Interactions of speech and speaker processing in early evoked components

Paula Rinke[1,3], Nadine Lavan[2] and Mathias Scharinger[1,3]

[1]Research Group »Phonetics«, Institute of German Linguistics, Philipps-Universität Marburg, Germany
[2]School of Biological and Behavioural Sciences, Queen Mary University of London, United Kingdom
[3]Center for Mind, Brain & Behaviour »CMBB«, Universities of Gießen & Marburg, Germany

paula.rinke@uni-marburg.de, n.lavan@qmul.ac.uk, mathias.scharinger@staff.uni-marburg.de

ABSTRACT

The voice of a speaker and the linguistic content of a message are linked to one another during speech production and perception, allowing to dissociate between what is being said by whom. The time course of the interaction between speech and speaker information is, however, less well investigated. Using time-sensitive neuro-physiological measurements (EEG) with Event-Related Potentials (ERP), the present study aims to address this question.

16 participants attended a 1-back-task while being presented with recordings of the German vowels [a], [i], [u] from 32 German-speaking men and women, falling into a younger or older age group, (96 stimuli in total), while brain activity was recorded from 32 active electrodes.

ERP-analyses showed that vowel category elicited strong effects in early evoked components, especially in the N1 time window (100ms after stimulus onset), with speaker age and gender exerting significant modulations. This suggests an early interaction of speech and speaker processing.

Keywords: speaker processing, voice processing, EEG, ERP

1. INTRODUCTION AND BACKGROUND

Speech and speaker information interact with one another. Even though the voice is often simply considered as the “carrier of speech” [1] its influence on speech processing is inevitable. The voice carries much social information (so-called “indexical information”) about the speaker, e.g., gender, age, emotional state and social or regional background. However, the perception of speaker-specific features is often considered as higher-order processing, that is separate from low-level speech processing.

Previous studies, however, show that speaker-specific cues can affect low-level speech processing such as speech sound categorization [2]. For example, Strand [3] provides evidence on how the gender attributed to a speaker influences the categorization of English [s] and [ʃ]. Moreover, Drager [4] shows that the perception of New Zealand English vowels is influenced by higher-order knowledge such as the perceived age

These results provide evidence that the perceived social characteristics of a speaker affect speech processing. Thus, speech and speaker perception appear as interdependent rather than two completely separated processes.

Aside from these behavioral data, evidence on the neural basis of this interaction is comparably small. Speech information, such as vowel category, are known to be retrieved during very early processing stages. As previous neurophysiological studies (electroencephalography (EEG) and Event-Related Potentials (ERP) as well as magnetoencephalography (MEG)) have shown, spectral information inherent in different vowel categories (e.g., formant frequencies) affect early brain responses such as the N1 [5, 6], an auditory evoked component with a negative peak between 80 and 150 ms after stimulus onset [5]. In particular, the first formant (resonance frequency of the vocal tract), F1, was found to modulate amplitude and latency of the N1 [7].

While the time course of speech processing is well investigated, research on the time course of social characteristics of the voice is relatively rare. The few existing EEG studies on voice processing found two neural components reflecting the processing of speaker-specific features: the Mismatch Negativity (MMN) and the P3a [8-10]. The MMN is an early and automatic brain response with a negative deflection that is sensitive to change detection, whereas the P3a is a later component with a positive peak approximately 300 ms after stimulus onset and is considered to indicate involuntary attention switches caused by a novel stimulus [11].

In the current study, we brought together the investigation of speech and speaker perception using time-sensitive EEG and ERP measurements. By manipulating speech-related information (vowel categories) and speaker information (age and gender), we attempted to characterize the time course of speech and speaker-related information. Based on the findings of previous ERP studies, we would expect vowel processing to be reflected in early brain components, such as the N1, with speaker's age and gender possibly modulating the response pattern.

2. METHOD

2.1 Stimuli

96 recordings of the German vowels [a], [i], and [u] from 32 speakers (16 male; 16 female) were selected from the "Saarbrücker Stimmdatenbank" (http://www.stimmdatenbank.coli.uni-saarland.de/). Each group was equally divided into two age groups representing either younger (20-34 years) or older adults (55-74 years; details are listed in Tab. 1). Consequently, each category (e.g., male-old or female-young) consisted of eight different speakers with each one producing the three vowels (in total 24 sounds per vowel category).

