The Role of the Input in the Development of L1 and L2 Sound Contrasts: Language-Specific Cue Weighting for Vowels

Paola R. Escudero
University of Reading

1. Introduction

The world's languages have different sounds that are contrasted with one another in language-specific ways. Acoustically, different types of information can signal a sound contrast (Lisker 1978, Nearey 1989, Scobbie 1998). For instance, English tense/lax vowel contrasts (e.g. /i/-/I/) have at least two cues, namely, the quantity (duration) and the quality (F1 and F2) of the vowel.

It seems that regional varieties do not use the cues equally. For instance, Scottish English /i/-/I/ differ almost exclusively in spectral cues. Conversely, the same Southern English vowels are produced with a considerable durational difference and the spectral difference is not as substantial.[1] Therefore, these varieties produce the cues to tense/lax vowel contrasts differently.

In perception, native speakers pay differential amounts of attention to acoustic cues (Nearey 1989, Nittrouer, Manning & Meyer 1993, Nittrouer 2000). That is, some information is primary, other secondary: there is a particular cue reliance/weighting when discriminating between sounds (Scobbie 1998). For instance, Scottish speakers perceive spectral cues as primary to tense/lax vowel contrasts, duration as secondary (Escudero 2000a, 2000b, to appear).

Children learning the sound contrasts of their first language (L1) must learn to detect the relevant acoustic cues and the relative importance that they have in production (Nittrouer 2000). It seems that the production data to which a child is exposed influence the preference for particular perceptual weightings. For instance, a child exposed to Scottish English will learn to listen to spectral information more than to durational, because the produced spectral difference is the more prominent and, therefore, the more reliable. Consequently, there may be a compelling association between the use of acoustic cues in production and the weighting/reliance of them in perception (see Raphael 1972).

In this paper, I will argue that the perception of tense/lax English vowels by Scottish, Southern English and Spanish speakers constitutes powerful evidence for the influence of production data in the perception of acoustic information. Moreover, I will claim that the analysis of perceptual attention to acoustic cues can reliably explain the difference between native and non-native perception. Before reporting the experimental study, I will review some issues in L2 perception as well as the relevant experimental research previously conducted.

2. Second-language (L2) perception of vowel contrasts

Observationally, adult perception of non-native sounds is different from that of native sounds. However, it is empirically relevant to enquire whether adult L2 speakers can learn to perceive non-native contrasts, and in what particular ways their perception is different from native (L1) perception.

Two of the dominant theories in L2 perception, the Speech Leaming Model (SLM, Flege 1995) and the Perceptual Assimilation Model (PAM, Best 1995), suggest that linguistic experience plays a predominant role (see also Polka 1995 and Polka & Werker 1994). The SLM argues that L2 speakers cannot perceive some non-native contrasts because they hear them as being perceptually equivalent; they can only learn to perceive them by detecting the L2 phonetic properties. The PAM argues for different types of L2 contrast assimilation to L1 categories: e.g. single-category assimilation for new contrasts and two-category assimilation for contrasts that already exist in the L1.

It seems that these models predict the behaviour of L2 learners confronted with specific sound contrasts on the basis of their linguistic background. For instance, in the case of the /i/-/I/ English contrast, the models will suggest that Spanish speakers of English have a single-category assimilation (perceptual equivalence): the two sounds will be assimilated to Spanish /i/.

Studies in line with the models have been conducted with different results. For instance, Fox, Flege & Munro 1995 conclude that Spanish speakers cannot discriminate between tense/lax vowel contrasts because of a lack of durational cues in their L1, so they have single-category assimilation. However, spectral cues may also be a problem: Spanish spectral differences for vowels are large; therefore, these speakers may not be able to detect the small spectral difference between American English /i/ and /I/.

On the other hand, Bohn 1995 and Flege, Bohn & Jang 1997 suggest that experienced Spanish speakers of English can learn to perceive the English /i/-/I/ contrast by means of detecting the L2 acoustic information. However, Bohn 1995 concludes that the L2 speakers use durational cues more than native speakers. Conversely, Flege et al 1997, after a statistical re-analysis of the same Bohn 1995 data, claims that the L1 and L2 subjects rely on the cues equally.

