pseudo)words occurs independently of semantic content (Rothermich et al., 2010). Therefore, we concluded that it is unlikely that the negativity reflects interference with lexical access, but rather a general error-detection mechanism. The current investigation aims to further illuminate this issue by directly comparing the early 'metric' negativity and the N400. Based on our previous findings, we predict that the negativity in response to metrically unexpected words differs qualitatively from the 'semantic' N400.

A further question concerns the influence of the task setting on metric and semantic processing. Magne et al. (2007) reported a P600 effect only in response to metric manipulations in an explicit metric judgment task, and not in an implicit semantic judgment task. In their study, participants focused on metric aspects in one session and on semantic aspects in another session. Results are in line with data provided by Astésano, Besson, and Alter (2004). The authors presented semantically congruous and semantically incongruous sentences that differed in their pitch contour. Some of the sentences were pronounced with the pitch contour of a question even though the sentence structure indicated a declarative sentence. Similarly to Magne et al. (2007), all sentences were tested with a focus either on the prosodic contour or on the semantic congruity. When participants' attention was directed to incongruent prosodic contours, a positive component (P800) was elicited, while a focus on the semantic structure led to an even larger positivity and a N400. When the focus was on semantics, no positivity was elicited by prosodic incongruities, while semantic incongruities resulted in an N400. In summary, both experiments (Astésano et al., 2004; Magne et al., 2007) indicate that semantic processing is not affected by attentional task demands (on prosody/meter), while prosodic/metric processing seems to be attention-dependent.

The current study investigated the influence of metric predictability on the N400 component and the interaction of metric and semantic information. We predicted that (1) semantically unexpected words would elicit an increased N400 amplitude, (2) metrically unexpected words would elicit a biphasic pattern of an early negativity and a P600, (3) semantic and metric processes would be influenced by task demands, and (4) regular metric sentence context would facilitate semantic processing (i.e. reduce the N400 amplitude).

2. Methods

2.1. Subjects

Twenty healthy native speakers of German (10 females; mean age: 25) participated in the experiment. One participant did not meet the inclusion criteria as he showed very discrepant behavior. His performance was below 75% correct in more than two conditions, indicating problems understanding the task assignment. Based on his discrepant behavior we consider this participant as an outlier and have excluded him from further analysis. All subjects were right-handed as determined by the Edinburgh inventory (Oldfield, 1971). They received a small fee for participating. The experiment was approved by the Ethics Committee of the University of Leipzig.

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