Preattentive phonotactic processing as indexed by the mismatch negativity (MMN)

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Supplementary material

Experiment 1

Methods

Participants

To control for potential influencing factors, information about dialectal background and dialectal usage, second-language experience and phonetic education of the participants was assessed.
Dialectal background and dialectal usage: 12 participants grew up in eastern central Germany (Thuringia, Saxony), ten of them reported slight dialectal usage. Two participants had dialectal background of southwestern Germany (Swabia), one participant came form southeastern Germany (Bavaria), and one participant grew up in northeastern Germany (Brandenburg), none of these reported any dialectal usage.
Second-language experience of the 16 participants ranged from 1 to 5 languages (mean 2.81, SD 1), including English (16), French (9), Russian (7), Latin (7), Swedish (3), Italian (2), Spanish (2), and Hindi (1). Since Swiss German and Dutch do not require the application of DFA, [εx] is a well-formed syllable in these languages. For this, participants were asked for potential experience with these languages. 12 participants reported no experience with Swiss German or Dutch, 2 participants have Dutch or Swiss German speaking friends, 2 participants had been in German-speaking Switzerland or the Netherlands on holiday.
Linguistic education: 13 participants had no linguistic education at all. 2 participants had taken courses of English Linguistics over 6 month, and 1 participant had studied German Linguistics and can be considered to be phonetically trained in general, but did not know about DFA in particular.

Stimuli

Since we used natural unspliced speech material, we had to deal with coarticulatory effects. Especially the part of the syllables containing the fricative might be influenced by the articulatory settings of the preceding vowel. To control for confounding acoustical differences possibly caused by coarticulation, we examined the spectral qualities of the fricatives used in the stimulus material by means of the routines provided in the PRAAT software. We did not examine the vowel transitions, because the influence of vowel transition on the identification of the fricative has been shown to play a subordinate role in German, whereas the spectrum of the fricative seems to be the main cue for its identification (Wagner et al. 2006).

The spectral qualities of the fricatives were compared by measuring the spectral moments: centre of gravity (COG), skewness, and kurtosis (Gordon et al. 2002). For this purpose, we calculated FFT spectra from the 100 msec in the middle of each fricative token. Mean values are as follows: [x] after [ɛ] COG 2902 Hz (SD 486), skewness 0.728 (SD 0.274), kurtosis -0.495 (SD 0.500); [x] after [ɔ] COG 2866 Hz (SD 477), skewness 0.811 (SD 0.260), kurtosis -0.544 (SD 0.529); [ʃ] after [ɛ] COG 4927 Hz (SD 271), skewness -0.027 (SD 0.207), kurtosis 0.192 (SD 0.324); [ʃ] after [ɔ] COG 4107 Hz (SD 315), skewness 0.287 (SD 0.201), kurtosis 1.053 (SD 0.869). Two-tailed t-tests were calculated to compare the spectral qualities within each fricative category in regard to possible influences of the preceding vowel. The velar fricatives after front and back vowel show no significant difference regarding COG (t_{18}=0.165; p=.871), skewness (t_{18}=-0.696; p=.495), and kurtosis (t_{18}=0.215; p=.833), whereas the spectral qualities of the sibilants differ in respect of the preceding vowel (COG: t_{18}=6.242; p=.000; skewness: t_{18}=-3.446, p=.003; kurtosis t_{18}=-2.934; p=.013). This analysis shows that the main spectral properties of the velar fricatives in *[ɛx] and [ɔx] were not strongly affected by the preceding vowel. Hence, a confoundation of the preceding vowel and the phonotactic violation in the stimulus syllable *[ɛx] is considered as unlikely.

