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Electrophysiological correlates of language
acquisition:

Prosodic processing in infancy

Doctoral (PhD) thesis booklet

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1. INTRODUCTION

This dissertation explores infants' linguistic prosodic processing in the sensitive period of language acquisition. Electrophysiological correlates of prosodic processing of 6- and 10-month-old infants are discussed from three different aspects. First, infants' results are compared to those of adults', which enlighten the differences that take place in-between early and mature language comprehension. Second, electrophysiological interpretations are discussed with respect to behavioral results. And third, our results of a fixed-stress language, that is Hungarian, are compared to results of languages that use lexical or contrastive stress. This way we aimed to define the differences in prosodic processing related to its functional role in native languages.

Central question in early language acquisition is how infants segment words from fluent speech in the absence of clear cues to signal boundaries (Gósy, 1995). According to the statistical approaches of language acquisition, in the absence of clear acoustical realization of any lexical and syntactical boundaries, infants rely on language-specific heuristics. These heuristics rely on the phonological and phonotactic regularities that govern sound sequences (Seidl, Cristià, Bernard, & Onishi, 2009; White, Peperkamp, Kirk, & Morgan, 2008) and transitional probabilities in-betweens (Gervain & Mehler, 2010; Saffran, Werker, & Werner, 2006; Thiessen, Hill, & Saffran, 2005; Thiessen & Saffran, 2003). The phenomenon that infants are sensitive to statistical dependencies is domain-general as they also show distributional learning of visual shapes, for instance (Feldman, Griffiths, Goldwater, & Morgan, 2013). In case of linguistic information, perceptually available auditory features are organized into patterns, which establish contingencies with a language's morphosyntactic structure. Extracting these contingencies and applying them in new situations is generally called a bootstrapping mechanism (Gervain & Mehler, 2010; Gleitman & Wanner, 1982).

Mehler et al. (2004) proposed that rhythm was exploited for bootstrapping morphosyntactic structure, while recent results on stress processing suggest that word stress pattern is also utilized for bootstrapping word form extraction

(Gervain & Mehler, 2010). The presented experiment investigates word level stress processing from different aspects.

Different acoustic features determine stress. Usually F0, duration and intensity are the three main factors, but the manifestation is highly language specific (Varga, 2002). Infants have sensitivity for these acoustic cues from birth (Werker & Tees, 1984), and after a few months of exposure to their native language, they extract language-specific patterns of them, and use them for segmentation purposes for signaling boundaries of word level units of fluent speech (Jusczyk, Houston, & Newsome, 1999). There is a transition during development from focusing on salient acoustic features (bottom-up mechanisms), to linguistic familiarities and expectancies (top-down processing).

Event related potential (ERP) studies support the presence of early sensitivity for word level stress pattern regardless of the native language (Friederici, Friedrich, & Christophe, 2007), while the results of headturn preference paradigm (HPP) studies vary across different languages. Nine-month-old Spanish infants could distinguish different stress patterns of bi-syllabic words, while French infants succeeded only if different tokens of the same pseudo-word were used. (Skoruppa et al., 2009). At the age of 6 months, both groups showed preference only when segmentally unvaried stimuli were used (Skoruppa et al., 2013). This led the authors to the conclusion that Spanish infants' stress pattern processing develops between 6 and 9 months, while French infants show no development for stress processing. They explained this distinction with the difference in roles stress has in the two languages. Spanish has lexical or contrastive stress, meaning that a stress pattern can change the meaning of a word form, while French is a fixed-stress language with an obligatory word-internal position for stress.

Regarding early segmentation, in fixed-stress languages word level stress patterns offer not only a heuristic, but also a perfect cue for identifying units of speech. However, concerning fixed-stress languages the provocative question may be raised: when stress is fully predictable, what function does it serve (Cutler, Dahan & van Donselaar, 1997)?

Along this question, some studies reported stress "deafness" in fixed-stress language speaking participants. It was found that French adults have difficulties in

perceiving contrastive stress pattern that Spanish speakers can easily accomplish (Dupoux, Peperkamp, & Sebastian-Galles, 2001). Also, other fixed-stress languages were taken into account, and the authors found that Hungarian, Finnish and Polish participants show difficulties in a sequence recall task using stress cues, while they performed well when relying on phonemes (Dupoux, Sebastián-Gallés, Navarrete, & Peperkamp, 2008). Interestingly enough, stress specific neural representations have also been reported in adults as well as in infants. Ylinen et al., (Ylinen, Strelnikov, Huotilainen, & Näätänen, 2009), Honbolygó & Csépe (2013) and Domahs et al. (2012) have reported language-specific discrimination abilities in all three fixed-stress languages, where the performance of sequence recall task was poor. A common trend in infants' language acquisition studies is to broaden the techniques used in experiments to build more valid theories.