Category	Mean	Range	SD
Female young	24.13	20-34	4.86
Male young	24.25	21-28	4.35
Female old	62.63	55-74	5.66
Male old	63.00	56-72	4.80

Table 1: Overview of different age groups in stimulus material

The German vowels [a], [i], and [u] are distinct in their tongue position, openness and backness with each vowel falling into easily separable locations in the German vowel space. They thus show distinctive spectral properties such as systematic differences in vowel formants, especially in F1 and F2.

Sounds were edited in Praat [12] and adjusted to an intensity level of 75 dB. Furthermore, all sounds were trimmed to a duration of 400ms in Audacity.

2.2 Experimental Design

Participants were presented with all 96 vowel stimuli, which were repeated 40 times across six blocks. During stimulus presentation, participants were asked to complete a 1-back-task for speaker identity. To test for continuous attention, we included vigilance trials for which additional vowel stimuli were selected (24 altogether). Vigilance stimuli were repeated 16 times and evenly distributed over the six blocks. In total, participants were presented with 4224 vowel stimuli.

Participants were placed in a shielded room approximately 1 m in front of a screen on which the instructions and the task were presented. The 1-back-task was completed via press of keyboard keys to indicate whether the presented and the preceding stimuli were the same (same vowel and speaker). Sounds were delivered via loudspeakers placed on the right and left side of the screen. To prevent extensive eye movement, participants were asked to focus on a white fixation cross on the screen during stimulus presentation and try to blink only right after responding to the task.

The experiment lasted approximately 70 minutes.

2.3 Participants

16 participants took part in the study (8 males, 8 females; mean age 26.13 years, range 19–36; standard deviation [SD] 5.12 years). All participants were native German speakers and had no reported history of hearing or neurological disabilities. Written informed consent was collected from all participants in order to participate in the study. The study was approved by the local ethics committee.

2.4 EEG recording

Continuous EEG was obtained from 32 active electrodes placed on a standardized 10–20 system cap. The reference electrode was placed on the nose while the ground electrode was placed on the forehead between Fp1 and Fp2 positions. Impedance was kept below 10 kΩ while EEG signals were sampled at 1000 Hz and online pre-filtered between 0.016 and 250 Hz using the Brain Vision Recorder software (Brain Products, Gilching, Germany), running on a Windows 10 personal computer.

2.5 EEG preprocessing

Continuous EEG was preprocessed using fieldtrip [13]. First, erroneous EEG channels (maximally 2 per participant) were identified and interpolated. Next, eye movements and blinks were identified through independent component analysis (ICA). Again, maximally 2 eye components per participant were identified and removed. Subsequently, the continuous EEG was split in epochs aligned to vowel onsets, starting 100 ms before and ending 700 ms after vowel onset. Epochs were bandpass-filtered (between 0.01 and 30 Hz) and the mean voltage of the 100-ms baseline was subtracted. Epochs were then averaged across repetitions within each participant and thereby corresponded to ERPs in a 3 (vowels [a], [i], [u]) x 2 (speaker age: old, young) x 2 (speaker sex: male, female) setup.

2.6 Statistical analyses

Visual inspection of the preprocessed data revealed two substantial time windows between 90 and 150 ms and 350 and 500 ms that correspond to the time windows of the N1 and the N4/P3. The statistical analysis was carried out for these two time windows and was based on the mean values of each item (i.e., vowel per speaker and age group). Vigilance trials were excluded; thus, the analysis was done for test items only. Mean amplitude in the time windows of interest and the latency of the highest N1 peak were calculated.

Linear mixed models (LMMs) were based on the Fz electrode and calculated for N1 amplitude and latency and for P3/N4 amplitude with vowel category, speaker's gender and age as fixed effects and subject as random intercept. Data were analyzed in Jamovi [14].

2.7 Results

2.7.1 Amplitude

The LMM on N1 amplitude (Tab. 2) showed a main effect for gender (p<.001) and vowel category (p<.001), but not for age (p>0.2). N1 amplitudes were more negative for male than for female voices, and more negative for [i] than for the other two vowels. The interaction of gender and vowel category (p=.018) was driven by larger between-vowel differences for female than for male voices.