Results

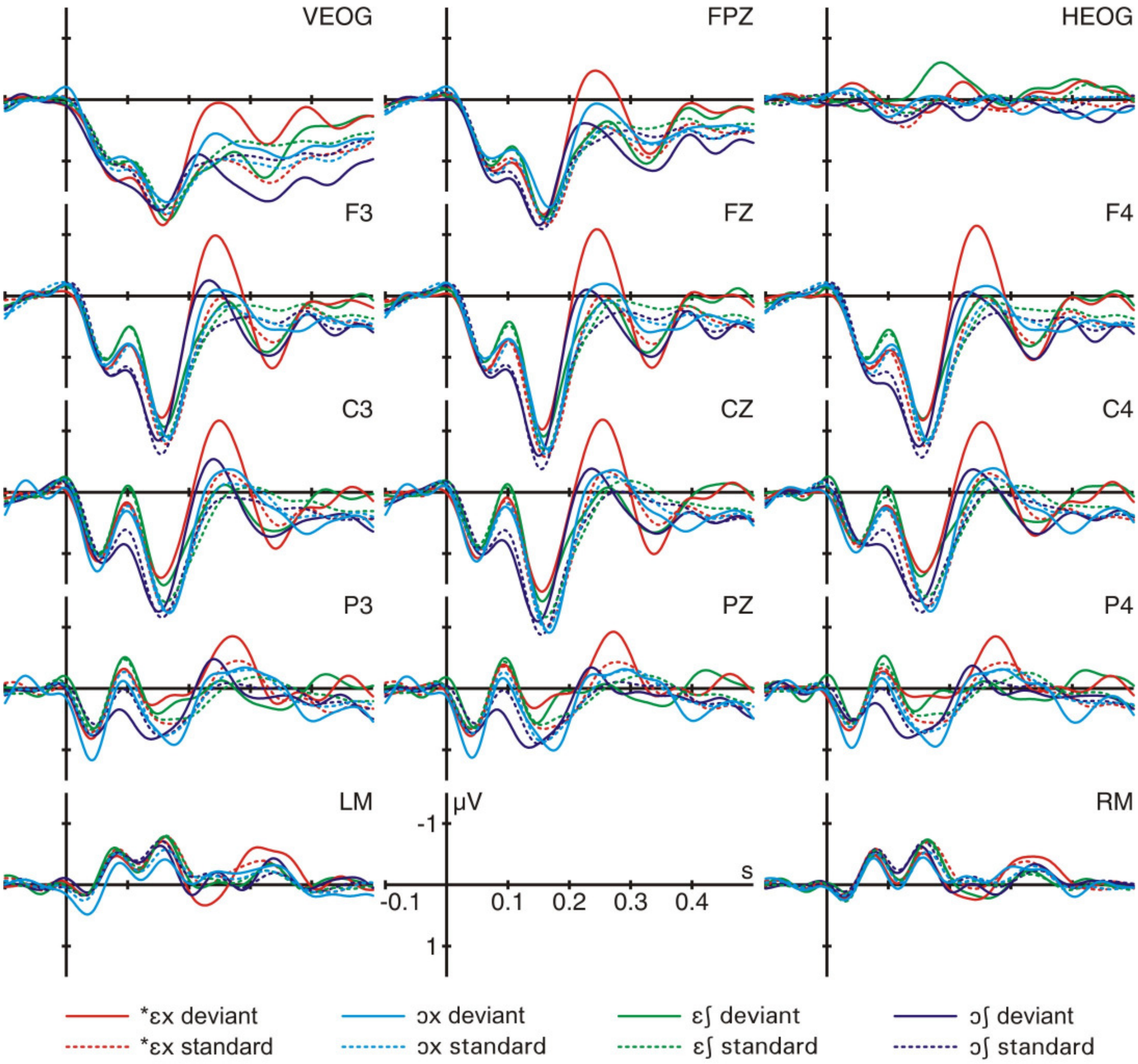


Figure 1. Grand-averaged ERP responses elicited by all four stimulus types presented as deviants (solid lines) and standards (dashed lines) in Experiment 1. Nose-referenced data are shown for a subset of measured electrode sites. Scales are in milliseconds and microvolt.