Because of the contradictory results, a pilot study testing the perception of English /i/-/I/ was devised (Escudero 2000a). The subjects were Scottish English speakers and Spanish speakers of English with more than three years of exposure to Scottish. Since Scottish /I/ is spectrally closer to Spanish /e/ than to Spanish /i/, it was thought that the L2 subjects could have a two-category assimilation, which would suggest that the type of input has a crucial role in L2 contrast development. However, most L2 subjects manifested exclusive or primary durational reliance. Beside the finding of methodological problems, a later re-analysis of the subjects' L2 background suggested that the majority had been exposed to a different English variety before coming to Scotland. Consequently, further experimentation with a larger group and better methods was considered essential for reliable conclusions.

3. Research questions and hypotheses

The study that will be reported here aimed at answering two questions, namely, 1) what influences the developmental changes in native and non-native sound contrast perception? and 2) what are the underlying differences between the native and non-native perception of sound contrasts? Two hypothesis were constructed: 1) the type of input (i.e. the particular use of acoustic cues in production) plays a crucial role in learning to perceive sound contrasts; 2) differences in native and non-native perception can be captured effectively by an analysis of the speakers' cue reliance/weighting.

4. The experimental study

60 subjects were tested in a perception experiment that aimed at measuring the perception of the vowels /i/ and /I/ in native and non-native speakers. This experiment was devised to assess the hypotheses posed in the previous section.

The subjects for the experiment were 20 speakers of Scottish English, 10 speakers of Southern English and 30 Spanish speakers of English. The subjects reported no hearing problems and agreed to participate in the experiment voluntarily. The testing of the Scottish and Spanish groups was carried out and reported previously (Escudero 2000b, to appear), whilst the Southern English subjects were recently tested and the results are reported here for the first time.

4.1. Materials

Two vowel sounds, /i/ and /I/, were synthesised using the Sensyn version of the Klatt synthesiser; they were based on naturally produced Scottish vowels. The synthesised vowels varied in height (F1 and F2) and length (duration) according to the Scottish speakers' production. For the stimulus manipulation, seven steps for each of the cues were considered and they could be visualised by means of a square graphic (Figure 1). This square would show the spectral manipulation on the vertical axis and durational manipulation on the horizontal one. In a six by six steps square, 49 different vowel sounds and 16 different vowel continua of seven stimuli each could, in principle, be considered. For this study, I used seven different continua from /I/ to /i/ and a total of 37 vowel sounds.

The synthetic /I/ and /i/ vowels constituted the bottom left and the top right stimuli in the square and the basis for the rest of the manipulations. Average values were taken for F1 and F2: the average F1 for naturally produced /I/ was 484 Hertz and 343 for /i/, while the average F2 was 1890 Hertz and 2328 Hertz, respectively. At the same time, durational values that represented an enhanced difference between Scottish /I/ and /i/ were taken. The pilot study (Escudero 2000a) had suggested that these values enhanced the secondary use of durational cues in Scottish listeners: 83 ms for /I/ and 177 ms for /i/.

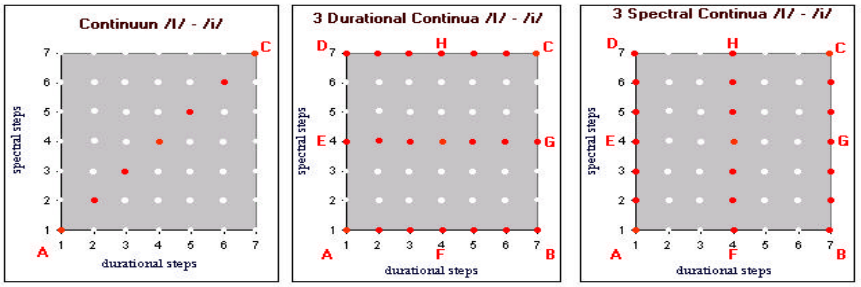

Figure 1: Three different graphs of the same square with the 7 continua.

