DERIVED CONTRASTS IN SCOTTISH ENGLISH: AN EEG STUDY

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ABSTRACT

We assessed the Gradient Phonemicity Hypothesis by testing whether a duration-based derived contrast in Scottish English can be seen phonemic just as a contrast based on vowel quality. We examined the electrophysiological correlates of the perception of such contrasts in native Scottish and French speakers. Results revealed differences between the two groups, mostly in the perception of duration-based contrasts and suggest that derived contrasts may be regarded as phonemic contrasts.

Keywords: Gradient Phonemicity Hypothesis, derived contrasts, EEG, MMN, P3

1. INTRODUCTION

Phonemicity and non phonemicity have often been assumed to be hard categories: if the occurrence of sound *x* instead of *y* is totally unpredictable, then *x* and *y* form a phonemic contrast, otherwise (i.e. if the distribution is predictable to some extent), *x* and *y* are allophones. However, empirical evidence suggesting that predictability is a matter of degrees has constituted a long-standing – though often overlooked – challenge to this binary view. Along with other authors [2, 4, 12], we contend that contrasts can be more or less phonemic, and we thus introduce the Gradient Phonemicity Hypothesis (GPH) and propose its assessment through perceptual experiments.

In many varieties of Scottish English, duration is restricted to an allophonic role in simplex words. However, under the influence of the past morpheme <-ed>, a few duration-based derived contrasts emerge, yielding minimal pairs such as *brood*/*brewed*, *need*/*kneed*, *side*/*sighed* [11]. Such contrasts are atypical because they are conditioned by morphological factors, and their functional load is low. Therefore, following GPH, the perceptual correlates of their difference are expected to display intermediate values between those recorded for full-fledged phonemes and those elicited by allophones.

In the present study, we investigated the potential differences in phonemicity between a clear phonemic contrast (relying on vowel quality) and a duration-based derived contrast through event-related potentials (ERPs) in an ‘oddball’ paradigm.

2. ELECTROPHYSIOLOGICAL CORRELATES OF SPEECH PERCEPTION

Over the last 20 years, an abundant literature has been produced on ERPs in speech perception, mostly using the ‘oddball’ paradigm (a ‘deviant’ stimulus is occasionally delivered within a sequence of ‘standard’ sounds). The deviant induces the automatic detection of unexpected information, followed by a switching of the attentional focus toward the new event. This chain of processes produces a cascade of cortical electrical signals, including the frontal mismatch negativity (MMN) peaking around 150-250 ms after deviance onset [5], and the fronto-centrally distributed subcomponent of the P300 (i.e., P3a) peaking between 200 and 650 ms after deviance onset [9].

The MMN is an automatic brain response induced by the detection of acoustic changes. However, it also reflects higher order perceptual processes, as its amplitude increases when the deviance relies on the activation of stored phonological knowledge [5, 10]. It is consequently useful in the investigation of phonological processes. The P3a is assumed to index potentially non-conscious attention switches from the focus of voluntary attention to deviant sounds [9]. The detection of regularity violations by low-level sensory processes triggers this brain response, which can be further modulated if the *significant* event activates pre-existing long-term memory traces. In our study, deviant events should therefore elicit an MMN and a P3a in both groups due to sensory oddity. However, since a change in vowel duration has potential phonological relevance only for Scottish listeners, higher amplitude is expected in Scottish but not in French participants.

3. METHODS

3.1. Participants and stimuli

Seven native Scottish and 19 native French speakers aged 18-26 years participated in the study. Scottish participants had been in France for less than 3 months at the time of testing. All participants were right-handed (mean score Edinburgh inventory = 92, SD 13, [8]) and had normal peripheral auditory thresholds (< 20 dB-SPL in 125-8000 Hz). They gave their written informed consent and were paid for their participation.

The stimuli were taken from previous recordings of 15 Glaswegian speakers. The typical durations for the vowels in *brood* and *brewed* were approx. 70 and 175 ms respectively. One occurrence of the word *brewed* spoken by a male speaker was selected, vowel boundaries were identified as the limits of the steady-state portion of the formant pattern, and the vowel was time-compressed and resynthesized with the Praat program, yielding two words whose vocalic duration was 70 (*brood*) and 175 ms (*brewed*). One occurrence of *bit* and *bet* spoken by the same speaker was also selected. The four stimuli were peak-normalized, and their amplitude envelope was smoothed at stimulus onset and offset in order to avoid popping noises.