Table 1. Significant results of a 5-way repeated-measures ANOVA for the Factors Stimulus (Deviant, Standard), Vowel ([ɛ], [ɔ]), Fricative ([x], [ʃ]), Position (F-, C-, P-lines), and Laterality (7-, 3-, z-, 4-, 8-lines) calculated for the re-referenced mean ERP amplitudes of the standards and deviants (analysis window: 192 to 232 msec).

Source	F	Degrees of Freedom	G-G-Epsilon	p
Stimulus (Deviant, Standard)	59.11	1, 15	-	.000
Position (F, C, P)	10.88	2, 30	0.56	.000
Vowel × Fricative	32.85	1, 15	-	.000
Stimulus × Vowel × Fricative	9.65	1, 15	-	.007
Stimulus × Position	27.68	2, 30	0.58	.000
Fricative × Position	4.42	2, 30	0.56	.048
Vowel × Fricative × Position	15.73	2, 30	0.55	.001
Stimulus × Vowel × Fricative × Position	11.32	2, 30	0.56	.003
Stimulus × Laterality	8.66	4, 60	0.52	.001
Vowel × Laterality	4.79	4, 60	0.50	.016
Stimulus × Vowel × Fricative × Laterality	4.85	4, 60	0.55	.012
Stimulus × Position × Laterality	2.97	8, 120	0.38	.041
Vowel × Position × Laterality	3.84	8, 120	0.46	.009
Fricative × Position × Laterality	2.67	8, 120	0.51	.039

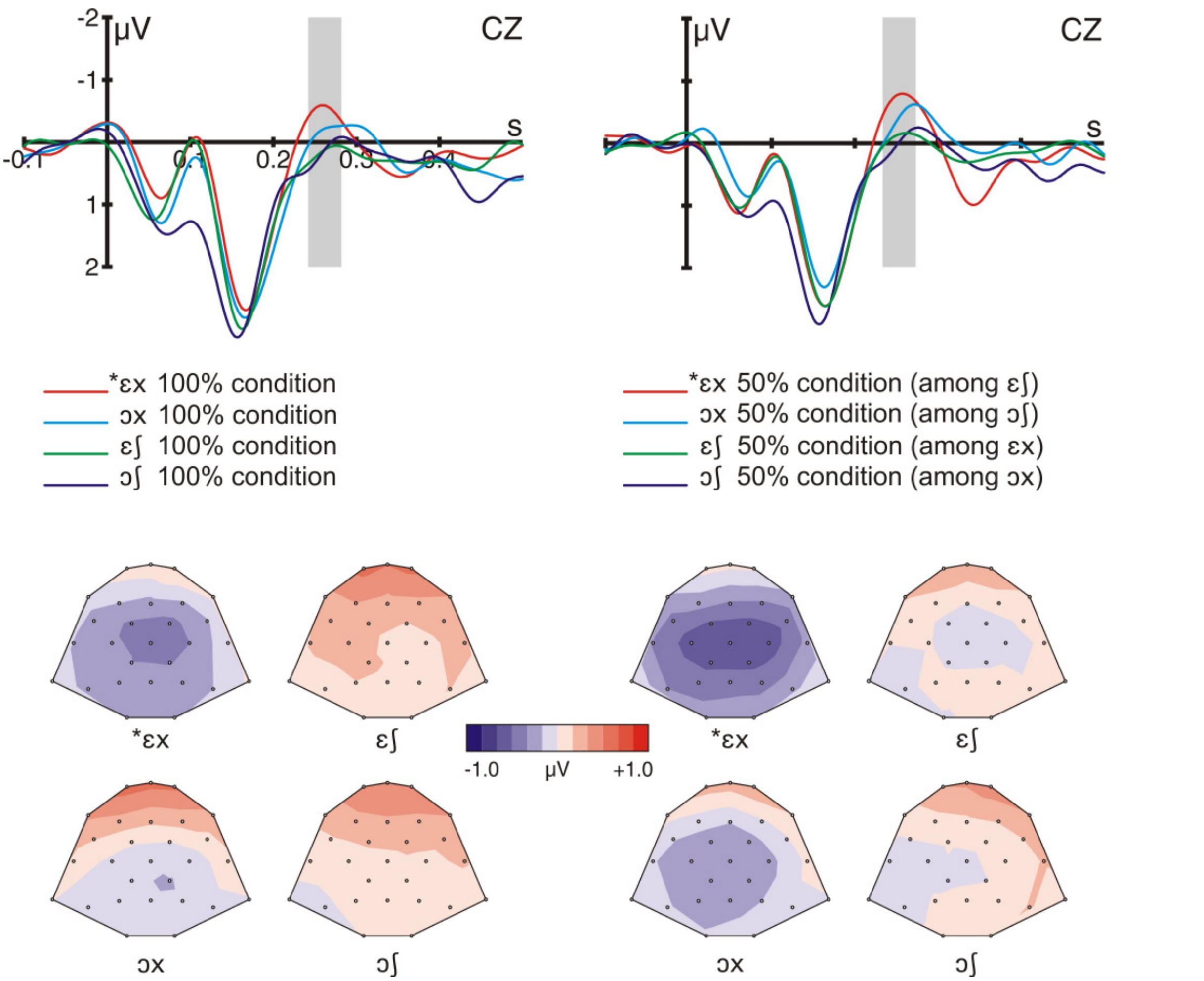
Table 2. Significant results of a 4-way repeated-measures ANOVA for the Factors Vowel ([ɛ], [ɔ]), Fricative ([x], [ʃ]), Position (F-, C-, P-lines), and Laterality (7-, 3-, z-, 4-, 8-lines) calculated for the re-referenced mean ERP amplitudes of the 100% control condition (analysis window: 242 to 282 msec).

