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Putting German [f] and [ç] in two different boxes: native German vs L2 German of French learners

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Abstract
French L2 Learners of German (FG) often replace the palatal fricative /ç/ absent in French with the post alveolar fricative /ʃ/. In our study we investigate which cues can be used to distinguish whether FG speakers produce [ʃ] or [ç] in words with the final syllables /ʃ/ or /ç/. In literature of German as an L2, to our knowledge, this contrast has not yet been studied. In this perspective, we first compared native German (GG) productions of [ʃ] and [ç] to the FG speaker productions. Comparisons concerned the F2 of the preceding vowel, the F2 transition between the preceding vowel and the fricative, the center of gravity and intensity of the fricatives in high and low frequencies. To decide which cues are effectively choices to separate [ʃ] and [ç], the fricatives appear generally at the end of the word (Buch [bux], book) or at the end of a morpheme (rieb-en [rix-\text{"e}n], smell).

In this paper, we study the voiceless palatal fricative which is often replaced by FG speakers by its closest neighbour the French consonantal inventory. Other than /h/, which is a well-know difficulty among French native speakers [2, 3], there are two voiceless fricatives: one palatal /ʃ/ (Ich-Laut) and one velar /x/ (Ach-Laut) that are considered as allophones because they appear in complementary positions in the German lexicon.

In this study, we investigate the acoustic properties of the German fricatives [ʃ] and [ç] produced by German native speakers (GG) and French learners of German (FG).

1. Introduction
Learning a second language does not only imply learning grammar and vocabulary but also accurate speech production. The latter is necessary to become an accepted member of a linguistic community. In our research, we are interested in German L2 speech production by French native speakers living in France. German and French do not share the same phonemic inventory. On one hand, there are no nasal vowels in standard German except for French loanwords like Restaurant or Ragout fin. On the other hand, the consonants /h/, /y/ and /ç/ (Ich-Laut) are not phonological in standard French.

The post alveolar fricative /ʃ/ can appear at the beginning or at the end of a German syllable, e.g. schnell [\text{"snrll}] (fast) and Fisch [\text{"fis\text{"c}}] (fish) and in the suffix -isch. At the end of monosyllabic words, the voiceless palatal fricative /ç/ often appears in a cluster with the plosive /t/: Licht [\text{"l\text{"c}}t] (light), echt [\text{"e\text{"t}] (real).

In this study, we investigate the acoustic properties of the German fricatives [ʃ] and [ç] produced by German native speakers (GG) and French learners of German (FG). We believe that acoustic measures can help teachers to provide quantitative and qualitative pronunciation feedback. In this study, we investigate the acoustic properties of the German fricatives [ʃ] and [ç] produced by German native speakers (GG) and French learners of German (FG). French learners of German tend to replace the palatal fricative /ç/ by the post alveolar fricative /ʃ/ or to overgeneralize [ç] productions once the phoneme has been well learned.

1.1. The German fricatives /ʃ et /ç/
There are several fricatives in German that are not present in the French consonantal inventory. Other than /h/, which is a well-know difficulty among French native speakers [2, 3], there are two voiceless fricatives: one palatal /ʃ/ (Ich-Laut) and one velar /x/ (Ach-Laut) that are considered as allophones because they appear in complementary positions in the German lexicon.

Anterior vowels (as well as consonants) are followed by [ç], posterior vowels and the vowel /a/ are followed by [x] [4]. Both fricatives appear generally at the end of the word (Buch [bux], book) or at the end of a morpheme (rieb-en [rix-\text{"e}n], smell).

In loanwords however, [ç] can also appear word initial (Chemie [\text{"kemj}], chemistry), China [\text{"tsja}], China etc.)

In this paper, we study the voiceless palatal fricative which is often replaced by FG speakers by its closest neighbour the French consonantal inventory. Other than /h/, which is a well-know difficulty among French native speakers [2, 3], there are two voiceless fricatives: one palatal /ʃ/ (Ich-Laut) and one velar /x/ (Ach-Laut) that are considered as allophones because they appear in complementary positions in the German lexicon.