3.2. Procedure

Participants sat in an electrically and acoustically shielded chamber. They were instructed to watch a silent movie and to ignore the auditory stimuli that were delivered binaurally via headphones at a comfortable listening level. The stimuli were presented in an oddball sequence with 77% of standards and 23% of deviants with a stimulus onset asynchrony of 500 ms. Sequences of 3 to 6 standards separated consecutive deviants. The experiment was divided into four blocks of 642 stimuli each (522 standards and 120 deviants). In Block 1, *brewed* served as standard and *brood* as deviant while the reverse was true in Block 2. In Block 3, *bit* was used as standard and *bet* as deviant, and vice-versa in Block 4. The order of blocks was counterbalanced across participants.

3.3. EEG acquisition and analysis

EEG was acquired and analyzed according to standard procedure [1]. MMN waveforms were computed by subtracting standard-induced from deviant-induced ERP waveforms for each block and participant. Grand-averages were then calculated across all participants for each block. Based on visual inspection of the grand-averages at Fz, the MMN was defined as the maximal negativity peaking around 150-250 ms after deviance onset. MMN amplitude was quantified for each participant and block within a time-window ranging between the zero-crossings on either side of the peak. MMN latency was determined as the point of maximal amplitude within the same time-window. P3a latency and amplitude were calculated similarly in the 250-400 ms range after deviance onset.

For both MMN and P3a, the largest responses were found at electrode Fz; statistical analysis was thus restricted to this electrode. For the sake of clarity, blocks were averaged according to the type of contrast, namely a duration-based contrast (*brewed*/*brood*; Blocks 1 and 2) and a contrast relying on vowel quality (*bet*/*bit*; Blocks 3 and 4).

Amplitudes and latencies of the MMN and P3a were subjected to two-way repeated-measures ANOVAs including Native Language (Scottish English vs. French) as between-subject factor and Contrast (duration vs. vowel quality) as within-subject factor. When interactions were significant, multiple comparisons were performed to evaluate differences between conditions[2].

4. RESULTS

4.1. MMN

Figure 1 displays the grand-averaged difference waves for each group and type of contrast. The difference waves revealed large negative deflections, identified as MMNs, peaking on average 187 ms after deviance onset, distributed over fronto-central sites and showing polarity inversion at mastoids. The ANOVA on MMN amplitude showed no significant effects of Native Language or Contrast and no significant interaction between the two factors. In the following, only significant results will be reported. The ANOVA on MMN latency revealed a significant main effect of Native Language ($F(1, 21) = 5.64$, $p = .027$), with shorter latency in Scottish (179 ms, SD 17) than in French participants (196 ms, SD 19).

4.2. P3a

As illustrated in Figure 1, a large positive wave, identified as P3a, was elicited at Fz for each type of contrast in each group. P3a peaked on average 298 ms after deviance onset and was maximal over fronto-central electrodes. The main effect of Native Language (F(1, 21) = 7.87, p = .01) showed that P3a latency was significantly shorter in Scottish (291 ms, SD 28) than in French participants (316 ms, SD 28). A main effect of Contrast was also observed (F(1, 21) = 5.86, p = .02), however we chose not to interpret this effect as latency measures were time-locked to deviance onset, which was difficult to estimate exactly for the two types of contrasts.

Figure 1: Grand-averaged difference waveforms at Fz in (a) Scottish and (b) French participants for the two types of contrast (duration: black, vowel quality: grey).

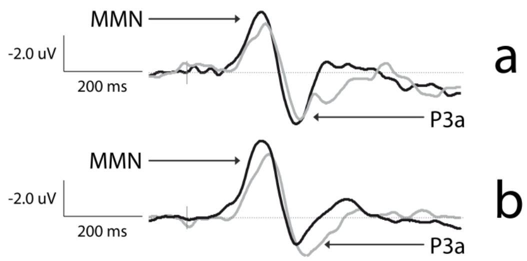
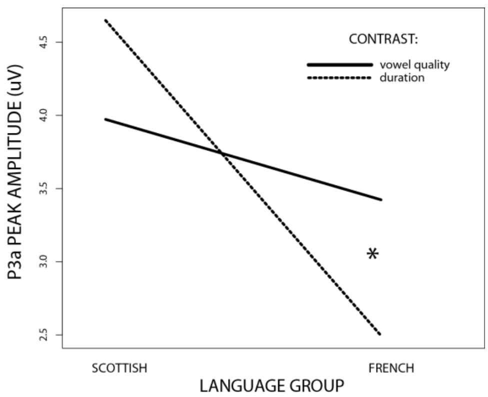


Figure 2: Language × Contrast interaction on P3a amplitude. P3a amplitude is represented as a function of Language (Scottish English vs. French) and Contrast (duration (solid line) vs. vowel quality (dotted line)). (*) indicates a significant difference between conditions. Note that the difference between Scottish and French speakers for the duration-based contrast was significant.