Source	F	Degrees of Freedom	G-G-Epsilon	p
Fricative ([x], [ʃ])	9.09	1, 15	-	.009
Position (F, C, P)	5.35	2, 30	0.56	.030
Position × Laterality	3.07	8, 120	0.50	.023

Table 3. Significant results of a 4-way repeated-measures ANOVA for the Factors Vowel ([ɛ], [ɔ]), Fricative ([x], [ʃ]), Position (F-, C-, P-lines), and Laterality (7-, 3-, z-, 4-, 8-lines) calculated for the re-referenced mean ERP amplitudes of the 50% control condition (analysis window: 236 to 276 ms).

Source	F	Degrees of Freedom	G-G-Epsilon	p
Fricative ([x], [ʃ])	9.68	1, 15	-	.007
Laterality (7- , 3-, z-, 4-, 8-line)	3.63	4, 60	0.48	.041

Figure 2. Grand-averaged, re-referenced ERP responses elicited by the four stimulus types shown for electrode site Cz in Experiment 1. ERPs to stimuli presented in the 100% conditions (left panel) and in the 50% conditions (right panel). Topographical maps are shown for each ERP in the time window of 242 to 282 msec (left panel) and 236 to 276 msec (right panel). Scales are in milliseconds and microvolt.



Supplementary Discussion of Experiment 1

Lexicality of [ɔx]

Another factor possibly having an effect on the MMN in the current data is the lexical status of the stimulus syllables. Jacobsen et al. (2004) found that the deviance detection mechanism is affected by the lexical status of the standard stimulation. In the context of a lexically meaningful standard stimulation stronger MMN responses to the deviants are elicited than in the context of lexically meaningless standards. Through its occasional usage as an interjection in German [ɔx] might have reached a level of lexical meaningfulness unequalled by the other syllables used in the present study. This might, in principle, have caused the asymmetry between the MMN responses to [ɔʃ] and [ɔx] in our data. If this was the case, the opposite asymmetry between the MMN responses to *[ɛx] and [ɛʃ] could not be explained exclusively by means of the phonotactic violation, because the influences of the fricative change cannot be estimated. We will further respond to this possible objection in the supplementary discussion of Experiment 2.