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2. Material

2.1. Speech resource
We performed our research on the French Learners Audio corpus of German speech (FLACGS) recorded in 2014/15 in the Laboratoire de Phonétique et de Phonologie, Paris 5 (LPP) in Paris (France) [6]. This corpus includes both German native
speech and German L2 speech of French native speakers. In this corpus, 40 participants (20 L1 German, 20 L1 French) were recorded. The French native speakers ranked their knowledge of German from A2 up to C2 according to the Common European Framework of Reference for Languages (CEFR). The participants performed three tasks of increasing speech complexity: repetition, reading and picture description. In the present study we will only concentrate on the repetition task.

The repetition task counts 55 distinct words in central position in one of the following carrier sentences: Er sagt ... klar und deutlich and Ich sage ... klar und deutlich. The material were recorded by a German female native speaker. The participants listened through headphones to all the spoken utterances in a randomized order and repeated them.

We decided to focus on the repetition task in this study because our target words appear in the same syntactic environment. Prosodic changes due to syntactic placements do not affect them.

2.2. Material choice

We extracted words with the suffixes -/ʃ/ or -/ç/ like solidarisch [zoliˈdarnʃ] (showing solidarity) or freundlich [ˈfrontliʃ] (friendly). The word itself appears in a stressed syntactic position whereas the targeted suffix is unstressed.

A German native speaker and trained phonetician perceptively judged the 280 tokens on their realization. This intermediate step was taken in order to ensure the data set and to directly judge the 280 tokens on their realization. This inter-.

tactic position whereas the targeted suffix is unstressed.

Table 1 summarizes the perception results. The table shows that in the FG group, the mean of the F2 for /ʃ/ is 2162 Hz (sd=276), for /ç/, 2149.861 Hz (sd=242). This difference is significant (p ≤ 0.001). At the vowel/fricative transition point, the group mean of the F2 for /ʃ/ is 2236 Hz (sd=443) and 2199 Hz (sd=232) for /ç/, which is not significantly different (p ≥ 0.05). No normalization of the formant values was undertaken. In the FG group, the mean at the center of the vowel is 2112 Hz (sd=420) for /ʃ/ and 2155 Hz (sd=284) for /ç/. At the vowel/fricative transition point, the F2 mean for /ʃ/ is 2185 Hz (sd=376) and for /ç/ the F2 mean is 2242 Hz (sd=270). Neither point shows any significant difference in the FG group’s F2 productions (p ≥ 0.05).

Table 1: Perception results of /ʃ/ and /ç/ in GG and FG

<table>
<thead>
<tr>
<th></th>
<th>women</th>
<th>men</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>/ʃ/</td>
<td>/ç/</td>
</tr>
<tr>
<td>[ʃ]</td>
<td>100.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>/ç/</td>
<td>0.0%</td>
<td>87.5%</td>
</tr>
<tr>
<td>Ambiguous</td>
<td>0.0%</td>
<td>12.5%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>women</th>
<th>men</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>/ʃ/</td>
<td>/ç/</td>
</tr>
<tr>
<td>[ʃ]</td>
<td>75.3%</td>
<td>40.0%</td>
</tr>
<tr>
<td>/ç/</td>
<td>16.7%</td>
<td>45.0%</td>
</tr>
<tr>
<td>Ambiguous</td>
<td>10.0%</td>
<td>15.0%</td>
</tr>
</tbody>
</table>

Table 1 summarizes the perception results. The table shows three perceptive categories: [ʃ], [ç], and a third category that is not clearly identified as [ʃ] or [ç]. In both groups, the acoustic properties of the third category are more like the properties of the [ç] than of the [ʃ]. That is why in the following analysis, the third group will be annotated as [ç]. In the FG group, we observe confusions between /ʃ/ and /ç/ that are absent in the GG group regarding the repetition task. Substitutions of /ç/ with [ʃ] have been reported by other research teams that are interested in German as an L2 for French learners [7]. But that /ʃ/ can also be replaced by [ç] is not mentioned by Jouvet et al. (2015).