The square had spectral cues that were prototypically Scottish and enhanced durational cues, which were seen to match the Southern English durational difference.seven continua from /I/ to /i/ were generated using the two basic square edges: one had the two cues manipulated at the same time (AC), three had durational manipulation only (AFB, EG and DHC), and the other three spectral manipulation only (AED, FH and BGC). The spectral steps were equal on the Mel scale[2] and the seven durations had six fractional steps of 1.135. To test the input hypothesis, it was thought that the union of the Scottish and the Southern English squares could elicit language-specific perception[3]. AC tested the level of vowel identification and the other six continua the cue weighting and reliance. Figure 1 above shows the diagonal, durational and spectral continua.

4.2. Procedure

The subjects were tested in a soundproof room, the Exp eriment Room at the Department of Theoretical and Applied Linguistics of the University of Edinburgh. The experiment consisted of two forced identification tests that were devised using the experiment design program Psyscope. For the first test, the subjects listened to the diagonal continuum stimuli in 10 blocks, each containing the seven vowels played in a randomised order. For the second, they heard 10 blocks of sounds, each containing the 37 vowels played in a randomised order. The subjects were encouraged to take breaks after blocks and between tests.

The subjects had to decide whether the vowel they heard was represented in the picture of a “ship” or the picture of a “sheep” by pressing one of two buttons. They had verbal and written instructions, they were told to guess if not sure and could take as much time as thought convenient to make a decision; they knew that the next trial would not appear until a decision was made.

Before the tasks, the subjects were asked for the names of the objects on the pictures (“sheep” and “ship”). The experimenter did not produce the words nor did she mention that they were different. The natives and 90% of the non-natives produced distinctive words. Most non-natives produced “sheep” with a long [i:] and “ship” with a short [i]; they said it was a length difference. Crucially, some Southern subjects but no Scottish made a similar judgement.

4.3. Results

The result section will present the group scores in the diagonal continuum (AC) and the perception of the 37 stimuli that shows the cue weighting/reliance. Likewise, it will show an attempt to organise the individual scores. Figure 2 shows the /i/ responses for the seven stimuli in AC (an average for the two identification tests). The three groups' identification lines show a slope and a category boundary. However, the slopes for the native groups (Eng. and Sco.) are steeper than the non-native (Spa.) slope. A univariate factor analysis with the diagonal continuum as the variable and language group as the factor showed that the three groups were significantly different ($p<0.05$).

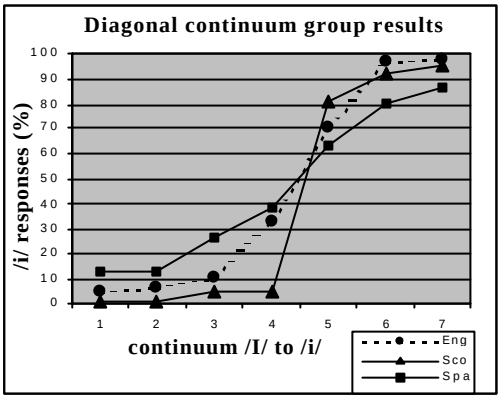

Figure 2: Diagonal contrast (AC) results.

However, a hierarchical cluster analysis shows that only 25 of the 30 subjects clustered with at least one member of the native groups. Four of the L2 subjects that did not cluster with the natives performed the two tests in an unexpected manner: they either changed their choice of buttons from test to test, or they chose "sheep" for /I/ and "ship" for /i/ (see Escudero to appear). The fifth subject could not accurately identify the sounds more than 70% of the times.[4] To sum up, we now know that all of the L1 and 25 of the L2 speakers are able to differentiate between /i/ and /I/.

For the cue weighting/reliance results, mean scores were computed, figure 3 below shows pictures with the values.[5] The pictures show the category boundaries and the cue reliance and weightings for durational (horizontal) and spectral (vertical) cues. The category boundary was drawn connecting the stimuli points where the number of 'sheep' scores was 5, i.e. 50%.[6] The spectral reliance was computed as the sum of the /i/ scores along the top row of the square (DHC) minus the sum of the /i/ scores along the bottom row (AFB), divided by 70, whilst the durational reliance is computed as the /i/ scores in the right edge (BGC) minus the /i/ scores in the left (AED), divided by 70.[7]

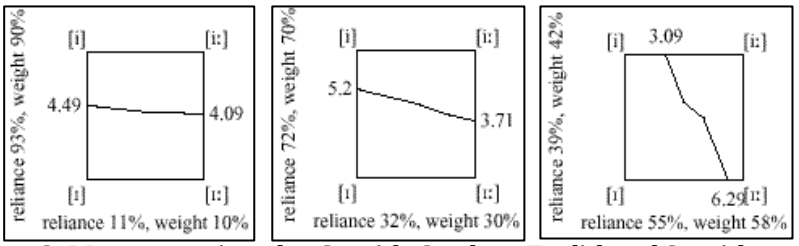

Figure 3: Mean scores, in order, Scottish, Southern English and Spanish.

