# REPRESENTATION OF PHONOLOGICAL FEATURES IN THE BRAIN: EVIDENCE FROM MISMATCH NEGATIVITY

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## ABSTRACT

The representation of phonological features in the mental lexicon has been examined using event-related brain responses, such as mismatch negativeity (MMN; an automatic auditory change detection response in the brain) or the P350 component (a correlate of lexical activation). This presentation will summarize some MMN studies that demonstrate support for (i) models proposing abstract underspecified representations in the mental lexicon, i.e. not all phonological features are stored; and (ii) top-down influence of the language-specific phonological system on the fine structure of the phonological representations. Constraints in using the MMN for investigations concerning phonological representations will also be discussed.

**Keywords:** speech perception, electroencephalography, abstract representations, mismatch negativity

## 1. INTRODUCTION

Speech is very rich in details which have to be transformed into manageable information used among others to understand the lexical content. This transformation takes place along the auditory pathway and should result in a set of information compatible with long term memory information stored in the mental lexicon. One of the open questions in understanding speech perception is whether the mental representations of language should be viewed as a one-to-one mapping of the speech input, or does the nature of the processing system prevent the building of wholly isomorphic representations in the mental lexicon. In a previous study [1], we tested this question for segmental level phonological information in vowels by contrasting predictions of models assuming the storage of all available information from surface representations with those assuming that predictable and non-distinctive information can be withheld from the mental lexicon resulting in underspecified underlying representations, as spelt out in the Featurally Underspecified Lexicon (FUL) model [5].

We examined these predictions using a component of the event-related brain potentials, the so called mismatch negativity (MMN). It is an automatic change detection response in the brain, which has been shown to be an index of experience-dependent memory traces and being among others sensitive to language-specific phoneme representations [7, 9, 11, 12]. The MMN is elicited by infrequent, deviant stimuli presented after a random number of frequent, standard stimuli. The standard stimuli create a so called central sound representation which is more abstract than the sum of perceived acoustic elements and correspond to the information content of the sound perception, the sensory memory and the long term memory. That means that the central sound representation corresponds in part to the long term memory traces and may thus convey information about the phonological representation in the mental lexicon, which is in linguistic terms the underlying representation. The percept created by the infrequent, deviant stimulus is more low level and has vowel specific information available around 100ms after stimulus onset [3, 8, 10]. So the MMN will reflect among others the level of coherence and conflict between the more abstract information in the central sound representation corresponding to the underlying form and the surface representation extracted from the deviant.

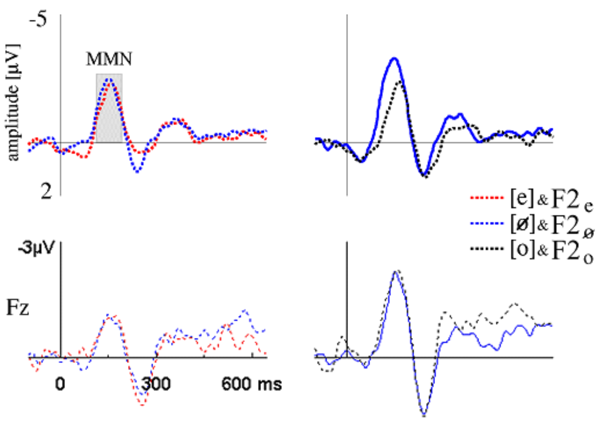
We presented naturally produced vowel pairs, differing almost equally in acoustics, especially the F2-frequency. Our standard and deviant stimuli were three German vowels [e], [ø] and [o]. Across blocks of measurement, each vowel could serve as a standard as well as a deviant. Models not assuming underspecification predict equal MMNs for vowel pairs regardless of the reversal. In contrast, enhanced and earlier MMNs were observed for those conditions where the standard was phonologically underspecified in the underlying representation (upper part of Fig. 1) which provided support for the FUL-model.

Supportive evidence for underspecified phonological representation comes not only from MMN measurements but also from behavioural studies [5] as well as experiments measuring alternative components of the event-related brain activity, such as the P350 using more complex stimuli than just vowels [2].

## 2. CONTROL FOR ACOUSTIC EFFECTS

Although the original experiment [1] controlled for the combinations of coronal and dorsal places of articulation as well as a variety of known confounds in MMN experiments, comparisons were based on different pairs of vowels which differed acoustically as well and covered different ranges in the acoustic space. As we used mid-vowels they mainly differed in the F2-frequency. To control for possible acoustic reasons for the asymmetric MMN effects in the original experiment, we used a set of F2-centered band-pass filtered noise stimuli in the same experimental setup as before.