As proposed by Zygis and Padgett (2010), we calculated the F2 slope by using the following equation:

\[
slope F2 = \frac{F2_{VC boundary} - F2_{VC midpoint}}{duration between these two points}
\]

Results of the formant transition are plotted in Figure 2. In the GG group, the slope difference between the syllables -/ʃ/

3. Acoustic Analyses

The acoustic measures aim to define which one of the two fricatives FG speakers (and GG speakers alike) produce in the different words. Acoustic measures were carried out with Praat [8]. Statistical analyses have been carried out with R [9], privileging two-way ANOVAs with unequal sample sizes as statistical tests.

The following measures have been carried out to distinguish between [ʃ] and [ç]:

- F2 transition
- Center of gravity
- Intensity in low and high frequency bands of the fricative

3.1. Formant analyses

The first three formants of the suffix /ʃ/ and /ç/ are plotted in Figure 1 for both the GG and the FG group. The figure shows that in GG speakers, there is a clear difference for the F2 transition between /ʃ/ and /ç/. In the center of the vowel, the group mean of the F2 for /ʃ/ is 2162 Hz (sd=276), for /ç/, 2149.861 Hz (sd=242). This difference is significant (p ≤ 0.001). At the vowel/fricative transition point, the group mean of the F2 for /ʃ/ is 2236 Hz (sd=443) and 2199 Hz (sd=232) for /ç/, which is not significantly different (p ≥ 0.05). No normalization of the formant values was undertaken. In the FG group, the mean at the center of the vowel is 2112 Hz (sd=420) for /ʃ/ and 2155 Hz (sd=284) for /ç/. At the vowel/fricative transition point, the F2 mean for /ʃ/ is 2185 Hz (sd=376) and for /ç/ the F2 mean is 2242 Hz (sd=270). Neither point shows any significant difference in the FG group’s F2 productions (p ≥ 0.05).

GG speakers show a fairly large variability of the F2 which is conditioned by the following fricative. The GG group’s F2 transition indicates that both fricatives have different articulatory places. In the FG group however, the less variable F2 transition suggests that the articulatory places for [ʃ] and [ç] are globally less well separated.

In studies carried out on L1 speech, F2 transitions were found useful to distinguish between fricatives. It was found that F2 transition works as a valid predictor in CV contexts. In VC contexts however, F2 transitions are less solid [10, 11, 12].

As proposed by Zygis and Padgett (2010), we calculated the F2 slope by using the following equation:

\[
slope F2 = \frac{F2_{VC boundary} - F2_{VC midpoint}}{duration between these two points}
\]
and /-ç/- is significant. In the FG group, we find no significant difference. Overall, the F2 slopes in both the FG and GG groups are similar for /-ç/- As we saw in Figure 1, F2 in the FG group for both syllables are as high as in the GG group for /-ç/- and vary little while transitioning from the vowel to the fricative.

The F2 transition appears to be a solid cue to distinguish between [j] and [ç] in German native speakers but not for German L2 speakers who have French L1.

The center of gravity (CoG) is the measure of the frequency mean of an frequency interval which is weighted to its amplitude. Several research teams presented this measure to distinguish between fricatives in native speech [11, 12, 13, 14].

In order to know how the center of gravity progresses over the whole fricative, we extracted the center of gravity in the beginning, the center and the end of the fricative in our target words using Praat.

Results of two way ANOVAs with unequal sample sizes for GG groups’s [j] and [ç] show first no significant difference for the beginning of the fricatives, then significant differences for the other CoG values that were extracted (mean CoG: p ≤ 0.05, CoG in the center and the end of the fricatives: p ≤ 0.01). In the FG group, statistical analysis show significant CoG values all over the fricative (mean CoG, CoG of the center of the fricatives: p ≤ 0.01). The significant differences in both groups are rather due to the frequency span the CoG occupies than the FG group's CoG in the center and the end of the fricatives: p ≤ 0.001). The significant differences in both groups are rather due to the frequency span the CoG occupies than the FG group's CoG in the center and the end of the fricatives: p ≤ 0.001). The significant differences in both groups are rather due to the frequency span the CoG occupies than the FG group's CoG in the center and the end of the fricatives: p ≤ 0.001).

