Perception of place of articulation in English fricatives by Spanish listeners

Silvia Carmen Barreiro Bilbao
Universidad Nacional de Educación a Distancia
sbarreiro@flog.uned.es

Abstract

Differentiating speech contrasts which are not functionally distinctive in the mother tongue is a difficult perceptual task for non-native listeners. A two-fold experiment was carried out in order to investigate the L2 perception by 26 Spanish listeners of English, with an English group used as a control. In the first part of the study, listeners were exposed to the English contrast /s/ vs. /ʃ/, which is not phonemic in Spanish, in two synthesized words, Sue and shoe. The results showed that a great number of listeners had already acquired the contrast and the existence of language-specific differences in the use of some of the acoustic cues that signalled this contrast. Furthermore there was no correlation between the results obtained and the variables age of L2 learning, length of L2 learning, or listener's age. The second part of the experiment, based on voicing differences, will be shown in a subsequent paper.

Keywords: L2 perception, Spanish listeners, acoustic cues, English sibilants.

Resumen

Establecer diferencias entre fonemas que no son funcionalmente distintivos en la lengua materna es una tarea ardua para oyentes no nativos. En el presente trabajo se exponen los resultados del experimento que se llevó a cabo con el fin de investigar la percepción de contrastes no nativos por parte de 26 oyentes hispanohablantes, que se utilizaron como informantes. Un grupo de hablantes ingleses sirvió como el grupo de control. Los oyentes fueron expuestos al contraste inglés /s/ vs /ʃ/, que no es fonémico en español, en dos palabras sintentizadas, Sue y shoe. Los resultados mostraron que un gran número de oyentes habían adquirido el contraste; además, se apreciaron diferencias en el uso de ciertos índices acústicos que señalaban el contraste, causadas por la influencia de la L1. Asimismo, los resultados no tuvieron correlación ni con la edad ni el tiempo de aprendizaje de la L2, ni la edad del participante.

Palabras clave: Percepción de la L2, oyentes españoles, índices acústicos, sibilantes inglesas.

1.Introduction

L1 background, *L2 experience* and *age of the learner* are some of the subject variables that appear to contribute to the ability to distinguish phoneme contrasts in the speech of non-native speakers (Bohn, 1995; MacKain et at., 1981; Bohn & Flege, 1990; Polka, 1991; Mayo et al., 1997; Flege, 1998; or Bradlow & Pisoni, 1999, Escudero & Boersma, 2004; Hall et al., 2004, Cebrian, 2009, among others). These variables that a listener "brings to the task of perceptually organising non-native contrasts" (Bohn, 1995: 84) interact with what the person "is trying to organise perceptually" (Bohn, 1995: 84), the contrast variables.

Some non-native contrasts are more difficult to perceive than others (Lasky et. al., 1975; Werker et al., 1985; Flege, 1998, Best et al., 2001; Johnson, 2004; Boomershine et al., 2008, to mention a few). For instance, a lack of experience in L1 with regard to aspiration contrasts, such as /p/ and /b/ (as is the case with native Spanish speakers, for example), would lead to a greater perceptual difficulty in differentiating L2 phonemic contrasts based on this difference. These perceptual difficulties encountered by non-native listeners when differentiating speech contrasts which are not functionally distinctive in the mother tongue, or which are phonemic in the native language but differ in the phonetic realisation in the L2, are partially determined by contrast variables.

Apart from this interaction of phonological and phonetic factors and the difficulty in perceiving non-native contrasts, there are other contrast variables that we should bear in mind: The acoustic factors (Polka, 1991; Kabak & Maniwa, 2007). L2 learners seem to weigh the information available in the signal differently from the way L1 learners do when making a linguistic distinction (e.g. Strange and Jenkins, 1978; Underbakke et al., 1988; Yamada et al., 1992; Flege, 1984; Hazan & Boulakia, 1993; Bohn, 1995; or Williams, 1977, McCasland, 1983, and Flege & Eefting, 1987, for Spanish studies). In other words, the weighting given to relevant information provided by acoustic cues, used to identify a phoneme category, seems to be language-dependent.

In the case of fricatives, the spectral, temporal and amplitudinal properties that have proved to be key acoustic cues regarding place of articulation and/or voicing perception are the following (Silbert & de Jong, 2008): (1) The spectral properties of the frication noise, the frication amplitude, and, to a lesser extent, formant transitions and frication duration, for the perception of fricative place of articulation, and (2) the presence of phonation, the relative durations of vowel and fricative segments, and the frication amplitude, for fricative voicing perception.

In this paper, only place distinctions in sibilant fricatives will be studied. Two kinds of acoustic cues will be analysed, namely, the spectral properties of the frication noise, in particular, the spectral peaks (frequency and amplitude) and formant transitions. The former comprises inherent properties of the frication noise, and the latter refers to the transitions of the second formant (*T2*), an extrinsic spectral cue that takes place in the surrounding vowels. Distinctions based on voicing differences will be explained in a subsequent paper coming soon.

An analysis of previous studies shows that these acoustic cues for the perception of fricative place of articulation have been analysed in depth, especially in English.

The relevance of the location of the spectral peaks in sibilants has been supported by numerous studies (Harris, 1954; Whalen, 1991; Pickett, 1980; Jongman, 1985; Behrens & Blumstein, 1988a; Barreiro, 1994; Jognman et al., 2000; Kent et al., 2002; Raphael et al., 2011, among others), which indicate that English sibilants can be clearly distinguished by the frequency and the amplitude of the lowest peak, i.e., the spectrum shows a peak around 4-5 kHz for English alveolars and around 2.5-3 kHz for English palato-alveolars (Abdelatty Ali et al., 2001). Apart from the significant (inter- and intra-)speaker-dependent effects on the fricative spectrum (Hughes & Halle, 1956; Seitz et al., 1987; Behrens & Blumstein, 1988a, McMurray & Jongman, 2008; Maniwa et al., 2009; McMurray & Jongman, 2011), a farther back production, together with lip rounding and protruding, seems to account for the lower frequencies associated with palato-alveolar sounds. Results with sibilants reported that the amplitude in the F3 region in the vocalic portion was closely related to place of articulation (/s/ vs. /ʃ/) (Hedrick & Ohde, 1993), while at F5 it was related to sibilance but not place within each class (McMurray & Jongman, 2011).