Experiment 2

Methods

Participants

Dialectal background and dialectal usage: 9 participants grew up in eastern central Germany (Thuringia, Saxony), five of them reported slight dialectal usage. Four participants had dialectal background of north eastern Germany (Brandenburg), one of them reported slight dialectal usage. Two other participants came form central Germany (Hesse) and north western Germany (Lower Saxony), none of them reported any dialectal usage. Data of one participant are missing.

Second-language experience of the 16 participants ranged from 2 to 4 languages (mean 3.13, SD 0.74), including English (15), French (11), Latin (6), Spanish (4),Russian (3), Hindi (1), Italian (1), Portuguese (1), ancient Greek (1), Finnish (1), Estonian (1), Swahili (1).

Experiences with Swiss German or Dutch: 8 participants reported no experience with Swiss German or Dutch, 3 participants have Dutch or Swiss German speaking friends, 4 participants had been in German-speaking Switzerland or the Netherlands on holiday.

Linguistic education: 11 participants had no linguistic education at all. 3 participants were students of Modern Languages (American studies, African studies, Roman studies, Latin) and have taken courses of linguistics within their field of study.

Results

Figure 4. Grand-averaged ERP responses elicited by all four stimulus types presented as deviants (solid lines) and standards (dashed lines) in Experiment 2. Nose-referenced data are shown for a subset of measured electrode sites. Scales are in milliseconds and microvolt.