Table 1: Individual cue reliance and weighting.

	Scottish			Southern			Spanish		
	spectral	duration		spectral	duration		spectral	duration	
Ams	100.0%	11.4%	hb	24.3%	57.1%	abg	47.1%	40.0%	
As	87.1%	24.3%	jo	72.9%	24.3%	adcg	100.0%	−1.4%	
Cb	100.0%	0.0%	jr	88.6%	1.4%	af	11.4%	87.1%	
Cm	80.0%	24.3%	kr	75.7%	50.0%	al	94.3%	12.9%	
Dm	98.6%	−10.0%	ma	84.3%	25.7%	arg	20.0%	94.3%	
Gk	100.0%	11.4%	mb	70.0%	42.9%	ba	−17.1%	94.3%	
Hc	95.7%	5.7%	mp	92.9%	7.1%	cc	65.7%	−1.4%	
Hm	100.0%	7.1%	mss	78.6%	20.0%	ct	85.7%	67.1%	
Jf	100.0%	4.3%	rc	45.7%	57.1%	ef	−10.0%	85.7%	
Kp	100.0%	7.1%	rh	91.4%	30.0%	fjrg	27.1%	94.3%	
Ks	100.0%	−1.4%				jad	97.1%	−7.1%	
Lh	100.0%	−2.9%				jg	77.1%	37.1%	
Lp	52.9%	57.1%				jtn	27.1%	98.6%	
Mg	98.6%	10.0%				lchr	77.1%	14.3%	
Pm	92.9%	25.7%				lg	95.7%	0.0%	
Rb	100.0%	10.0%				lj	35.7%	70.0%	
Sb	90.0%	−1.4%				manl	−7.1%	90.0%	
Sm	87.1%	10.0%				mao	−17.1%	95.7%	
Ss	92.9%	2.9%				mc	−2.9%	78.6%	
Tb	91.4%	15.7%				mcsc	81.4%	28.6%	
						mf	100.0%	−5.7%	
						mt	100.0%	−10.0%	
						mvl	−4.3%	85.7%	
						of	−7.1%	98.6%	
						pn	−4.3%	90.0%	
						snd	20.0%	88.6%	

The cue weightings are computed from the two reliances, if both are zero or greater. Thus, the weighting for the spectral cue is obtained by: spectral reliance / (spectral reliance + durational reliance) = spectral weighting, and durational weighting by: durational reliance / (spectral reliance + durational reliance) = durational weighting. Table 1 above shows the individual results for the 20 Scottish, 10 Southern English and 26 Spanish subjects.

The statistics are shown in table 2 below. The table also shows the lower and upper values of the 95% confidence interval for the mean reliances, computed with the t-distribution.

Table 2: Statistical measures.

	Scottish		Southern		Spanish	
	spectral	duration	spectral	duration	spectral	duration
Mean	93.3%	10.6%	72.4%	31.6%	39.1%	54.8%
Std. deviation	11.2%	14.4%	21.8%	19.7%	43.6%	41.6%
Std. error of the mean	2.5%	3.2%	6.9%	6.2%	8.6%	8.2%
Lower	88.1%	3.8%	56.9%	17.5%	21.5%	38.0%
Upper	98.6%	17.3%	88.0%	45.7%	56.7%	71.7%

Qualitatively, the 55 subjects could be divided in five groups following an observational criterion. G1: has an exclusive reliance on spectral cues, G2: reliance on spectral cues predominantly (durational reliance of less than 20%), G3: reliance on both cues (spectral higher than 30% and durational higher than 20%), G4: durational reliance predominantly (spectral reliance of less than 30%), and G5: exclusive durational reliance. The subject grouping is shown in table 3.