2. THE AIMS AND RESULTS OF PRESENT STUDIES

The present studies aimed to investigate the early stages of word level stress processing. Infants' initial stages of stress pattern processing, reflected by mismatch responses, were compared to that of adults, as reflected by discriminative cortical responses. The interpretation of the results is combined with results of behavioral studies. The main idea of this series of experiments was to investigate 1) different age groups (groups from the sensitive period and matured participants); 2) with the same sets of stimuli; 3) with different techniques (event related brain potentials (ERP), headturn preference paradigm (HPP)).

2.1. ERP EXPERIMENT WITH INFANTS: PSEUDO-WORDS

We aimed to investigate word level stress pattern processing in infants to:

- Establish whether (and if so, when) Hungarian infants are sensitive to stress pattern changes on word level
- Explore the level at which this sensitivity is presented; divide top-down and bottom-up processes
- Understand subtle differences between infant and adult stress processing

We have found two consecutive MMNs elicited by the pseudo-word deviant of illegal stress, whereas the legal pattern deviants contrasted with standards of illegal stress position elicited no mismatch response. Our finding is in agreement with prior literature suggesting high predictability of word stress in fixed-stress languages (Honbolygó & Csépe, 2013; Ylinen et al., 2009).

We also found legality difference between the standards. Processing of stress pattern is influenced by the legality instead of its role in the oddball paradigm. We can conclude that infants' stress processing is based on stress templates. Moreover expectancy of the legal stress pattern is too rigid to accommodate it to the different conditions of an oddball paradigm

We can summarize the results as:

Thesis 1. Hungarian infants are sensitive to language-specific stress patterns: using pseudo-words they discriminate illegal stress pattern.

2.2. HPP EXPERIMENT WITH INFANTS: PSEUDO-WORDS

In this experiment, we explored whether, and if so, when in development, a language-specific neural coding manifests in observable behavioral preferences in infants.

We conducted a HPP paradigm with 6 and 10 months old Hungarian infants. The experiment used the same set of stimuli as our earlier ERP paradigm that revealed discrimination abilities for illegal stress pattern in both 6 and 10-month-old infants without any age effect.

We found that 6-month-old infants do not show any preference for either legal or illegal stimuli. On the other hand, 10-month-olds showed novelty preference, as average looking time was longer for the illegal stress pattern. This is the first time when preference relying on earlier language experience was obtained for infants learning a language with fixed-stress pattern in a behavioral experiment.

We can summarize the results, as:

Thesis 2. 10-month-old infants show preference for illegal stress pattern, implicating expectancies for native language stress pattern.

Discordance between behavioral and electrophysiological data reveals an important theoretical and methodological issue. While in the HPP paradigm we obtained differences between the two age groups, there was no age effect in the ERP paradigm. This sheds light to the advantage of both methods. Behavioral studies are able to reveal the ability of usage of a representation, but they are less accurate in assessing the presence of these neuronal representations than the ERP method.

2.3. ERP EXPERIMENT WITH INFANTS: WORDS

Our main question was how different segmentation strategies may interact in infants while learning a fixed-stress language:

- We investigated whether top-down processing of stress pattern still takes place in the presence of (proto)lexical cues.

We applied a frequently used Hungarian word rendered with different stress patterns in a passive oddball paradigm for infants learning a fixed-stress language as a mother tongue. We found that while infants discriminated the legally stressed word as a deviant accompanied by two significant MMRs, both synchronized to the onset of the two syllables, the illegal word as a deviant elicited only a later MMN right after the second syllable (c.f. Ragó, Honbolygó, Róna, Beke, & Csépe, 2013) strengthening the suggestion that long-term representations have impressed the processing of stress patterns. Our data support that, beyond the

particular speech-sound memory traces, more complex language-specific traces are also available for infants. These results are consistent with our hypothesis that stress templates that are used for segmentation are also processed with great appreciativeness if the auditory word form is already highly familiar. In this sensitive phase, prosodic information is processed automatically with high efficiency among words and pseudo-words.