**Figure 1:** Summary of the MMN results of the original study using German mid-vowels [1] (upper row; taken from [1]) and the control experiment using F2 centered band-pass filtered noise (lower row). Data represent the Fz electrode re-referenced against the linked mastoids. Left column shows the [e] - [ø] pairs (as well as the corresponding F2 centered band-pass filtered noise conditions) and the right column illustrates the [ø] - [o] pairs. Note the earlier onset and peak of the MMN as well as the larger amplitude in the condition where [ø] was the deviant with /o/ being the standard. The corresponding condition in the control experiment (blue line in the right column) reflects the acoustic change in the same way as in the condition with reversed assignment of the stimuli as standard and deviant.




The experiment was identical in terms of bocks of measurement, number of conditions and pairs of stimuli. The variability of F2-frequency resembled those of the original study.

As shown in Fig. 1, the earlier and more pronounced MMN in the condition where non-coexisting phonological features like [CORONAL] and [DORSAL] conflict is dependent on the presence of [DORSAL] in the underlying and [CORONAL] in the surface representation. In the reversed case the MMN is delayed and smaller which can be interpreted as a less conflicting situation. The most probable interpretation of this pattern of results is the underspecification of [CORONAL] in the mental lexicon. Moreover, if the linguistic underlying representations are impossible to hit upon due to stimulus characteristics, as it is the case for the noise conditions, a similar acoustic change does not evoke any asymmetric MMN effects.

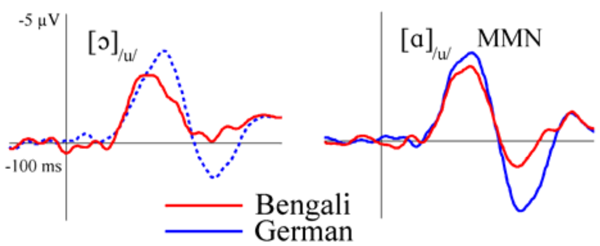
## 3. INFLUENCE OF THE LANGUAGE SPECIFIC PHONOLOGICAL SYSTEM

The formation of underlying representations is mainly driven by the speech input. However, phonological analyses claim that the fine structure of the underlying representations is tuned to support the usage of phonological rules to make certain linguistic processes more efficient [5, 6]. As the inventory of rules is different across languages the fine tuning of phonological representations should differ as well.

Most MMN studies investigating the influence of the language systems on speech perception compared existing with non-existing phonemes (e.g. [7]) or looked for differences between speech sounds which are allophonic in one and contrastive in the other language. Although these studies are very informative and control for purely acoustic differences between stimuli, there are still a number of possible confounds, such as (1) a tremendous difference in the experience of subjects with the rather non-prototypical stimuli compared to the normally used phonemes, (2) the unclear situation what is made by the listener out of the non-prototypical speech input? Is it interpreted as a non-linguistic auditory object, a non-legal phoneme or just a non-prototypical member of a different phonetic category? If the latter is true, which category will be chosen by the listener? All these questions make it difficult to interpret the MMN results from this kind of studies in the framework of phonological feature and their reality for the brain.

A step further would be to study MMN effects to pairs of phonemes which are productive and prototypical in two languages but have (at least due to phonological analyses) a differential specification of circumscribed phonological features in both languages. Such a test case was found for vowels differing along the tongue height dimension in a Bengali-German comparison. As known from phonological analyses (such as vowel raising in verb inflectional paradigms [6]), mid vowels in Bengali pattern with low vowels and must be specified for [LOW]. This makes the tongue height specification differential in both languages for the mid-vowels (unspecified in German), whereas the height specifications for high and low vowels can be the same. If the fine structure of mental representation is indeed fine tuned that way, we predict a conflict between tongue height information pre-activated by the [u]-standard whenever vowels specified for [LOW] are used as deviants.

**Figure 2:** Summary of the MMN results of the cross-linguistic study comparing the differences in the sensitivity to tongue height contrasts between vowels in Bengali (red color) and German subjects (blue color). Data represent the Fz electrode re-referenced against the linked mastoids. Left and right columns indicate different contrasts. Note the earlier peak of the MMN in the condition where the tongue height conflict was present for Bengali but not German subjects (left column). No difference between groups was seen when the tongue height conflict was present for Bengali as well as German subjects. There was a general amplitude difference between the groups which did not interact with the conditions.