Table 3: Observational grouping by reliance.

Groups	Scottish	Southern	Spanish (25 Subjects.)
G1	5 (25%): cb, dm, ks, lh, sb.	0	6 (24%): adgc,cc,jad,lg mf,mt.
G2	11(55%):ams,gk,hc,hm jf,kp,mg,rb,sm,ss,tb.	2 (20%): jr, mp.	2 (8%): al, lchr.
G3	4 (20%): as, cm, lp, pm.	8(80%): hb,jo,kr, ma,mb,mss,rc,rh.	4 (16%): abg, jg,lj, mcsc.
G4	0	0	5 (20%): af, arg, fjrg, jtn, snd.
G5	0	0	8(32%): ba,ef,manl,mao, mc,mvl,of,pn.

5. Discussion

The discussion section will address four main issues, namely, 1) the native subjects (Scottish vs. Southern English) and the input hypothesis, 2) the non-natives and the input hypothesis, 3) duration in L2, and 4) cue reliance/weighting scores for revealing the difference between native and non-native subjects.

1) The native group results show that most Scottish speakers (80%) rely predominantly or exclusively on spectral cues, and that their mean spectral reliance is much higher than that of the Southern English. However, all Southern English speakers (most notably Jr and Mp[8]) show an appreciable spectral reliance, perhaps caused by the availability of the 'Scottish' spectral range, which must have constituted for their ears an enhancement of the acoustic spectral contrast. It was also found that all Southern English subjects had spent more than 3 years in Scotland, so they may have been sensitised to spectral cues because of such input exposure.

On the other hand, the results show that most Southern English speakers (80%) have an appreciable durational reliance, much higher than that of the Scottish. However, some Scottish subjects (especially As, Cm, Pm and Lp) manifest a durational reliance that resembles the Southern, perhaps caused by the availability of the 'Southern' durational range. The Scottish subjects with the highest durational reliance turned out to be the ones with the longest exposure to Southern English.

Consequently, it could be said that both the type of stimuli presented and the type of input throughout life influence the measured adult L1 cue reliance.

2) The non-native group shows two divergent tendencies that correlate with the regional variation of the input, namely, exclusive to predominant durational reliance for Southern English exposure and exclusive spectral reliance for Scottish exposure.

The majority of the L2 subjects (52%) clearly manifest the first tendency: eight of them (see G5 in table 3) have an exclusive durational reliance and five of them (G4) a predominant durational reliance. Crucially, the type of input to which these learners have been exposed is restricted to Southern English.

The second tendency was shown in six subjects who have exclusive spectral reliance (G1). Four of them are experienced speakers of Scottish English with an exposure limited to this variety, whereas the remaining two are inexperienced speakers of English exposed to the Scottish sounds for the first time, which suggests that they may perceive them as Spanish /i/ and /e/.

Some other performances are also shown. First, two L2 subjects have a predominant spectral reliance (G2); it is concluded that they have a Southern target language because they have been exposed to this variety only (they are very experienced Southern English speakers). Second, four other subjects show the same performance as that of most Southern English speakers (G3) and they have also been exposed to Southern English only. Finally, the subject that did not cluster with the native group (i.e. Ct) has G4 reliance; she has also been

exposed to Southern English only. That is, these seven subjects have a reliance that is predicted by the input hypothesis for a Southern English learner.

Therefore, it is argued here that the L2 perceptual development of the /i/-/I/ contrast could follow two different sequences according to the input exposure. Spanish learners of Southern English have exclusive to appreciable durational reliance with a possible single-category starting point. Conversely, learners of Scottish have exclusive spectral reliance and assimilate /i/-/I/ to an existing L1 contrast (i.e. Spanish /i/-/e/). However, the sequential nature of these developments needs empirical testing through a longitudinal study.

3) The predominant or exclusive durational reliance in the L2 group seems to cast some doubts on the crucial role of the input. That is, since none of the Southern English speakers manifest such behaviour, a further explanation not input related needs to be addressed. It is worth mentioning again that the enhancement of the cues could have caused both the native and the non-native reliances. Likewise, it may be the case that durational reliance is also preferred at some point in the L1 learning of the vowel contrast.