The CoG values of [j] between both speaker groups, GG and FG, do not show any significant difference for the CoG that was extracted of the fricative. The same comparison carried out on [ç] show significant differences in CoG in all three places of the fricative and the mean CoG (p ≤ 0.001). These results suggest on one hand that FG speakers produce two different fricatives. On the other hand, FG speaker’s [ç] is not the same voiceless palatal fricative we can find in GG speakers. For [ç], both groups show a wide frequency span in their CoG but in the GG group the CoG is situated in higher frequencies than in FG. In the FG group, maximal values of the CoG for [ç] are equal to those found in their [j] whereas the GG group tend to produce [ç] with CoGs situated in higher frequencies than in their [j].

### 3.2. Center of gravity

Concerning the GG group, results show significant intensity differences in both low frequency bands as well as in the high frequency band 3kHz-6kHz (p ≤ 0.001) whereas there is no significant difference of the intensity values on the second high frequency band (4kHz-7kHz). In the FG group, in both high and low frequency bands, we find significant differences (p ≤ 0.001). Regarding group differences, GG speakers and FG speakers do not show any significant differences for the intensity of high frequencies in [j] and the low frequencies in [ç]. However, for low frequency bands in [j] (1kHz-3kHz, 1kHz-4kHz: p ≤ 0.001) and high frequency bands in [ç] (3kHz-6kHz: p ≤ 0.05, 4kHz-7kHz: p ≤ 0.01), the intensity values in GG and FG speakers are significant different.

To summarize, the intensity of frequency bands is more distinctive for the fricative production in FG speakers than in GG speakers. Nevertheless, this local measure seems to have the potential of becoming a valid cue to distinguish between [j] and [ç] in German native and non-native speech.

### 3.3. Intensity in low and high frequencies

We extracted the intensity of low (1kHz-3kHz, 1kHz-4kHz) and high (3kHz-6kHz, 4kHz-7kHz) frequency bands because both fricatives, /f/ and /ç/ spread their energy in an unequal way over the spectrogram. For /f/, low frequency bands are more charged with intensity than high frequencies. The contrary is true for /ç/.

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To summarize, the intensity of frequency bands is more distinctive for the fricative production in FG speakers than in GG speakers. Nevertheless, this local measure seems to have the potential of becoming a valid cue to distinguish between [j] and [ç] in both GG speakers and FG speakers.

In the following, we are going to present our classification results for both speaker groups on [j] and [ç] using Weka.

### 4. Results and Discussion

In order to distinguish between [j] and [ç], the measures presented in Section 3 have been analyzed with the Weka implementation in R [15]. Figure 4 presents the results of this analysis for female speakers of both speaker groups (GG and FG). Separating the data set according to speaker group (GG or FG) and sex helped to increase the accuracy of the decision tree.

Weka was developped by the Waikato University (New Zealand) and is often used as a classification tool which also allows machine learning [16]. Weka in R creates a J48 tree. This decision tree uses a labelled data set and performs a relevance analysis of the features in order to decide which ones help best predict the labelled class (highest normalized information gain)
A similar result was obtained for male GG speakers. The tree in the center of Figure 4 shows female FG speakers. In male GG speakers, low frequencies and CoG are the strongest cues for the classification of [c ə] and [c ə]. In male GG speakers, only the intensity of different low frequency bands was used to build up the tree which leads to a lower error rate than using contextual measures in this speaker subset.

5. Discussion and Perspectives

We carried out different acoustic measures for [f] and [ç] in a VC context: formant analysis of the preceding vowel, CoG of the fricative and intensity in low and high frequency bands. Our results show that in order to distinguish between [f] and [ç], contextual measures are only solid cues in German native speech. Vowel quality in German L2 speech of French L1 speakers does not allow a solid distinction in a VC context. Leaving out contextual measures in German native speech does not lead to an increased error rate regarding classification.

Using only local measures extracted on the fricative may present another advantage: acoustic measures and decision thresholds do not have to be revisited with respect to the preceding vowel or position of the fricative (VC context versus CV context). In further studies, we will investigate this hypothesis to distinguish [f] and [ç] in native and non-native productions in reading and picture description. The analysis presented in this study are going to help rate speech productions of adult learners of German in a more accurate way in order to identify both accurate and erroneous pronunciation and to quantify L2 pronunciation progress over time.

6. Acknowledgements

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7. References