As shown in Fig. 2, the language groups show similar MMN effects when [HIGH] and [LOW] information is conflicting in the same way (right column). However, when the mid-vowel is used as the deviant, Bengali subjects show an earlier MMN component compared to German subjects which can best be explained by the differential specification of tongue height in both groups.

The same methodological principles have been used for a second cross-linguistic study comparing Turkish and German subjects while processing front vowels. As presented in detail by S. Lipski (this volume), the differential specification for tongue height resulted in asymmetric MMN effects according to predictions based phonological analyses.

Theses initial results are promising and support the idea that the brain may operate on perceptual units and units of storage showing a similar systematic as well as combinatorial principles as the system of phonological features derived from linguistic analyses by a variety of authors and laboratories. As these hierarchical systems still differ in details, the MMN approach can be used to develop an optimized phonological feature system combining linguistic analyses with the neurobiological reality obtained during speech perception.

The results available so far studied mainly the articulators and were mainly conducted with vowels as stimulus material. It should be pointed out, that studies in other featural dimensions and experiments using consonantal as well as linguistically more complex stimulus material are desirable to derive more general conclusions about the phonological features and their reality for the brain.

## 4. CONSTRAINTS IN USING THE MMN

Across the MMN studies we have run in our group (some are in progress), a number of constraints with respect to the possibility of examining phonological representations can be reported.

(1) We had repeatedly problems in getting an MMN component evoked for initial stop consonants in CV syllables as well as CVC words. The stimuli were carefully matched and cross-spliced so that almost no additional acoustic difference could help to evoke the MMN in these experiments. Having the same phonetic contrast word medially reliable MMN components could be measured. This demonstrates that the impact of dynamic aspects in the stimulus and complexity alone does not account for the problems with the initial stops.

(2) Across studies, the predicted differences in the MMN can be seen for amplitude, latency or both. The usual interpretation is a difference in strength and/or speed of activation if certain phonetic contrasts occurred. Both interpretations have their eligibility and point into a similar direction in terms of the sensitivity to phonetic contrasts. However, a stronger consistency with respect to the sensitive dependent variable would be desirable. Overall, the number of MMN studies

in this narrow field is too small up to now to finally conclude about an insufficient consistency.

(3) Interference of other levels of linguistic processing: In an ongoing study, S. Cornell is comparing MMN effects for differences between German mid-vowels embedded in words with those in phonotactically legal disyllabic non-words. All pairs of stimuli used as standard and deviant are minimal pairs. Preliminary results show that the results of [1] can be replicated for the set of non-word stimuli, however, the pattern of MMN differences to phonetically identical differences in words is different. The most probable interpretation for us is the interference of lexical processing which may take place only (or at least to a different degree) in the conditions with minimal word pairs. The effects of lexical processing are probably superimposed with the phonological effects. The effect reported here is not to compare with the so called "wordness"-effect shown in numerous studies of Pulvermuller and colleagues (for review see [11]), which can be measured when words as deviants are contrasted with non-words as standards. The effects reported here refer to minimal phonological differences between two words or between two non-words. Nonetheless it is in line with the interpretation of the wordness-effect, that the lexical level matters.

(4) The MMN is a neural correlate of the pre-attentive detection of any change in the auditory characteristics between standard and deviant. Consequently, a permanent problem in interpreting MMN results is the difficulty to separate acoustic and phonological levels of processing. Feasible strategies to overcome this problem include using a wide range of acoustic variability, such as proposed in [9], or making cross-linguistic comparisons as done in the studies reported here, in [4, 7, 12] and many others.

In sum, there are constraints in using the MMN for the investigation of phonological representations in the mental lexicon. They have to be taken into account during the design of further studies.

## 5. CONCLUSIONS

Given the known limitations, which mainly restrict the possibility of conducting studies aiming to generalize the results across different classes of speech sounds, the MMN is a useful instrument to study the representation of phonological features in the brain. Aspects like the existence of abstract underspecified representations in the mental lexicon, or the differential specification of phonological features in different languages for the same surface forms have been shown for vowels. Studies in other featural dimensions and other types of stimuli are needed to derive general conclusions about the veracity of phonological features for the brain.

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