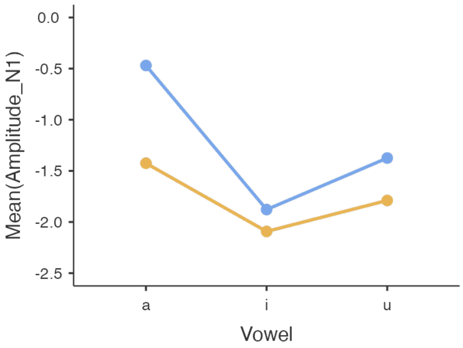


Figure 1: Amplitude differences of the N1 depending on vowel category and speaker gender.

The interaction of gender and age (p=.014) showed that the gender effect was more pronounced for the young compared to the old speakers. No other interactions were significant (all p-values>0.2).

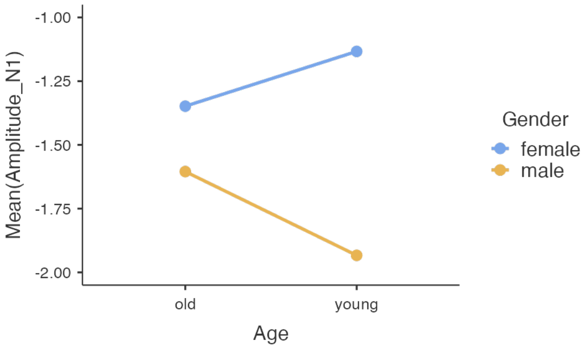
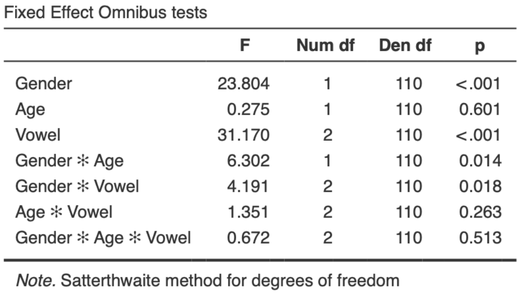


Figure 2: Amplitude differences of the N1 depending on speaker age and speaker gender.



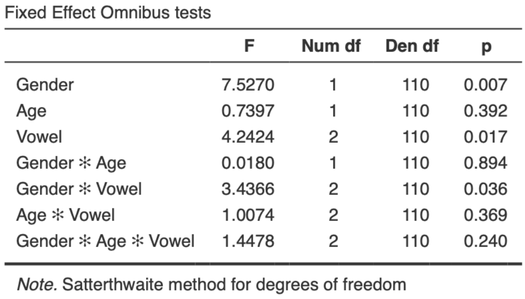
Fixed Effect Omnibus tests

	F	Num df	Den df	p
Gender	23.804	1	110	<.001
Age	0.275	1	110	0.601
Vowel	31.170	2	110	<.001
Gender ✻ Age	6.302	1	110	0.014
Gender ✻ Vowel	4.191	2	110	0.018
Age ✻ Vowel	1.351	2	110	0.263
Gender ✻ Age ✻ Vowel	0.672	2	110	0.513

Note. Satterthwaite method for degrees of freedom

Table 2: Linear Mixed Model for N1 amplitude.

The P3/N4 amplitudes (Tab. 3) were similar to the patterns observed patterns for the N1: main effects were found for vowel category (p=.017) and gender (p=.007), but not for age (p>0.2). The effect of gender depended on vowel category (p=.036). No other interactions were significant (all p-values>0.2).



Fixed Effect Omnibus tests

	F	Num df	Den df	p
Gender	7.5270	1	110	0.007
Age	0.7397	1	110	0.392
Vowel	4.2424	2	110	0.017
Gender ✻ Age	0.0180	1	110	0.894
Gender ✻ Vowel	3.4366	2	110	0.036
Age ✻ Vowel	1.0074	2	110	0.369
Gender ✻ Age ✻ Vowel	1.4478	2	110	0.240

Note. Satterthwaite method for degrees of freedom

Table 3: Linear Mixed Model for N4 amplitude.

2.7.2 Latency

For N1 latency (Tab. 4), there were significant main effects of gender (p=.021) and vowel category (p<.001), but no age effect (p>0.2). Notably, the vowel [a] elicited earlier N1 responses than [i] or [u]. Vowels pronounced by female speakers also elicited earlier N1 responses than vowels pronounced by male speakers. No interactions were significant (all p-values>0.1).