Transition cues in relation to fricative perception of place of articulation mainly refer to F2 & F3 formant transitions. There is an apparent contradiction in the results reported in previous works. On the one hand, some studies report that formant transitions, especially T2, correspond to place distinctions between English sibilants, either voiced or voiceless (Soli, 1981). More specifically, F2 onset for a given vowel context seems to be progressively higher as the place of constriction moves back in the oral cavity, being around 100-300 kHz higher for /ʃ/ than for /s/ (Wilde, 1993; Mann & Repp, 1980; Whalen, 1981; Nittrouer, 1992, among others).

On the other hand, some studies state that formant transitions are a secondary or alternative cue for fricative place of articulation (Harris, 1958; Sharf & Hemeyer, 1972; Repp & Mann, 1980; Whalen, 1981a, 1981b & 1991; Hedrick & Ohde, 1993; Pittman & Stelmachowicz, 2000; Kent et al., 2002; Raphael et al. 2011) or even doubt their role in the perception of fricative place of articulation (e.g., Jongman et al., 2000;

McMurray & Jogman, 2011). It has been suggested that, although T2, and even T4 and T5, have moderate effects of place of articulation (McMurray & Jongman, 2011), other cues, such as frication spectrum, override context-dependent formant transition cues (Hedrick & Ohde, 1993; Nittrouer, 2002).

Individual differences in the use of transitions for the identification of sibilants may account for the apparent contradictory results reported in previous works (Casserly, 2010). Nevertheless, Wagner provides another interesting explanation when she claims (2009: 2777) that "listeners optimize their uptake of information to the demands of their native phoneme inventories", in particular, "attention to formant transitions as cues for fricative identification differs as a function of the presence of perceptually confusable fricatives in the listeners' native language" (Wagner et al., 2006: 2274). This is the case in English with an alveolar and a palate-alveolar fricative category, in contrast to Spanish. Therefore, it would be logical to assume that, with spectrally similar fricatives in their perceptual space, English listeners pay more attention to formant transitions than Spanish listeners.

Regarding the interaction with context variables, spectral peak location is noticeably influenced by the quality of the adjacent vowel, that is, it is vowel-dependent (Carney & Moll, 1971; LaRiviere et al., 1975; Soli, 1981; Yeni-Komshian & Soli, 1981; Whalen, 1983; Behrens & Blumstein, 1988a; Maniwa et al., 2008). In particular, vowel context mainly affects the frequencies of those spectral peaks in the fricative spectra that are associated with the F2 of the adjacent vowel (between 1.5 and 2 kHz). They are around 100-300 Hz higher when they precede front vowels than when they precede back vowels (Mann & Repp, 1980; Soli, 1981; Yeni-Komshian & S.D. Soli, 1981; Shadle et al., 1996, Seitz et al., 1987), although the change is only significant for the alveolar fricatives (Jongman, 1989; Jongman et al., 2000).

Vowel quality has a mild effect on transitions, more pronounced in voiceless fricatives (Mann & Repp, 1980; Repp & Mann, 1980; Whalen, 1981a, 1981b), with higher F2 onset values for front vowels compared to back vowels (Jongman et al., 2000). Also, F2 onset values increase significantly as a function of increasing vowel height. These authors specified that place by vowel interaction is significant for alveolars, while for the palate-alveolars this is restricted to /i, e/. Borzone de Manrique & Massone (1981) highlighted the influence of formant transitions and adjacent vowel when identifying Spanish fricatives, although their effect varied according to the spectral characteristics of the consonants and the surrounding vowels.

Finally, it has been reported that the actual location of the spectral peaks differs across syllable position, with higher values in initial position than in mid and final positions (Seitz el al., 1987). Also, VC transitions seem to have more perceptual weighting than CV transitions (Sharf & Hemeyer, 1972; Zeng & Turner, 1990). In Spanish, Moreno Llaneza (1990) refined the role of the formant transitions by claiming that in Spanish the influence of the transitions of pre-consonant vowels was almost irrelevant compared to that exerted by those of the post-consonant vowels.

Based on previous literature, a two-fold experiment was set up in order to test how non-native speakers, specifically, Spanish speakers, perceive two English contrasts:

a) /s/ vs. /ʃ/: The difference is based on the *place of articulation* feature. This contrast is phonemic in English but not in Spanish, since the palato-alveolar is not present in the Spanish phonemic system.

b) /s/ vs. /z/: The difference is based on the *voicing* feature. This contrast is phonemic in English but allophonic in Spanish, as the voiced consonant only occurs when followed by a voiced consonant.

The main aims of the first part of the experiment, carried out to investigate fricative place of articulation distinctions, were as follows:

a) To test Spanish listeners' categorisation ability in an English phonemic contrast which does not occur in Spanish, /s/ vs. /ʃ/ as well assessing the stage of speech-perceptual development that listeners have reached, if any.

b) To find out (i) if place distinctions in fricatives can be perceived by using multiple cues and (ii) which cues had the greatest perceptual weighting for that population.

c) To examine subject variables in order to analyse (i) language differences (Spanish vs. English) in relation to the acoustic information that is taken into account for English sibilant identification, (ii) inter-speaker variations in the use of perceptual acoustic cues on the identification of non-native contrasts, and (iii) effects of intra-speaker variables (namely, *length of L2 learning, age of L2 learning* and *age of the listener*) on results, if any.

2. Method

2.1. Test material

Synthetic speech was used to control what was in the signal as this allowed the manipulation of the acoustic cues and the contrast different conditions, and subsequently made it possible to ascertain which cues had the greatest perceptual importance for a given listener, or group of listeners. The synthetic speech patterns used for the experiment were provided by *SPA* (Speech Pattern Audiometer). A minimal pair, *Sue/shoe* had been produced by computer-generated synthesis, with a very high quality that enabled us know which speech patterns elements, or acoustic cues, were being used to establish a contrast. Furthermore, "by testing listeners on minimal pairs graded in terms of speech pattern complexity" (Hazan et al., 1995: 119), it is possible to assess the stage of speech-perceptual development that the listeners have reached.