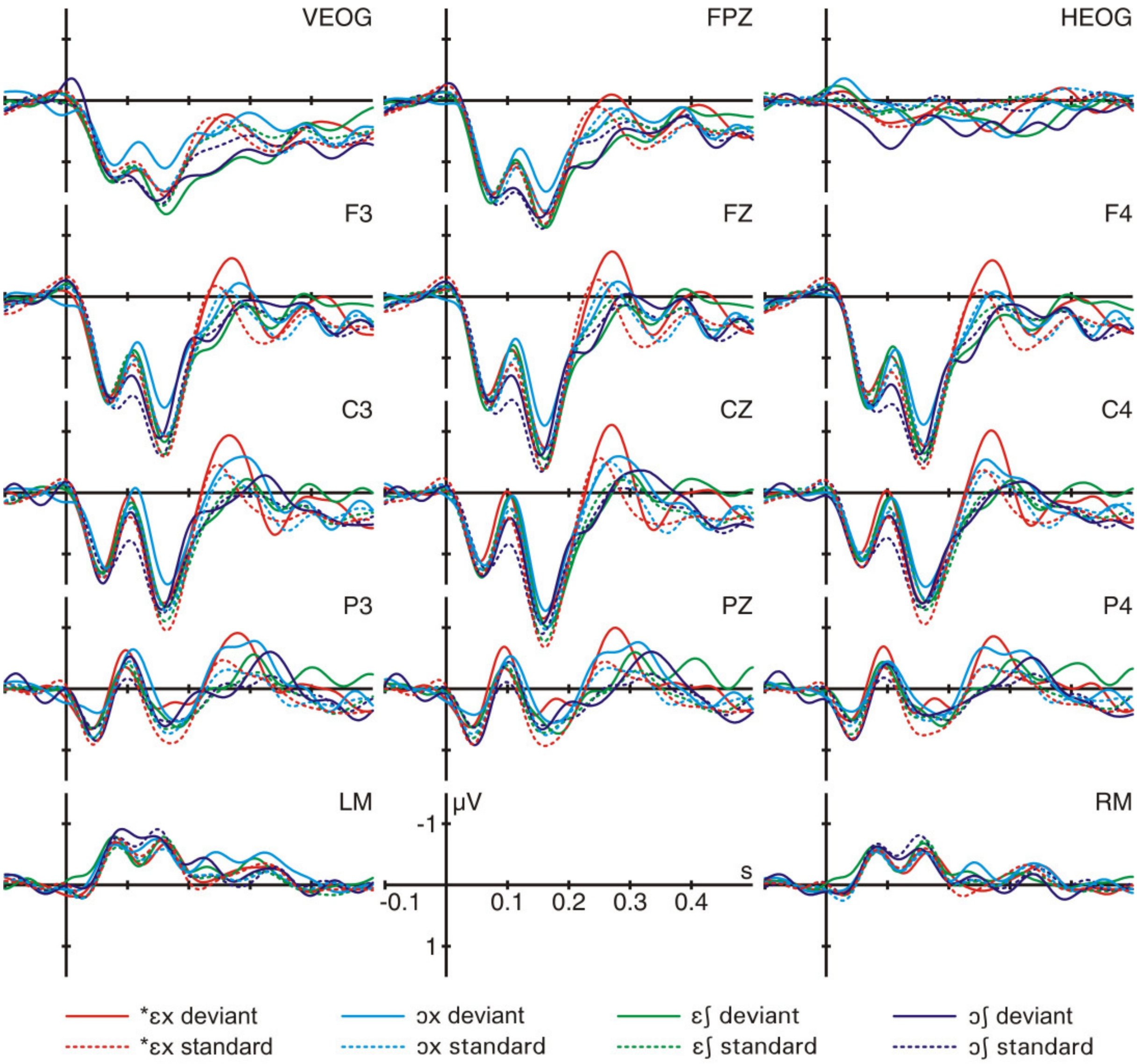


Table 4. Significant results of a 5-way repeated-measures ANOVA for the Factors Stimulus (Deviant, Standard), Vowel ([ɛ], [ɔ]), Fricative ([x], [ʃ]), Position (F-, C-, P-lines), and Laterality (7-, 3-, z-, 4-, 8-lines) calculated for the re-referenced mean ERP amplitudes of the standards and deviants (analysis window: 100 to 200 ms).

Source	F	Degrees of Freedom	G-G-Epsilon	p
Stimulus (Deviant, Standard)	8.92	1, 15	-	.009
Fricative ([x], [ʃ])	6.88	1, 15	-	.019
Position (F, C, P)	39.61	2, 30	0.57	.000
Laterality (7- , 3-, z-, 4-, 8-line)	22.67	4, 60	0.32	.000
Vowel × Fricative	6.19	1, 15	-	.025
Vowel × Fricative × Position	11.65	2, 30	0.54	.003
Position × Laterality	14.408	8, 120	0.41	.000

Table 5. Significant results of a 5-way repeated-measures ANOVA for the Factors Stimulus (Deviant, Standard), Vowel ([ɛ], [ɔ]), Fricative ([x], [ʃ]), Position (F-, C-, P-lines), and Laterality (7-, 3-, z-, 4-, 8-lines) calculated for the re-referenced mean ERP amplitudes of the standards and deviants (analysis window: 266 to 306 msec).

Source	F	Degrees of Freedom	G-G-Epsilon	p
Fricative ([x], [ʃ])	8.67	1, 15	-	.010
Position (F, C, P)	15.44	2, 30	0.58	.000
Stimulus × Fricative	20.24	1, 15	-	.000
Stimulus × Vowel × Fricative	7.06	1, 15	-	.018
Stimulus × Vowel × Fricative × Position	5.76	2, 30	0.62	.022
Stimulus × Laterality	4.26	4, 60	0.54	.020
Stimulus × Vowel × Fricative × Laterality	3.50	4, 60	0.47	.046
Position × Laterality	2.85	8, 120	0.48	.034
Stimulus × Vowel × Fricative × Position × Laterality	3.10	8, 120	0.41	.024