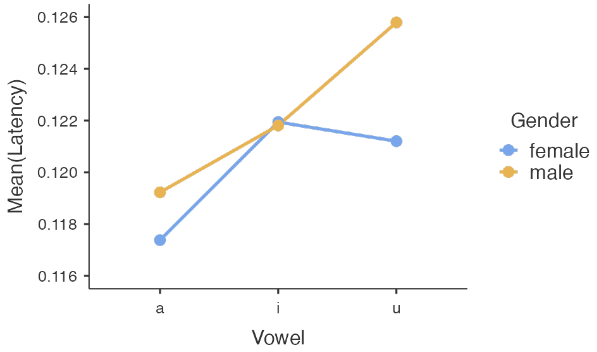


Figure 3: Latency differences of the N1 by vowel category, plotted separately for female and male voices.

Fixed Effect Omnibus tests

	F	Num df	Den df	p
Gender	5.485	1	110	0.021
Age	0.111	1	110	0.740
Vowel	11.699	2	110	<.001
Gender ✻ Age	2.084	1	110	0.152
Gender ✻ Vowel	2.327	2	110	0.102
Age ✻ Vowel	0.575	2	110	0.564
Gender ✻ Age ✻ Vowel	0.122	2	110	0.885

Note. Satterthwaite method for degrees of freedom

Table 4: Linear Mixed Model for N1 latency.

3. DISCUSSION

As predicted, the results show a significant influence of vowel category and gender on the amplitude and latency of the early N1 brain potential.

Despite large acoustic inter-speaker variability, the vowel category appears to have a strong influence on the shape and latency of the N1. As the results show, even when articulated by different speakers the different vowels [a], [i] and [u] modulate the N1. Differences between the vowel categories are most prominent in N1 latency and amplitude: [a] shows the smallest N1 latency, i.e., elicits the N1 significantly faster than the other vowels. When looking at later brain responses, the vowel category shows an influence on N4 amplitudes, albeit a weaker one in comparison to the N1 amplitude.

Regarding N1 properties, these results are in line with the findings of previous studies on German vowels affecting early brain potentials [7]. They provide data on how the N1 is sensitive to discriminative spectral features by demonstrating that N1 properties are affected by different formant frequencies (i.e., F1 and F2).

As the N1 analysis reveals, the different vowel categories show different effects on N1 properties. While [i] elicited the largest amplitude, [a] elicited the shortest latencies. It could be speculated that different F1 properties have the strongest effect on the N1. However, note that German /a/ is not realized as a front vowel but rather retracted as central vowel [a̠]. As a consequence, [a] and [i] also show differences in F1 and F2 properties. Thus, the current results cannot be exclusively attributed to one particular formant frequency.

The speaker's gender was found to be relevant for both observed time windows and in particular for the amplitude and latency of the N1. Vowels produced by a male voice elicited a stronger but later N1 than vowels produced by female voices.

Since a person's gender is often considered as "most primary judgments that human perceivers make of each other" [3] it is not surprising that its influence stretches across multiple time windows.

From an acoustic point of view, gender is strongly (but not solely) associated with the fundamental frequency (f0). F0 plays an important role in vowel perception besides fundamental frequencies. This is also displayed in the present study by the strong interaction of gender and vowel category for N1 amplitude. Thus, it is plausible that the speaker's gender is retrieved during early speech processing reflected by the N1 as well as during speaker processing displayed by the N4.

When focusing on the perceived age of the speaker, no effects on the amplitude and latency of the early brain response N1 as well as the later N4 can be observed. Thus, as expected from previous voice studies, the speaker's age does not show any influence on early brain components which are mainly modulated by vowel categories and gender. However, significant interactions with the speaker's gender were found for N1 amplitude, with a stronger effect of gender for younger than older speakers, which again highlights the importance of gender for early processing stages.

Regarding the interpretation of the gender effect on N1 properties, it is important to point out a possible limitation of these analyses. The N1 is an early component that is sensitive to acoustic changes. Since male and female voices differ substantially in F0 and other acoustic characteristics [15], we note that the differences found in amplitude and latency could at least partially reflect these low-level acoustic differences.

However, there were additional effects of gender in the later N4 time window. This time window is associated with higher-level processing (as opposed to early acoustic processing), which we cautiously interpret as a result of the processing of the speaker characteristic "gender".

Overall, the current data confirm that speaker characteristics can in some cases influence early and later brain responses to speech-related information. The data thus show that speaker and speech-related information in fact routinely interact and inform each other during the perception of human vocal stimuli.

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