The acoustic cues had been carefully and individually manipulated. A continuum of six steps was created from the minimal pair, in which one or two cues had been changed in small equal steps. The acoustic cues that were varied in order to signal the contrast were the *frequency and amplitude of frication* and *F2 transitions*.

Three different test conditions were then constructed in which cues had been varied together or in isolation. These were:

a) Contrast signalled by changes in both cues: *the frequency and amplitude of the frication* was varied in six steps, going from /s/ to /ʃ/, as can be seen in table 1:

Table 1. Parameters changed in the continuum of the *Sue/shoe* test

	Amp. F2	**Amp. F4**	**Amp. F6**	**Freq. F2**	**Freq. F5**
Step 1	30	45	58	1900	5400
Step 2	33	46	55	1940	5102
Step 3	36	47	52	1981	4820
Step 4	39	48	49	2022	4553
Step 5	42	49	46	2065	4302
Step 6	45	50	43	2108	4064

Different parameters were changed along the continuum with the values of the amplitude (in dB) of F2, F4 and F6 interpolated linearly, whereas with the values of the frequency (in Hz) of F2 and F5 there was a logarithmic interpolation. Other values, however, were kept fixed, namely, the amplitude of F2 (at 55 dB), and the frequency of F3, F4 and F6 (at 3084 Hz, 4000 Hz and 6800 Hz, respectively). The onset of the frequency of F3 was fixed.

As far as the *F2 transitions* were concerned, there was a change in their frequency along the continuum from its corresponding value in each step (see table 1 above) to 2063 Hz, over a period of 30 ms.

b) Contrast signalled by changes in *the frication* with no transitions between the consonants and the following vowel.

c) Contrast signalled by changes in *F2 transitions*, as previously described, i.e., keeping the frequency of the frication fixed in a neutral, intermediate value between the two consonants.

Random number tables were used in order to assign a random presentation of the material from *SPA* system. The material was then recorded in a *DAT* (Digital Audio Tape), with a level of recording of around -10 dB in both channels (right and left).

The forced choice test was designed as an *identification test*. Therefore, there were a fixed number of presentations (in this case, 10) of the randomised stimuli, and the listeners were instructed to use a restricted set of responses (*Sue* or *shoe*).

2.2. Listeners

26 Spanish listeners were chosen as the subjects of the experiment. They all used Spanish (Castilian) as their L1 language, and had their permanent residence in Spain. Information was gathered via a questionnaire, including their family language background, age of L2 learning and length of time they had been studying English. We also included questions for self-assessment of their level of English (production and perception). They all reported having normal hearing.

The average age was 26 (s.d. 5) years old, the average age of starting L2 learning was 11 (s.d. 4) years, and the average length of studying English was 15 (s.d. 4) years, including at least one year of instruction at university level. They all considered themselves to be *monolingual*, with an *intermediate* or *advanced* level of English comprehension and fluency (12 listeners vs. 14, respectively). They were all willing to participate in the experiment, although they did not receive any money for doing so.

Control data was obtained from a group of 20 native speakers of British English, working or studying at UCL, who had already listened to the same material with an adaptive procedure rather than a fixed number of presentations. Their average age was 24 (s.d. 7) years old. They also reported having normal hearing.

2.3. Test Procedure

The group of Spanish listeners was tested in the *Laboratorio de Fonética* of León University (Spain). The laboratory was equipped with a Tandberg Educational Language System, comprising a master table from which we could control the recording material given to the listeners.

The *DAT* tape was played back on the master recorder and the subjects listened to the tape through headphones (with a total impedance 200 ohm) played at a comfortable listening level.

Initial instructions and clarifications were given in their mother tongue (Spanish). After the initial explanations, the *Sue/shoe* test with 180 stimuli was carried out. The test was preceded by six examples of the material (each extreme of the continuum was presented three times). Immediately after this, listeners heard one stimulus every four seconds and were told to label it, and, if they were not sure which sound they had heard, to guess. Listeners were provided with a stimulus response sheet to record their judgements. They had ten blocks of eighteen *Sue-shoe* pairs on their response sheet and had to underline the identified word of each pair. There was an interval of twenty seconds between the fifth and sixth blocks to avoid *fatigue* effects.

2.4. Test Analysis

The analysis of the data from the two acoustic cues under investigation (frequency and amplitude of the frication and F2 transitions) was carried out with the program *BASIC*, an identification test scoring program. The outcome was the number of *Sue* responses at each step.

The assessment of the mean identification functions (or *labelling curves*) was based on the overall shape of the curve, the values obtained at the extremes of the range, the phoneme boundaries (defined as the point on the continuum where each category is heard equally often), and the gradient or slope of the curve (Hazan & Fourcin, 1985; Hazan et al. 1995).

The labelling curves plotted the average percentage of /s/ responses across the range of stimuli in each of the three test conditions.

The *MLE* (Maximum Likelihood Estimate) was used to obtain a quantitative measure of phoneme boundaries and gradients.

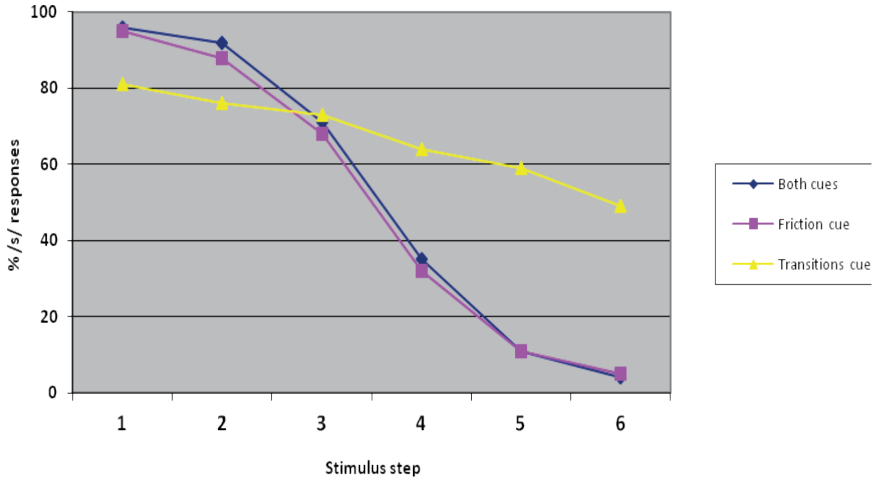
3. Results

The data of each member of the group of Spanish listeners (from *BASIC*) as well as the mean values of the gradients for the English and the Spanish groups (from *MLE*) can be seen for each of the test conditions in the appendix section (appendix 1 and 2, respectively).

