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Lexical access enhances the activation of predominant stress templates in infants

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Abstract

Infants develop different kinds of long-term linguistic representation as early as in their first year of life. We examined the interaction of early lexical access and prosodic processing.

It is proposed that familiar word forms are stored in a protolexicon before linking any concepts to them, enabling early (proto)lexical segmentation from fluent speech. Additionally, previous results strengthened the fundamental contribution of speech prosody to segmentation in infants. Electrophysiological data show that the discrimination of illegal stress pattern elicits mismatch responses in infants, while stimulus with a legal stress pattern does not. We assessed event related brain potentials reflecting assumed interaction between prosodic processing and lexical access. We hypothesised that significant neural responses might appear for the predominant stress pattern, when familiar words are presented.

We investigated 10 (35) and 6 (17) months old infants presenting two stress variations of a frequent word in an acoustic passive oddball paradigm (400 items, deviant: *p*=25%). We compared results to earlier data using pseudo-word: ERPs to the familiar word with predominant stress pattern showed enhanced brain responses compared to the pseudo-word. We interpret this finding as elaborated and more flexible processing of words stress when lexical cues are available in this stage of development.

Index Terms: language development, prosody, mismatch response

1. Introduction

Even before pronouncing their first words, infants learn a considerable amount of information about their mother tongue's typical patterns and rules. They use both segmental [1] and suprasegmental cues to trace word or phrase boundaries [2] at a very early stage. Phonotactic cues, allophonic variations of phonemes, and prosody of native language have all been shown to be useful markers of segmentation [3]. Prosody, and more specifically word stress, is one of the most complex cues of them. It can convey different kinds of information such as structural, pragmatic, and emotional [4], but even if prosody as a phenomenon and some of its functions are universal, the determining cues vary across languages. Earlier studies have shown that language environment influences word stress processing from a very early age on 7. Behavioural studies show that English [5], Spanish [6], German and French [7] 6- to 9-month-old infants are able to discriminate stress patterns on word level, and they also have a bias toward the typical pattern of their mother tongue, except for French infants (and probably infants speaking other fixed stress languages). Electrophysiological results have confirmed language-specificity at the neural level adapted to the mother tongue as early as 4 months of age [8]–[10]. This indicates that recognition of the typical stress pattern at a very early age is general, regardless of the specificity of the mother tongue.

In general, electrophysiological methods offer a far more sensitive methodology for assessing neural representations than behavioral studies. Moreover, because of their precise temporal resolution, they are highly appropriate for studying high-speed speech processing. Because overt responses are not necessarily needed, electrophysiology is especially suitable for studying populations where behavioral responses are limited. The most commonly applied method in infant studies is the event related potential (ERP), which is a stereotyped electrophysiological response to a stimulus (event). Experiments with infants usually assess a specific ERP component, called mismatch response (MMR) that is related to both acoustic saliency and to long-term representations of linguistic information, i.e., stress pattern. This component is a marker of change detection, when an infrequent (*p*=6-25%) stimulus violates a series of frequently presented ones. This paradigm is the so-called oddball paradigm. In all of the studies mentioned earlier the presence of MMR component was observed for discrimination of illegal stress patterns – i.e. a stimulus with an illegal stress pattern disrupts a series of legally stressed pseudo-words, where legality is determined by the given language. However, MMR responses do not appear in the other way around: discriminating legal stress pattern, when it violates a series of illegally stressed stimuli does not result in significantly different brain responses. Two possible explanations are proposed for this lack of discrimination component. The results of this comparison are affected by both short-term and long-term memory traces of the stimuli. [11]. The long-term traces of the linguistic representations serve as recognition patterns parallel to short-term traces established by the actual standard stimulus [12]. Apparently,

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the illegal stress pattern neither matches the assumed long-term pattern nor produces a short-term trace as it violates the long-term pattern. These results indicate a rigid mode of processing of language predominant word stress patterns in young infants.

However the weighing or usage of word segmentation abilities (like stress based segmentation) that infants develop at this young age are also constantly changing, or even regressing, when they begin to attend to meaning [2], [13]. Lexical acquisition is usually regarded as a process when linguistic labels are associated with concepts, but word forms presumably learnt and stored by infants as sound patterns prior to link any meaningful content to them [14], [15]. At the age of 11 months, a functional "protolexicon" is hypothesized to exist in infants [14], where they store word candidates extracted earlier relying on other cues. This "protolexicon" could be beneficial in the acquisition of language-specific features on different levels. It can retain the results of bottom up distributional learning and serve as a basis for refining linguistic processes and representations that rely on top-down mechanisms, when extracted rules are generalized. It is indeed underpinned by electrophysiological results, as differences in event related brain potential (ERP) for words and nonsense words were observed, verifying that the familiarity of a word form is processed at a very early stage at the neural level [12]. This supports the claim that linguistic information can be assessed pre-attentively by eliciting mismatch responses at different linguistic levels (i.e. phoneme level, words level [15]).