Bohn 1995 suggested that the use of durational cues for the perception of tense/lax vowel contrasts follows a general tendency of using durational information when spectral information is not available. He suggests that Spanish speakers are "desensitised" to small spectral differences, so that they use the most acoustically salient cue, which is duration.

Several factors may cause duration to be a more salient cue. One of them is the fact that it is a uni-dimensional cue (simple to process) and not a multi-dimensional cue like spectrum (constituted by different types of frequencies F1 and F2, therefore, difficult to process). A further factor can be the universal use of duration in the languages of the world: duration plays at least a pragmatic contrastive role universally, and in Spanish and English it signals contrastive stress.

It is suggested here that in order to test the universal primacy of either spectral or durational cues, we should investigate the L1 perceptual development of vowel contrasts. According to the input hypothesis, it is predicted that Scottish babies will not have a stage in their vowel contrast development where they rely on durational cues predominantly, or if so, it would be very short in time. Conversely, Southern English babies will definitely have a stage with even exclusive duration reliance. However, if we could test their earlier development on an enhanced cue square (Scottish spectrum and Southern duration), we might learn which of the cues is universally preferred.

4) Although the majority of the Spanish subjects have a cue reliance/weighting that differs from that of the adult native group, they can accurately identify the vowels, as tested by the AC continuum. That is, if these subjects are tested in words that differ minimally in /i/ and /I/, they will be extremely proficient. In conversational speech, they may or may not have some problems. Likewise, it may be that these L2 learners could get away for a long time without using spectral cues, until sufficient detected unreliability of the cue makes them change their strategy. Nevertheless, it could be concluded that an

analysis of the cue reliance will reveal differential strategies in L2 subjects that otherwise seem not to have problems in discriminating between vowels.

6. Conclusions

1) The type of input does influence the development of sound contrast perception. Two pieces of evidence have been shown here. Firstly, adult Scottish speakers rely on spectral cues more than adult Southern English, whilst Southern speakers rely on duration more than Scottish. That is, the final state in these native speakers' perception is different because of a difference in the input data to which they are exposed. Secondly, the L2 subjects that were exposed to Southern English use durational cues exclusively or primarily when discriminating between /i/ and /I/. Conversely, Spanish speakers exposed to Scottish have a two-category assimilation and rely on spectral information exclusively. To sum up, L1 and L2 perceptual development is decisively influenced by the nature of the input to which the learners are exposed.

2) The only effective way of finding the underlying differences between native and non-native perception is to analyse their use of acoustic information. In support of this, it was found that most L2 speakers that can successfully discriminate and identify vowel contrasts have non-native cue reliance/weighting: they perceive /i/-/I/ by using durational cues exclusively or primarily. Crucially, no native speaker relies on duration in that same way.

7. Endnotes

* Special thanks go to Dr. Paul Boersma for his very illuminating comments and statistical advice. Thanks to Prof. Michael Sharwood Smith, to the Department of Theoretical and Applied Linguistics of the University of Edinburgh and to the subjects that participated in this study. Comments could be addressed to p.r.escudero@reading.ac.uk

1. Southern English tense vowels have a further qualitative difference, formant transition, which could be another cue. In opposition, Scottish tense vowels are monophthongs, so their format transition does not vary significantly. In this paper, I will concentrate on the cues that are used in both English varieties.

2. The frequency in Mels (f) was computed as $(1000/\log 2) \log (f/1000 + 1)$, while the inverse (re-conversion to Hertz) was $1000 (10^{f/(1000/\log 2)} - 1)$.

3. With an enhanced value for both cues, the listeners can potentially rely on the two cues equally or on either of them more than on the other.

4. This was measured by subtracting the score for stimulus one from the score for stimulus seven in AC. That is AC7 – AC1 = X / 10* 100 = identification score.

5. The four Spanish subjects that performed the tests differently were not included in the L2 average score.

6. In this procedure, the four inner points on the diagonal were ignored, and only the 33 points on the three horizontal and three vertical continua were used.
7. If a subject's /i/ scores for DHC are 9, 10, 10, 10, 10, 10 and 10, and 1, 0, 1, 1, 4, 2 and 4 for AFB, her spectral reliance will be the sum of DHC minus the sum of AFB divided by 70. That is, (69−13)/70 = 0.8 = 80%. If the same subject scores 4, 6, 6, 7, 9, 10 and 10 in BGC and 1, 0, 0, 6, 9, 10 and 9 in AED, her durational reliance will be 24%.
8. Mp was the only subject that pointed out a difference in accents; she was probably making her decisions as if she were a Scottish speaker.