3.1. Spanish results

Figure 1 shows the mean identification functions obtained from the Spanish group's data in the *Sue-shoe* test for the three test conditions.

Figure 1. Mean identification functions of averaged Spanish listeners in the test *Sue-shoe* test



3.1.1. Both cues condition

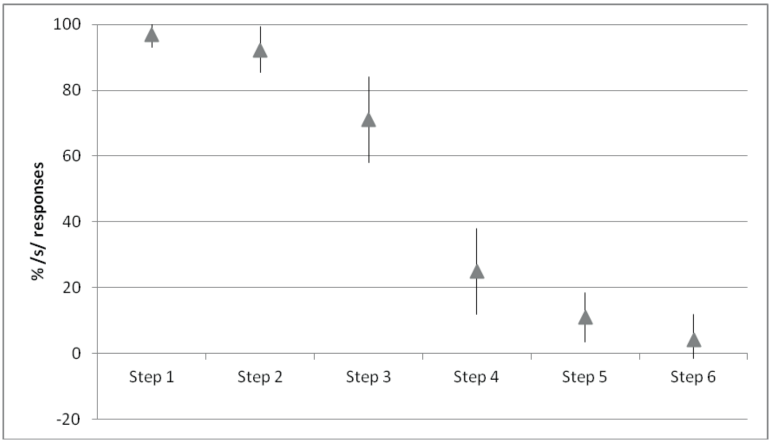
When both cues were present, the Spanish listeners identified the first two steps of the continuum as /s/ over 90% of the time, and steps 5 and 6 were reported to be /ʃ/ over 90% of the time. The mean identification function obtained could be described as *progressive*, which means an "ability to label the extremes of the ranges, but responses to the intermediate stimuli shows the processing ability is not yet fully established" Hazan & Fourcin, 1985: 328).

The phoneme boundary separating both consonants occurred between step 3 and 4 from to /s/ to /ʃ/. According to the *MLE* results the perceptual shift took place at exactly 3.561 (s.d. 0.602). At that point, the spectral peaks of the fricative had the following values: (i) the frequency of F2 was between 1981 Hz and 2022 Hz, with the amplitude between 36 dB and 39 dB; and (ii) the frequency of F5 was between 4820 Hz and 4553 Hz, with the amplitude fixed at 55 dB. Regarding the F2 transition, its frequency had risen by around 63 Hz.

The analysis of the individual differences showed great variability among the listeners (figure 2), especially clear in the phoneme boundary, which ranged from

2.396 to 4.934. The perceptual shift from the alveolar to the palate-alveolar fricative occurred between steps 3 and 4 for 14 subjects. Also, the phoneme boundary had shifted to the left (between the step 2 and 3) for 5 subjects, and it was situated further to the right (between the step 4 and 5) for 5 other subjects.

Figure 2. Percentage of /s/ responses (mean and standard deviation) of the Spanish listeners' results in the /s/-/ʃ/ contrast when both cues are present



19 subjects out of the 26 showed sharp or *categorical* identification functions. In other words, there were "confident responses at the extreme of the range and consistent categorization of intermediate stimuli" (Hazan & Fourcin, 1985: 328), showing that listeners had an ability to clearly divide the stimuli continuum into two categories. 5 subjects obtained mean identification functions that could be described as *progressive* and only 2, *random*. It is worth mentioning that *random* refers here to what is not progressive or categorical, comprising many different types of labelling shapes, including those with a flat response around 100% /s/ identification, those completely random at the level of the phoneme boundary, and those with values scattered across the continuum.

Correlation analyses were carried out across the 26 speakers included in the experiment, relating the intra-speaker variables (i.e., *length of L2 learning, age of L2 learning* and *age of the listener*) and the type of labelling curve identified. According to the results of Pearson's tests ($r = 0.302$, $r = -0.236$, $r = -0.122$ at $p > .05$, respectively), no significant correlations were observed between any of these factors and the identification functions.

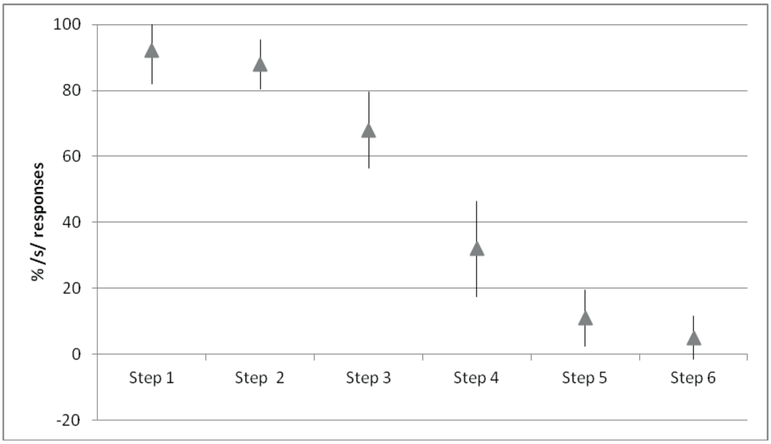
Another interesting result from the experiment was that, although not statistically significant ($r = 0.390$, $p > .05$), the number of categorical identification functions was greater within the group of listeners with an advanced level of English than within those with an intermediate level (79% vs. 67%).