We hypothesized that protolexical access might have a significant influence on processing word stress. Based on the models emphasizing interactional benefit, the familiarity of the presented stimulus would facilitate the processing of other rule based linguistic features, like the stress pattern. Illegal stress pattern with a familiar word form is acceptable enough to support a memory trace as standard stimulus – resulting in mismatch responses for legal stress pattern.

In order to test this hypothesis, we used the experimental paradigm of Honbolygó and Csépe [16] designed for testing the stress template hypothesis. We have already used this paradigm before, presenting pseudo-words to infants. This time we presented familiar words (legally and illegally stressed) in a passive oddball paradigm.

2. Methods

2.1 Participants

A total of 46 infants were recruited for the experiment, and 35 were included in the statistical analyses. Eleven infants were excluded due to extensive artifacts. There were 17 six-month-olds (girls: 9; *min*: 185 days, *max*: 199 days; *SD*=4.58) and 18 ten-month-olds (girls: 5; *min*: 303 days, *max*: 320 days; *SD*= 4.26). Birth weight and GA did not differ significantly in the two age groups. Participants were all monolingual infants, none of them had known hearing problems, neurological impairments or any known developmental delay. Parents were given detailed information about the experiment and signed consent for their child's participation. The study was approved by the Ethical Review Committee for Research in Psychology.

2.2 Stimuli

Two versions of a highly frequent CVCV Hungarian word ('*baba'* means: baby, infant and also doll) were used for the experiment. This word is eminently suitable for the experiment as the segmental features of its syllables are identical, and has similar structure to our earlier used pseudo-word: '*bebe*' [9], [16]. Hungarian language characterized by syllable-timing, first syllable legal position of accent and non-existent lexical stress [17]. According to this, the natural variant had been produced in adult-directed speech with predominant (legal) stress pattern. As our word consisted of identical syllables, the illegal stress variant was edited by reversing the order of the two syllables using Praat [18], exactly the same way as we constructed the pseudo-word stimuli in our earlier study [16]. This way we established that the two stimuli differed only in their prosodic structure. In both versions the two syllables differed in maximum intensity (3.49 dB), maximum f0 (18.51 Hz) but not in duration. In Hungarian, duration is a segmental cue itself.

2.3 Procedure

Stimuli were presented in a passive oddball paradigm in random order (deviant probability of 25%) [9]. To avoid rhythmic affects stimulus onset asynchrony (SOA) varied randomly between 730 and 830ms. We used two stimulus presentation conditions, here we present the *Legal Deviant* condition, when the illegal stimulus was presented as the standard and the predominant legal one was the deviant stimulus.

The order of the two conditions was counterbalanced across participants. Each condition contained 100 deviants in two blocks. Recording lasted approximately 12 minutes, in order to avoid fatigue among the infants. Stimuli were presented via loudspeaker (Soundkey MS-310, 70 *dB*) that was placed at the distance of 100 cm from the participants. The experiment was performed using Presentation software (version 12.1, http://www.neurobs.com). The total experimental time was 1 hour including preparation and pauses. Infants were sitting on their parents' lap and were kept calm by puppeting silently by an assistant.

2.4 Data collection and analysis

The EEG was recorded with Ag-AgCl electrodes using appropriate sized electrode cap at F3, Fz, F4, C3, C4, T3, T4, P3, Pz, P4, O1, O2, M1, M2 according to the international 10-20 system (500 Hz sampling rate, BrainVision Recorder, BrainAmp amplifier, EasyCap, BrainProducts GmbH). An additional electrode served as common ground electrode placed between Fz and Fpz on the midline. All electrodes were referenced to the Cz as one of the most artifact-free electrodes, then algebraically re-referenced offline to the average of the mastoids with BrainVision Analyzer software (BrainProducts GmbH). The EEG was band-pass filtered with 0.5-20 Hz (24 dB/oct) to keep the informative frequencies and remove other data that are not connected to the stimulus processing. Recordings were segmented into 800 ms epochs synchronized to the onset of each stimulus, adding a 100 ms pre-stimulus interval for baseline. Automatic artifact rejecting algorithm was applied using ±150μV thresholds within a sliding window of 300 ms in all channels. Eleven infants' data were rejected due to extensive artifacts this way resulting in 17 six-month-old and 18 ten-month-old infants' data ready for statistical

analyses. Latency windows were the same as for pseudo-words [9], where responses to prosodic processing were measured successfully: two 100 ms latency windows (300-400 ms and 450-550 ms). Epochs were averaged separately per electrode and participant for all deviants, and for the preceding standards balancing the number of trials taken into account (standard and deviant) and to maximize the observable difference between the stimuli. We measured mismatch responses (discrimination between standard and deviant stimuli) in two latency windows given above. We performed 3×2×2 mixed ANOVAs including frontal Electrodes (F3, Fz, F4) as they represented the largest responses, and Role (standard vs. deviant) as within-subject factors, and age group (6 MO vs. 10 MO) as between-subject factor.