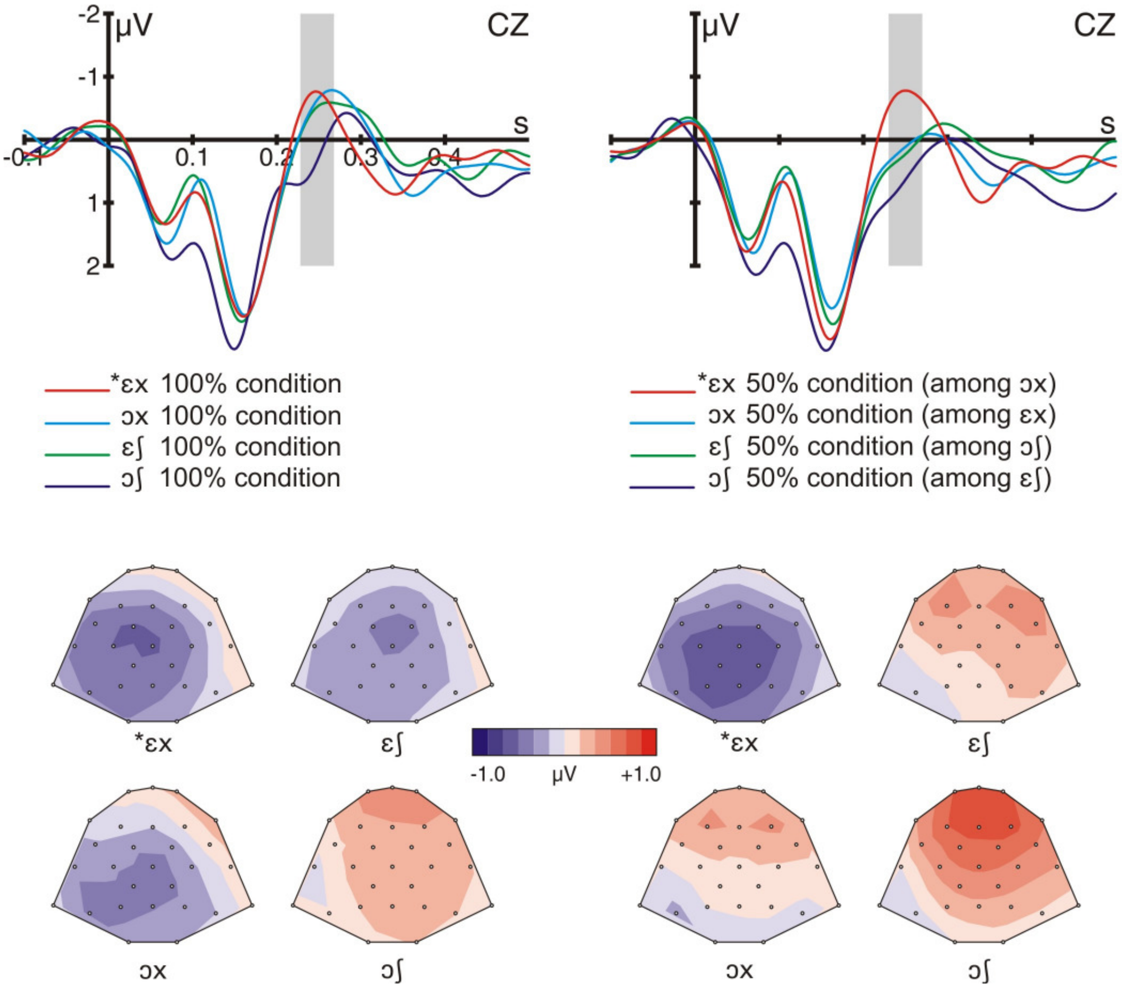
Table 6. Significant results of a 4-way repeated-measures ANOVA for the Factors Vowel ([ɛ], [ɔ]), Fricative ([x], [ʃ]), Position (F-, C-, P-lines), and Laterality (7-, 3-, z-, 4-, 8-lines) calculated for the re-referenced mean ERP amplitudes of the 100% control condition (analysis window: 228 to 268 msec).