3.1.2. Frication cue condition

When there were no transitions and the contrast was only cued by the spectral characteristics of the frication noise, the Spanish listeners identified the first two steps of the continuum as /s/ over 90% of the time, and steps 5 and 6 were reported to be /ʃ/ over 90% of the time. The mean labelling curve obtained had almost exactly the same shape as in the previous condition test, with a phoneme boundary in a similar area, according to the *MLE* results, at 3.487 (s.d. 0.610). It could be categorised as *progressive*.

Regarding inter-speaker differences, the level of variability among the listeners was similar to that observed in the previous test condition (figure 3). Nevertheless, the number of subjects who showed *categorical* identification functions went down to 17, while the number of subjects with *progressive* identification functions increased (7 subjects). 2 subjects, the same listeners as in the other condition, showed *random* identification functions. This difference was not statistically significant.

Figure 3. Percentage of /s/ responses (mean and standard deviation) of the Spanish listeners' results in the /s/-/ʃ/ contrast when only the frication cue was present



Individual differences were also observed in the phoneme boundary. The perceptual change from one fricative place of articulation to the other occurred at the place mentioned above for 13 subjects. However, the phoneme boundary was shifted to the left (between the steps 2 and 3) for 6 of the subjects whereas for 5 others, it was moved further to the right (between the steps 4 and 5).

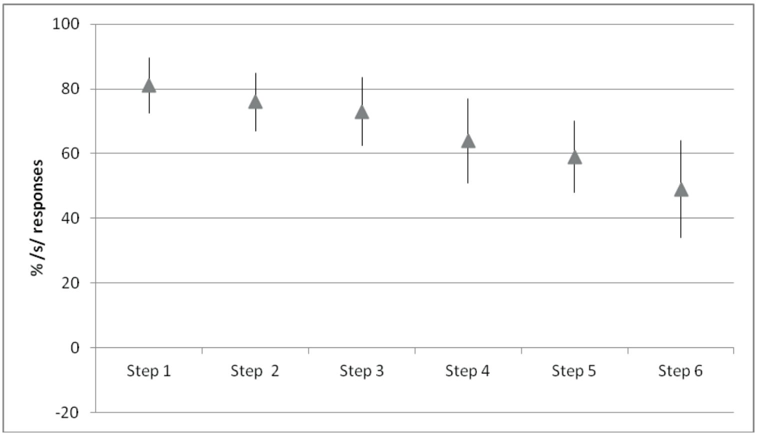
As in the previous condition test, no significant correlations were seen between the intra-speaker variables and the type of labelling curve identified (*r* = 0.112, *r* = 0.326, *r* = 0.013 at p > .05, respectively). Also, although not statistically significant (*r* = 0.280, p > .05), there were more listeners who showed categorical identification functions within the group with an advanced level of English than within the intermediate group (71% vs. 58%).

3.1.3. F2 transitions cue condition

When there were no variations in the frication and the contrast was only cued by the transitions of the F2, the mean labelling curve showed a totally different picture, described as *random*. Therefore, the Spanish listeners were not able to use the information provided by this single acoustic cue when making decisions about the place of articulation of the sibilant fricatives.

The majority of the subjects' identification functions had a similar overall shape, although they could be described as *progressive* for four of them (3 advanced listeners and 1 intermediate). The degree of this variability can be seen in figure 4.

Figure 4. Percentage of /s/ responses (mean and standard deviation) of the Spanish listeners' results in the /s/-/ʃ/ contrast when only F2 transitions cues are present



The statistical analysis supported the above observations: There was no significant effect of the intra-speaker variables on the results (*r* = 0.010, *r* = 0.134, *r* = 0.002 at p > .05, respectively), although more progressive labelling functions were obtained within the group of advanced listeners than within the intermediate group (21% vs. 8%, in that order).

3.1.4. Conclusions

These results indicate that the Spanish listeners were almost entirely reliant on the frequency and amplitude of the frication noise for establishing the place of articulation contrast and were not making use of the information given by the F2 transitions.

Most listeners showed a high level of confidence in identifying the contrast when both cues were present or the frication-cue only. Therefore, it can be stated that the majority of them (between 65.4% and 73.1 % of the total subjects, depending on the condition) were able to confidently label the non-native phonemic contrast /s/-/ʃ/. Furthermore, for a large proportion of the subjects (between 26.95% and 19%), the ability to process this contrast was almost fully established, and only in 7.7% of the listeners had it not yet been acquired.

The fact that in the third condition (*F2 transitions* cue only) 84.5% of the subjects did not manage to perceive a difference in the place of articulation of the sibilants was a clear indication that the cue did not provide the listeners with enough information about this contrast, even for those who had already acquired the ability to perceive it.

The result from the *General Linear Model* test carried out on the gradient values obtained for identification data to test for the effects of test conditions (two-cue vs. one-cue) was significant [$F(2,50) = 64.999$; $p < 0.0001$]. Furthermore, a *Pairwise comparison* test showed that the difference between the mean slopes of the averaged listeners for the first two conditions was not significant, but there was a significant difference between the mean slope of the third condition and the others, $p < 0.0001$.

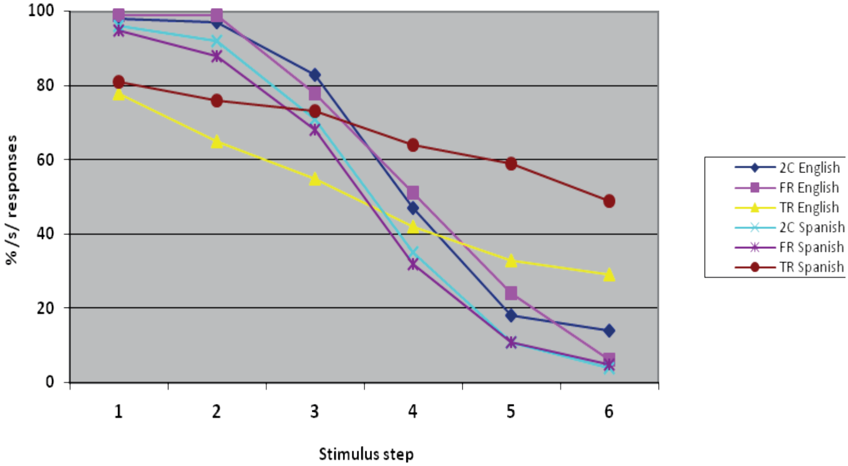
The results of a t-test analysing the phoneme boundary showed that the slight change that occurred when one of the cues was removed did not cause a significant perceptual shift from one place or articulation to the other.