Greenhouse-Geisser (G-G) correction was applied where appropriate. Main effects of factors Role and Age, as well as significant interactions among them including post-hoc comparisons are reported for the Legal Deviant condition, and its comparison to pseudo-words.

3. Results

As age effects were not statistically significant, data were pooled over the two age groups in Figure 1.

In the first latency window (300-400 ms) we found a Role main effect ($F(1,33) = 5.89$, $p < .022$, $\eta_p^2 = .15$) as the predominant stress pattern elicited smaller positivity then the illegally stressed word. This response was synchronized to the first syllable that was stressed as deviant.

In the second latency window (450-550 ms) we obtained a Role main effect as the predominant deviant elicited significantly different responses as compared to the standard stimulus ($F(1,33) = 14.76$, $p < =.002$, $\eta_p^2 = .31$). Discriminating the predominant stress pattern elicited a negative going difference wave.

We compared the results using words with the results of our earlier experiment using pseudo-words. The statistical analysis did not reveal any significant effect in case of discriminating the predominant stress pattern for pseudo-words. Difference waves computed by subtracting the averaged standard responses from the deviants are displayed for both types of stimuli on Figure 1.

4. Discussion

Discrimination of the legally stressed familiar word elicited two Mismatch Negativities (MMN) in infants. It indicates change detection ability at the neural level for the predominant stress pattern. Our hypothesis was that acquired abilities interact: amplifying rather than attenuating each other. This way different cues used for segmentation should enhance each other's processing. To examine this assumption we compared the ERPs recorded in this experiment using words to those recorded in our earlier experiment using pseudo-words [9]. In both experiment we used CVCV formulas with acoustically highly similar features regarding the structure and duration of the syllables. In both experiments we calculated the difference waves (deviants minus standard) and as Figure 1 shows the paramount peaks have rather the same latency, however the amplitudes are altered. The amplitude increase of the difference waves observed resulted from well measurable differences between responses to standards and deviants being larger for words than for pseudo-words for the predominant stress pattern detection. Significant effects were observed using words, but not pseudo-words. Since mismatch responses are to reflect the improvement of sensory processing even preceding discrimination performance changes [19], we can conclude that lexical features influence suprasegmental processing in a facilitating manner. The more types of cues are presented, the more flexible the neuronal mechanisms are that underlie the discrimination process, showing a somewhat more adaptive processing.

The MMN or MMR is influenced by permanent language-specific memory traces as it is assessed already for speech-sounds. According to the authors, these long-term traces serve as recognition patterns [19], like the predominant stress pattern [16]. Moreover it can serve as a recognition pattern as early as in the second half of the first year of life, even when it is still a less stable long-term representation as in adults. Hence processing the difference was influenced not only by the short-term trace of the standard as compared to the deviant stimulus, but also by a language-specific long-term trace (i.e. stress representation) of the presented word.

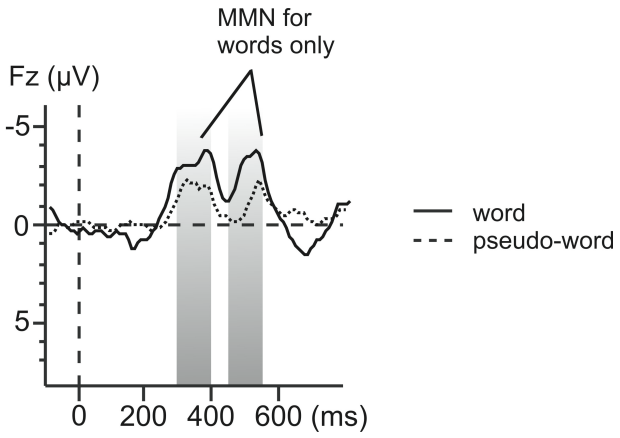

Figure 1: *Difference waves (deviant minus standard) ERPs recorded for words and pseudo-words with predominant stress pattern in infants.*

5. Conclusions

We revealed that protolexical information modulates processing of prosodic information. Enhanced brain responses for words reflect elaborated and more flexible processing of word stress. In the sensitive period of language development infants learn to extract regularities, to define categories, and to tune heuristic methods. Our data provide electrophysiological evidence for the view that lexicality influences suprasegmental processing on the protolexical level in this stage of development. An interesting question is how this influence takes place in adults, where lexical segmentation is the dominant strategy in contrast to in infants.

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