In general the difference between responses to the standard and to the deviant stimuli is larger for words than pseudo-words, moreover in the legal deviant condition the difference is significant only for words. Since mismatch responses are to reflect the improvement of discrimination performance (Näätänen, Paavilainen, Rinne, & Alho, 2007), we can conclude that lexical features influence suprasegmental processing in a facilitating manner.

We also found that legal and illegal stress patterns elicited significantly different waves in deviant role. This occurred only in the case of words but not in pseudo-words showing a somewhat more adaptable processing in the former case. In the case of words, illegal stress pattern is easier accepted for strengthening a short-term memory trace in an oddball paradigm, while this fails to happen using pseudo-word.

Thesis 3. Our results demonstrate that presenting infants more than one language specific cue at a time results in a more accurate processing with regards to the presented cues rather than one suppressing the other. Our results strengthen the view of interactive rather than sequential acquisition: prosodic, segmental and lexical acquisitions take place at the very same developmental period, when presented cues enhance the flexible use of the other.

2.4. ERP EXPERIMENT WITH ADULTS: WORDS

When other cues are fully available for lexical identification we aimed to assess:

- The sensitivity to word stress pattern,
- The interaction of cues from different linguistic levels,
- The difference of this interaction in infants and in adults.

We have conducted a passive oddball ERP experiment, presenting a frequent CVCV word with legal (familiar) and illegal (unfamiliar) stress patterns in a fixed-stress language. Hungarian adults responded with one MMN to the illegally stressed words as it was obtained for the illegally stressed 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. This component of discrimination was missing or masked for words. However, it is possible that when lexical information is available prosodic information is still processed, though in a different manner.

When violating the illegal stress pattern with a legal one, the familiar patterned deviant word elicits two consecutive MMN responses. For pseudo-words no MMN was found for the legally stressed deviant. The MMNs are synchronized to the syllables with additional stress and lack of stress. In this condition lexicality clearly enhanced the comparison of prosodic information between standard and deviant stimuli, contrary to the other condition.

Thesis 4. According to these results, lexicality or segmentation cues act as a filter. In the absence of segmentation familiarity, unfamiliar stress patterns are discriminated better. In the presence of segmentation familiarity other cues indicating the perfect match with lexically rich representations are exploited. Even though stress is fully predictable in Hungarian, it is taken into account during pre-attentive processing of linguistic input.

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 as a long-term, pre-lexical, language-specific representations.

Comparing infants' and adults' results, we found that in case of adults, lexicality acts as a filter and it facilitates familiar stress cue processing even in fixed-stress languages, while in infants lexical familiarity enhances prosodic processing.

3. CONCLUSION

Summarizing, the first main finding of our studies is that speakers of fixed-stress languages are sensitive to word level stress pattern in both infancy and adulthood. This has been best described by the native language commitment model (Kuhl, 2004), as stress is processed language-specifically at a neuronal level. Behavioral performance however, is modulated by altered integration strategies compared to learners of contrastive languages. This discrepancy is best regarded as the integration of stress and segmental cues. In this case of fixed-stress languages in particular, where only one word level stress pattern is accepted, learners favor segmentation information, and only familiar stress pattern is taken fully into account. This is not the case in the sensitive period of language acquisition. Presumably, the straightforward enhancing influence of lexical cues continues operating on until linguistic representations are fully stabilized. Later, segmental information might act as a filter in order to ensure an extremely fast speech comprehension.

An interesting question is what might happen to the protolexicon, when all linguistic patterns are fully stabilized. Once contingency detection of extracted regularities is not necessary, the protolexical level might shrink, encumbering later second language acquisition.

4. FUTURE DIRECTIONS

As language usage is the most complex cognitive mechanism, a combination of methods might be extremely fruitful, yet the pieces do not always fit perfectly. Further studies should investigate the integration of different cues. Comparing the integration of cues and not only the processing of a single cue in different languages might reveal the nature of specific stages; those are common in human language acquisition. Results in phonetics and linguistics should contribute to build a psychologically valid general language developmental model.

Another interesting question is to what extents are early abilities depend on maturation and experience? Further study with pre-term infants might aim to compare these data to define biological constraints and the experience that is needed to attain the early stages of language acquisition. Testing of models of cognitive and language development for mature and immature Hungarian infants are also in further considerations.

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