Finally, no significant correlation could be found between any of the intra-speaker variables and the results obtained in the present study.

3.2. Comparison with English results

The mean labelling functions obtained from the data for the English group are shown in figure 5 together with those from the Spanish group.

Figure 5. Mean identification functions of averaged English and Spanish listeners in the *Sue-shoe* test



Leaving aside the great variability among the listeners, in the first test condition, when both cues were present, the overall shape of both labelling functions was almost identical, but with a higher percentage of /s/ responses in all steps in English, rising to 13% higher at the phoneme boundary (between steps 3 and 4) where both groups seemed to perceive a shift from one consonant to the other one.

In the second test condition, when there were no transitions and the contrast was only cued by frication features, despite the great variability among listeners, the labelling curves from both groups were very similar to those obtained in the first test condition, almost identical in the case of the Spanish listeners. Once again, there was a higher percentage of /s/ responses for all steps in English, rising to 18% higher at step 4. For both groups, the phoneme boundary was located more or less in the same area, between step 3 and step 4.

In the third condition, when the contrast was only cued by the F2 transitions, and bearing in mind the existence of great individual differences, the mean labelling curves revealed that neither the English group nor the Spanish group could make a distinction based on this cue. Therefore, it can be stated that the information provided by this acoustic feature of the speech signal is not enough for a listener to perceive a place distinction among sibilants, regardless of the listener's mother tongue. It is worth mentioning however, that the Spanish labelling curve shows a flatter response, with a higher percentage of /s/ responses, especially at step 5 which is as much as 26% higher. Therefore, this cue provided less information for the Spanish group than for the English group.

4. Discussion and Conclusion

The aim of this experiment was to gain a better understanding of Spanish perception of the place or articulation of the English phonemic contrast /s/-/ʃ/, which does not occur in the Spanish language. The following paragraphs will discuss the impact of the results on the issues selected as the main aims of the experiment.

In relation to the *Spanish listeners' categorization ability* in a non-native phonemic contrast, the mean labelling functions for the average calculated for Spanish listeners when both cues were present revealed that listeners were able to confidently label the extremes of the range (above 90% or more) although there was some uncertainty with the intermediate values. Further, they perceived a gradual shift from one consonant to another one between step 3 and step 4. The average stage of development could be described as *progressive*. There was a clear indication that the ability to distinguish the sibilant /ʃ/ had been already acquired by the listeners.

There was an evident inter-speaker variation in the use of English fricative perceptual acoustic cues, which made us analyse the individual results in depth. It was found that the number of listeners who achieved *categorical* identification functions was high. Therefore, to avoid misleading information, the labels given to the speech-perceptual development of the average of all the listeners' results could only be taken as illustrative of the average tendency. Moreover, in order to be able to make a more valid statement about listeners' perception, discrimination tests should be carried out in order to establish if a listener or group of listeners have developed the ability to perceive categorically.

The comparison with the English group showed that, although most Spanish listeners seemed to perceive a clear shift from one category to the other, their results were slightly worse than those obtained from native speakers of English. Native listeners showed a somewhat higher level of confidence when identifying the phoneme of this phonemic contrast.

The *perceptual weighting of acoustic cues in native and non-native contrasts* was carefully analysed in order to ascertain if L2 learners weight the information available in the signal differently from the way L1 learners do in making a linguistic decision. The results of the experiment provided revealing information regarding this issue:

(1) All listeners, irrespective of their mother tongue, were able to establish the place of articulation contrast when both cues were present in the signal. And very similar results were obtained when the contrast was only cued by the frication spectral characteristics. An F2 transitions cue in isolation, however, was not sufficient to

distinguish between the two consonants. This result supports the idea that listeners do not pay attention to more or different cues when listening to non-native pronunciation (Wagner et al., 2006).

(2) Both groups of listeners were almost entirely reliant on the spectral characteristics of the frication in establishing the place of articulation contrast. Neither group was making great use of the information provided by the F2 transitions, although the information they provided was perceived as more useful for the English group than for the Spanish one. This slightly different language-specific pattern of taking F2 transitions into account for sibilant identification has already been observed by Wagner et al. (2006). English listeners relied on the information of additional acoustic cues, in this case formant transitions, for a contrast between very similar places of articulation in their phoneme repertoire, namely, the spectrally similar alveolar /s/ and palato-alveolar /ʃ/.

(3) The primary acoustic cue for both groups in making place distinctions between voiceless sibilants was contained in the frication noise for both groups. The information coming from the adjacent sounds, in particular, the F2 transitions was an additional or secondary cue, as had been observed in previous literature (Harris, 1958; Sharf & Hemeyer, 1972; Repp & Mann, 1980; Whalen, 1981a, 1981b & 1991; Hedrick & Ohde, 1993; Kent et al., 2002; Raphael et al., 2011).

Nevertheless, as the fricative position in the word seems to have a clear effect on formant transitions (e.g. Sharf & Hemeyer, 1972; Moreno Llaneza, 1990), it would be worth carrying out a further analysis to discover whether F2 transitions of post-consonant vowels have more perceptual weighting than CV transitions when identifying the place of articulation of sibilants, especially with non-native sounds. Furthermore, it would be interesting to know if listeners make greater use of F3 transitions, which were not manipulated in the present work, although it has been found to be a perceptual cue for the place of articulation contrast in some studies (Nitttrouer & Miller, 1997). Further research could also address the effect of vowel quality on transitions, more pronounced in voiceless fricatives (Mann & Repp, 1980; Repp & Mann, 1980; Whalen, 1981a, 1981b), by using different vocalic contexts.