8. References

Best, C.T. 1995. 'A direct realist view of cross-language speech perception'. In Strange, W. (ed.). *Speech perception and linguistic experience: Theoretical and methodological issues*. Baltimore: York Press. 171-203.

Bohn, O.-S. 1995. 'Cross language speech perception in adults: first language transfer doesn't tell it all'. In Strange, W (ed.). *Speech perception and linguistic experience: Theoretical and methodological issues.* Baltimore: York Press. 279-304.

Escudero, P.R. 2000a. 'The L1 perception of English vowels and its implications for L2 acquisition: Sub-phonemic reliance in the perception of the /i/-/I/ contrast'. Paper presented at *The Third Durham Postgraduate Conference in Theoretical & Applied Linguistics,* University of Durham.

Escudero, P.R. 2000b. *Developmental patterns in the adult L2 acquisition of new contrasts: The acoustic cue weighting in the perception of Scottish tense/lax vowels in Spanish speakers*. Unpublished M.Sc. thesis, University of Edinburgh.

Escudero, P.R. to appear. The perception of English vowel contrasts: Acoustic cue reliance in the development of new contrasts. In Leather, J. & James, A (eds.). *Proceedings of the 4th International Symposium on the Acquisition of Second-Language Speech, New Sounds 2000*. University of Klagenfurt.

Flege, J.E. 1995. 'Second language speech theory: findings and problems'. In Strange, W (ed.). *Speech perception and linguistic experience: Theoretical and methodological issues.* Baltimore: York Press. 233-277.

Flege, J.E, Bohn, O. –S, and Jang, S. 1997. 'Effects of experience on non-native speakers' production and perception of English vowels'. *Journal of Phonetics* 25: 437-470.

Fox, R.A., Flege, J.E., and Munro, M.J. 1995. 'The perception of English and Spanish vowels by native English and Spanish listeners: A multidimensional scaling analysis'. *Journal of the Acoustical Society of America* 97: 2540-2550.

Gerrits, E. 2000. 'The perceptual weighting of acoustic cues by Dutch children'. Paper presented at the 8th Meeting of the International Clinical Phonetics and Linguistics Association, Queen Margaret University College, Edinburgh.

Lisker, L. 1978. 'Rapid vs. Rabid. A catalogue of acoustic features that may cue the distinction'. *Haskins Laboratory Status Report on Speech Research* 54: 127-132.

Nearey, T.M. 1989. 'Static, dynamic and relational properties in vowel perception'. *Journal of the Acoustical Society of America* 85, 5: 2088-2113.

Nittrouer, S. 2000. *Learning to apprehend phonetic structure from the speech signal: the hows and whys*. Paper presented at the VIIIth Meeting of the International Clinical Phonetics and Linguistics Association, Queen Margaret University College, Edinburgh.

Nittrouer, S., Manning, C. and Meyer, G. 1993. 'The perceptual weighting of acoustic cues changes with linguistic experience'. *Journal of the Acoustical Society of America* 94: 1865.

Polka, L. 1995. 'Linguistic influence in adult perception of non-native vowel contrasts'. *Journal of the Acoustical Society of America* 97: 1286-1296.

Polka, L. and Werker, J.F. 1994. 'Developmental changes in the perception of non-native vowel contrasts'. *Journal of Experimental Psychology: Human Perception and Performance* 20: 421-435.

Raphael, L. J. 1972. 'Preceding vowel duration as a cue to the perception of the voicing characteristic of word-final consonants in American English'. *Journal of the Acoustical Society of America* 51: 1296-1303.

Scobbie, J. 1998. 'Interactions between the Acquisition of Phonetics and Phonology'. In Gruber, K., Higgins, D., Olsen, K. and Wysochi, T. (eds.). *Papers from the 34th Annual Meeting of the Chicago Linguistic Society, II*. Chicago: Chicago Linguistic Society.