Source	F	Degrees of Freedom	G-G-Epsilon	p
Vowel ([ɛ], [ɔ])	5.54	1, 15	-	.033
Laterality (7- , 3-, z-, 4-, 8-line)	4.47	4, 60	0.54	.002
Fricative × Laterality	3.95	4, 60	0.43	.038
Position × Laterality	3.11	8, 120	0.41	.031

Table 7. Significant results of a 4-way repeated-measures ANOVA for the Factors Vowel ([ɛ], [ɔ]), Fricative ([x], [ʃ]), Position (F-, C-, P-lines), and Laterality (7-, 3-, z-, 4-, 8-lines) calculated for the re-referenced mean ERP amplitudes of the 50% control condition (analysis window: 230 to 270 msec).

Source	F	Degrees of Freedom	G-G-Epsilon	p
Vowel ([ɛ], [ɔ])	8.01	1, 15	-	.013
Fricative ([x], [ʃ])	21.46	1, 15	-	.000
Position (F, C, P)	7.88	2, 30	0.55	.011
Vowel × Fricative	4.97	1, 15	-	.042
Vowel × Laterality	6.66	4, 60	0.41	.007
Fricative × Laterality	8.32	4, 60	0.50	.001

Figure 5. Grand-averaged, re-referenced ERP responses elicited by the four stimulus types shown for electrode site Cz in Experiment 2. ERPs to stimuli presented in the 100% conditions (left panel) and in the 50% conditions (right panel). Topographical maps are shown for each ERP in the time window of 228 to 268 msec (left panel) and 230 to 270 msec (right panel). Scales are in milliseconds and microvolt.



Supplementary Discussion of Experiment 2

Furthermore, it has to be discussed whether the potential quasi lexical status of the syllable [ɔx], which is occasionally used as an interjection in German, might have influenced the elicitation of the negativity observed for the syllable *[ɛx] when [ɔx] served as standard and *[ɛx] as deviant. Thus, the negativity elicited by the phonotactically ill-formed deviant *[ɛx] might have been amplified by the lexical use of the standard syllable [ɔx]. In this case, however, the amplification of the MMN should also and mainly occur at the time of stimulus onset, that is, when the deviation of the vowel occurs. Because the MMN responses elicited by the change of the vowels do not differ between the stimulus categories, any effect of the lexical status on our results is unlikely.

Supplementary General Discussion

Divergent results of the 100% and 50% conditions

The ERPs obtained in the 100% conditions for each syllable type should not differ between Experiments 1 and 2. However, all ERPs from Experiment 2 show greater amplitudes in the relevant time window compared to the data of Experiment 1. In our view, this amplitude difference should most likely be due to sampling effects.

The ERPs obtained in the 50% conditions differ between both data sets in regard to the difference between the ERPs elicited by *[ɛx] and [ɔx]. In Experiment 1, when [ɔx] was presented together with [ɔʃ], and *[ɛx] together with [ɛʃ], the ERPs elicited by [ɔx] and *[ɛx] which both contain the velar fricative but were presented in different blocks, both show a negative-going deflection between 200 and 300 msec, whereas the syllables containing the sibilant do not elicited any negativity in this time window. In Experiment 2, however, [ɔx] was presented together with the phonotactically ill-formed syllable *[ɛx] in the same block. In this context, [ɔx] did not elicit any negativity in the respective time window, whereas the ERP to the phonotactically ill-formed syllable shows such a negativity. Presenting *[ɛx] and [ɔx] in one block eliminates the negativity previously observed for [ɔx] when it was presented together with [ɔʃ]. This enlarges the difference between ERP of *[ɛx] and [ɔx] in this time window. The processing of both *[ɛx] and [ɔx] requires the activation of the same phonotactic constraint, namely DFA. Therefore, we suppose that the phonotactic evaluation is enhanced as indicated by the enlarged difference between the two syllables when they were presented together in the 50% condition of Experiment 2.

References

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