Analysis of the location of the *phoneme boundary* along test continua, showed no clear language-specific changes in the contrast /s/-/ʃ/. It varied slightly from one condition to another depending on the cue present in the signal, although the t-test results showed that this difference was not statistically significant.

Regarding the subject variables that interact to determine perceptual difficulty in the acquisition of non-native contrasts (Bohn, 1995), the results indicated that there was no correlation between the Spanish listeners' stage of speech-perceptual development and the variables *length of L2 learning, age of L2 learning* and *age of the listener*. Some listeners, who considered themselves as having an intermediate English level in the self-assessment, had never been abroad to an English-speaking country, or only for short periods of two or three months. Nevertheless they seemed to have better perception than others who had studied longer, had been abroad for longer periods of time, or started to study English earlier. It may be the case that the Spanish listeners' immersion in the L2 was not sufficient to cause significant differences, as they all lived in Spain, and the contact with the L2 was limited to relatively short periods abroad. Moreover, they all began learning English after the age of 5, i.e., they were *monolingual*, and described themselves as such.

In sum, the present study indicates that multiple cues are used by Spanish and English listeners to perceive place distinctions in voiceless English sibilants, the primary cue being the frication spectral features. F2 transitions do not provide enough information to signal the contrast, although they had a greater perceptual weighting for the English group, suggesting a different language-specific pattern in the use of this cue. There was great variation among the individual Spanish listeners, which was not related to *length of L2 learning, age of L2 learning* or *age of the listener*. Several aspects of the present study warrant further investigation, as pointed out above. First, it would be interesting to compare the effects of F2 transitions (and even of the F3 transitions) of different vowels, in both pre- and post-consonant positions, on the identification of non-native places of articulation in fricatives. It would also be interesting to analyse a more heterogeneous group that included other variables, such as *gender*, and subjects with objective differences in their level of English (as opposed to the self-assessment criteria used here) in order to reveal the significance of these subject variables for the results obtained.

Finally, to widen the scope of this research into the Spanish perception of English sibilants, it would be interesting to study the stage of perceptual development in a contrast with a different status in the L1, such as /s/ vs. /z/: The voiced sibilant is an allophonic realisation of /s/ only occurring when followed by a voiced consonant (mainly plosive). This difference, based on the *voicing* feature, will let us analyse if, as is claimed by some models of L2 speech perception working on the relative perceptual difficulty of non-native phonetic categories (such as Best & Strange's *Perceptual Assimilation Model* (*PAM*), 1992, or Flege's *Speech Learning Model* (*SLM*), 1995, among others), there would be a better perception of the contrast used in the present experiment, that is, /ʃ/ is more likely to have been acquired as a "new" category by native Spanish speakers of English than /z/. This experiment is underway and results will be published soon.

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Appendix

Appendix 1: Data from the spanish group in the (/s/ vs. /ʃ/) contrast

Two Cues

Gradient	s.d.	Intercept	Ph. Boundary	Chi-Square	d.f.	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
-3.72709	1.3993	11.0127	2.955	0.471	4	100	100	50	0	0	0
-3.72709	1.3993	11.0127	2.955	0.471	4	100	100	50	0	0	0
-3.78463	1.198	13.6683	3.612	0.0999	4	100	100	90	20	0	0
-2.06588	0.5381	6.4006	3.098	0.8301	4	100	90	50	20	0	0
0.1267	0.1528	-0.376	2.967	6.9683	4	70	30	40	40	50	80
-3.19729	1.0239	13.4045	4.192	0.502	4	100	100	100	60	10	0
-0.71724	0.2003	2.691	3.752	3.3307	4	80	90	50	60	30	10
-1.91261	0.4816	7.0792	3.701	3.8128	4	100	100	80	20	20	0
-4.06011	1.4846	11.2616	2.774	0.1065	4	100	100	30	0	0	0
-2.80667	0.8171	12.3448	4.398	0.6239	4	100	100	100	70	20	0
-4.45726	1.5744	16.4034	3.68	0.0399	4	100	100	100	20	0	0
-2.79862	0.8211	6.7065	2.396	4.8724	4	90	90	10	0	0	0
-4.45726	1.5744	16.4034	3.68	0.0399	4	100	100	100	20	0	0
-3.19983	1.0219	12.1841	3.808	0.504	4	100	100	90	40	0	0
-1.71564	0.4726	8.4653	4.934	1.8141	4	100	100	90	90	50	10
-1.82098	0.4561	5.639	3.097	2.8615	4	100	90	40	30	0	0
-2.61724	0.7409	8.6302	3.297	1.155	4	100	100	60	20	0	0
-3.7828	1.2002	16.601	4.389	0.0993	4	100	100	100	80	10	0
-2.79862	0.8211	12.8839	4.604	0.6134	4	100	100	100	80	30	0
-1.14807	0.2751	3.7741	3.287	2.5999	4	100	70	60	30	20	0
-1.14807	0.2751	4.2624	3.713	1.1021	4	100	90	60	40	20	10
-1.26466	0.3046	3.7647	2.977	4.9526	4	80	80	70	20	0	0
-1.20436	0.2881	4.5959	3.816	3.1553	4	100	80	70	60	20	0
-3.14811	0.931	11.0184	3.5	0.2981	4	100	100	80	20	0	0
-1.71074	0.4183	6.3335	3.702	13.1663	4	90	90	100	40	0	0
-2.19076	0.5782	7.227	3.299	0.8383	4	100	90	70	20	0	0
-2.5129			3.561		*Mean*	**96.54**	**91.923**	**70.7692**	34.6154	10.7692	4.23077