The main effect of Native Language on P3a amplitude was significant (F(1, 21) = 6.20, p = .02), the positivity being larger in Scottish (4.31 µV, SD 0.8) than in French speakers (2.96 µV, SD 1.54). A Native Language × Contrast interaction also emerged (F(1, 21) = 5.47, p = .029; Figure 2): P3a amplitude was significantly smaller for the duration-based contrast (2.49 µV, SD 1.57) than for the contrast based on vowel quality (3.42 µV, SD 1.41) in French (p = .02) but not in Scottish participants (duration = 4.65 µV, SD 0.64; vowel quality = 3.97 µV, SD 0.85; p > .05). In addition, P3a amplitude for the duration-based contrast was larger in Scottish than in French participants (p = .004) whereas amplitude for the quality-based contrast did not differ between groups (p > .05).

5. DISCUSSION

The present study tested the GPH by investigating whether a duration-based derived contrast in Scottish English can be considered as phonemic as a contrast based on vowel quality. In an oddball paradigm, we examined the MMN and P3a elicited by the perception of such contrasts in native Scottish and French speakers. Our results revealed that MMN latency was shorter in Scottish than in French participants, irrespective of the type of contrast. The MMN is thought to reflect memory traces for phonemes of the native language [5, 10] and in addition, MMN peak latency has been shown to decrease as easiness of deviance detection increases [6]. In our study, since Scottish English minimal pairs were used, deviance may have been detected more easily and more rapidly by native Scottish speakers as they have specific memory traces for these stimuli compared to French speakers who were not familiar with the stimuli. Regarding MMN amplitude, previous studies have shown enhanced MMNs for duration-based contrasts in native speakers of Finnish, where the long/short opposition is linguistically relevant compared to non-native speakers [7]. This MMN enhancement has been proposed to indicate high accuracy in the processing of familiar, early learned, language-specific features. Our results did not show such a pattern, but further analysis with a larger number of participants is required.

Regarding P3a, our study showed shorter latency and larger amplitude in Scottish participants. P3a is thought to index involuntary shifting of attention [9] and P3a latency is known to reduce when the inherent salience of the stimulus increases [1]. Here, Scottish English stimuli may have triggered faster and deeper processes in Scottish than in French speakers, hence the earlier and increased P3a.

Interestingly, P3a amplitude was differentially affected by the type of contrast depending on native language. While P3a amplitude was comparable for the two types of contrasts in Scottish speakers, it was larger for the quality-based contrast in French speakers. P3a amplitude was further enhanced for the duration-based contrast in Scottish compared to French participants; no difference was observed between groups for the contrast based on vowel quality. Our results can be interpreted in the frame of the "significance hypothesis" [3] suggesting that P3a indexes processes that are activated by significant events such as stimuli carrying new information or stimuli that are stored in long-term memory. Vowel quality is relevant for phoneme discrimination and categorization in both Scottish English and French; speech-specific information may thus be stored in the long-term memory of Scottish and French speakers, hence the similar P3a amplitude for the contrast based on vowel quality in the two groups. In contrast, phonological length is relevant for Scottish English derived contrasts only, suggesting that information about vowel duration is stored in long-term memory only in native Scottish speakers. This may account for the larger P3a amplitude for the duration-based contrast in Scottish than in French participants. The small sample size allows drawing only tentative conclusions. Comparable MMN and P3a amplitudes for the contrasts based on duration and on vowel quality in Scottish speakers may provide first evidence that these two features are equally relevant for speech processing in Scottish English. In this view, derived contrasts may therefore be regarded as phonemic contrasts. Further analysis with a larger number of native Scottish speakers will allow precisely investigating this issue as well as potential ERPs differences between short and long deviants which may be subserved by partly distinct neural generators [13].

6. ACKNOWLEDGEMENTS

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[1] EEG was continuously recorded from 32 scalp electrodes (international 10-20 system) using the Biosemi EEG system with a sampling rate of 512 Hz, filtered online between 0.1 and 100 Hz. Eye movements were monitored by recording horizontal and vertical electro-oculograms (EOG) with a bipolar montage of two electrode pairs. Data were analyzed with BESA software. Raw EEG recordings were segmented in 800 ms epochs starting 100 ms before deviance onset to 700 ms after onset. Epochs in which the EEG/EOG signal exceeded ±150 µV were discarded from analysis. ERPs were separately averaged for deviants and standards for each participant, block and electrode. Averages were baseline-corrected using the 100 ms period preceding deviance onset and re-referenced to linked mastoids.

[2] One French participant was excluded from data analysis due to very noisy signal. Two other participants, one Scottish and one French, were identified as outliers when plotting ERPs amplitudes and were thus excluded from statistical analysis. Results are reported for 6 Scottish and 17 French participants.