Friction Cue											
Gradient	*s.d.*	*Intercept*	*Ph. Boundary*	*Chi-Square*	*d.f.*	*Step 1*	*Step 2*	*Step 3*	*Step 4*	*Step 5*	*Step 6*
-1.85518	0.4653	5.9324	3.198	2.2722	4	100	80	70	20	0	0
-2.04907	0.5346	6.1428	2.998	48.4359	4	100	100	40	0	0	10
-3.83316	1.4275	12.0191	3.136	1.7101	4	100	100	70	0	0	0
-1.60627	0.388	5.785	3.601	5.2961	4	100	80	80	50	0	0
-0.19768	0.155	0.6233	3.153	6.8691	4	70	70	30	30	30	60
-3.19983	1.0219	12.1841	3.808	0.504	4	100	100	90	40	0	0
-0.37526	0.1647	1.3868	3.696	9.8906	4	100	40	50	30	60	30
-1.11064	0.2695	4.364	3.929	2.8836	4	90	90	80	60	10	10
-2.80667	0.817	7.302	2.602	0.6238	4	100	80	30	100	0	0
-1.03398	0.2628	4.5311	4.382	16.8145	4	80	100	80	90	30	0
-3.78463	1.1981	12.8241	3.388	0.1	4	100	100	80	10	0	0
-3.17909	1.0345	6.9673	2.192	0.4859	4	100	60	10	0	0	0
-3.78463	1.1981	12.8241	3.388	0.1	4	100	100	80	10	0	0
-1.85518	0.4654	7.0539	3.802	5.7477	4	100	100	80	40	0	10
-1.71642	0.4491	7.9295	4.62	2.5836	4	100	100	90	70	50	0
-2.81661	0.8107	9.5696	3.398	4.9866	4	100	90	90	10	0	0
-3.72709	1.3993	11.0127	2.955	0.471	4	100	100	50	0	0	0
-1.52218	0.3787	6.5751	4.32	16.583	4	90	100	90	80	20	0
-2.17377	0.5838	9.3526	4.302	3.0078	4	100	100	100	50	30	0
-1.10097	0.269	3.2605	2.962	2.1926	4	90	80	40	20	20	0
-1.13565	0.2717	3.9748	3.5	6.238	4	100	80	50	60	0	10
-1.03398	0.2628	2.7068	2.618	4.3851	4	70	70	60	20	0	0
-1.49425	0.3604	5.8409	3.909	1.1124	4	100	90	80	50	20	0
-3.08427	0.9841	9.5491	3.096	2.7252	4	100	90	70	0	0	0
-1.52218	0.3787	6.5751	4.32	22.5664	4	90	90	100	90	10	0
-3.78463	1.1981	12.8241	3.388	0.1	4	100	100	80	10	0	0
-2.1455			3.487		*Mean*	**95.38**	**88.077**	**68.0769**	**32.3077**	**10.7692**	**5**

Transitions Cue

Gradient	*s.d.*	*Intercept*	*Ph. Boundary*	*Chi-Square*	*d.f.*	*Step 1*	*Step 2*	*Step 3*	*Step 4*	*Step 5*	*Step 6*
-0.88862	0.2611	4.6028	5.18	6.4157	4	100	80	90	90	60	20
-0.71724	0.2003	2.691	3.752	5.5111	4	90	60	70	60	40	0
-0.62768	0.1988	2.9798	4.747	6.1886	4	80	80	90	70	60	10
-0.17788	0.1747	1.6556	9.307	0.6148	4	80	80	80	70	60	70
-0.0132	0.1625	-0.723	-54.754	1.3044	4	30	40	30	20	40	30
-0.30169	0.1857	2.22	7.358	1.2356	4	80	90	80	80	60	60
0.18579	0.1717	0.2994	-1.612	1.1778	4	70	60	60	80	80	80
-0.68392	0.2862	4.566	6.676	5.9595	4	90	100	90	100	80	50
-0.76626	0.2102	2.2123	2.887	2.9104	4	90	50	60	20	20	10
-0.28827	0.3244	3.7509	13.012	4.8555	4	90	100	100	100	80	90
-0.0764	0.1753	1.3703	17.936	4.9227	4	90	70	60	90	60	80
-0.59485	0.1908	1.4913	2.507	2.6031	4	70	70	30	20	30	10
-0.21791	0.1634	1.4024	6.436	1.4251	4	70	70	80	70	50	50
-0.33919	0.2049	2.6721	7.878	3.4076	4	90	80	100	70	80	60
0.18396	0.357	2.3446	-12.745	7.8158	4	90	100	100	80	100	100
-0.55238	0.1803	1.8523	3.353	0.1512	4	80	70	50	40	30	20
-0.62863	0.2019	3.0757	4.893	0.7883	4	90	90	80	60	60	40
-0.54087	0.2898	4.2251	7.812	1.887	4	100	100	90	80	80	80
0	0.4211	3.3673	0	4.1373	4	100	100	90	90	100	100
-0.38278	0.1759	0.5767	1.507	4.3976	4	50	50	30	30	40	0
-0.33668	0.1883	2.3582	7.004	2.4799	4	90	80	70	90	70	50
-0.06902	0.152	0.3755	5.442	2.7614	4	70	40	60	40	60	50
-0.05449	0.1653	0.6583	-12.08	3.737	4	70	80	60	50	80	80
-0.58891	0.1968	2.9154	4.95	4.0144	4	100	80	70	70	30	50
-0.33628	0.1931	2.4529	7.294	1.4928	4	90	80	80	80	80	50
-0.28344	0.1588	0.9921	3.5	10.4507	4	50	70	90	20	30	40
-0.3457					*Mean*	**80.77**	**75.769**	**72.6923**	**64.2308**	**59.2308**	**49.2308**

Appendix 2: Gradient values from mle

			English listeners' results				
		Step 1	Step 2	**Step 3**	**Step 4**	**Step 5**	**Step 6**
Mean	*Both cues*	97.8022	96.7033	83.37912	46.65751	18.30128	14.00732
Mean	*Friction cue*	98.9011	98.9011	78.22802	50.83333	23.91026	5.714285
Mean	*Transition cue*	78.43407	64.83517	55.49451	42.30769	32.69231	29.40934

			Spanish listeners' results				
		Step 1	**Step 2**	**Step 3**	**Step 4**	**Step 5**	**Step 6**
Mean	*Both cues*	96.53846	91.92308	70.76923	34.61538	10.76923	4.230769
Mean	*Friction cue*	95.38462	88.07692	68.07692	32.30769	10.76923	5
Mean	*Transition cue*	80.76923	75.76923	72.69231	64.23077	59.23077	49.23077