Assessing the Effects of Phonetic Training on L2 Sound Perception and Production

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1. Introduction

On the assumption that perception leads production in L2 Speech learning (Flege, 1995) and perceptual accuracy enhancement eventually leads to changes in production, phonetic training, and perceptual training in particular, has been shown to result in L2 learners' improved performance in the discrimination and identification of L2 sounds (Iverson & Evans, 2007; Iverson *et al.*, 2005; Logan & Pruitt, 1995; Pisoni & Lively, 1995) as well as in L2 speech sound production (Bradlow *et al.*, 1999). However, the effectiveness of phonetic training is not a direct consequence of the amount of exposure to L2 sounds learners receive or whether that exposure is more or less intense in time, rather its effectiveness depends to a great extent on how successful it is in directing learners' attention and L2 sound-processing ability to the phonetic cues native speakers attend to. The phonetic training paradigm that has proved most successful in doing this is the High Variability Phonetic Training (HVPT) method, which directs learners' attention towards relevant phonetic cues by presenting them with high-variability stimuli in different phonetic contexts (e.g., Bradlow *et al.*, 1997; Lively *et al.*, 1993) obtained from natural words produced by different speakers. However, although phonetic learning appears to be enhanced by exposure to acoustic variability, Jongman and Wade (2007) have shown that phonetic training with minimal variability focusing on target phonetic prototypes may be more effective in promoting the acquisition of difficult sound contrasts, suggesting that phonetic training methods may have to be adapted to the specific L2 sound contrasts to be acquired by learners, as the effectiveness of the treatment will also depend to a great extent on the nature of the interaction between the learners' L1 and L2 phonetic systems.

The present study further explores this line of research by investigating the effects of six two-hour phonetic training sessions on the perceptual and productive competence of a group of advanced Catalan/Spanish bilingual learners of English who have been exposed to the L2 mainly through formal classroom instruction in an EFL context in Catalonia, Spain. In this learning context L2 input is very limited and very likely to be strongly foreign-accented, so at the time of testing the participants in the study were very unlikely to have developed phonetic categories for the L2 sounds the training was specifically based on, and this was evident in the degree of foreign-accentedness of their L2 speech. The focus of the phonetic training sessions was on four L2 sound contrasts Catalan/Spanish learners of English have been reported to have difficulty with (Cebrian, 2002, 2006; Mora, 2007; Mora & Fullana, 2007), namely /p/-/b/ and /t/-/d/ in word-initial position and /iː/-/ɪ/ and /æ/-/ʌ/, and the approach was of the HVPT type, mainly (but not only) focusing on the target sound contrasts. The phonetic dimensions the training was based on presented crucial cross-linguistic differences. In English, the word-initial voicing contrast in /p/-/b/ and /t/-/d/ is realized mainly through VOT duration differences and the presence/absence of vocal cord vibration during closure is a secondary cue often missing in connected speech (Cruttenden, 2001), whereas in Catalan and Spanish closure voicing rather than VOT differences is used primarily to implement the contrast. The vowel pairs /iː/-/ɪ/ and /æ/-/ʌ/ present durational differences but the contrasts, which are lacking in Catalan and Spanish, are mainly qualitative, with Catalan and Spanish /i/ and /a/ occupying, respectively, a portion of the vowel space occupied by /iː/-/ɪ/ and /æ/-/ʌ/. Consequently, English /iː/-/ɪ/ and /æ/-/ʌ/ are typically assimilated to the Catalan and Spanish /i/ and /a/ vowel categories. Vowel duration is not used contrastively in Catalan and Spanish, but previous research has shown that Catalan/Spanish learners of English often overrely on temporal cues in the production of these vowels (García-Lecumberri & Cenoz, 1998; Mora & Fullana, 2007). The phonetic training method used in the present study was especially designed to enhance the use of VOT duration rather than closure voicing in the production of word-initial oral stops and to enhance the use of spectral rather than durational differences in the production of the /iː/-/ɪ/ and /æ/-/ʌ/ vowel contrasts.

The effectiveness of the phonetic training administered to the experimental group is measured in terms of how successful it is in changing learners' perceptual ability to categorize /p/, /b/, /t/ and /d/ stimuli (drawn from VOT continua) and to correctly discriminate between /iː/-/ɪ/ and /æ/-/ʌ/, and in improving learners' accuracy in the production of /p/, /b/, /t/ and /d/ through the use of longer VOT duration and shorter closure voicing and in the production of /iː/-/ɪ/ and /æ/-/ʌ/ through the use spectral rather than temporal differences.

Phonetic training studies do not only have interesting pedagogical implications for L2 pronunciation instruction but the findings obtained through this research paradigm also have a bearing on crucial issues in L2 speech learning, such as the ability of the adult perceptual system to remain adaptive to new input and change as learning progresses. Phonetic training studies also provide us with a context for testing the role of input quantity and quality in L2 speech learning in a controlled way, a possibility that has remained elusive in L2 speech learning studies carried out in naturalistic learning contexts.

2. Method

2.1 Participants

A total of thirty-six participants (32 females, 4 males) between the ages of 19 and 48 (mean age 21.62) took part in a pretest-posttest experiment: two groups of bilingual Catalan/Spanish undergraduate students of English Philology (NNS; *N*=29) at the University of Barcelona −grouped into experimental (*N*=18) and control (*N*=11)− and a control group of NSs of British English (*N*=7) who provided base-line data. Only the experimental group went through a six-week phonetic training period, after which all groups did the same perception and production tasks again (post-test). The volunteering learners had been learning English formally for 8 years and had not had any previous phonetic training experience or experience abroad. The age at which they began learning English ranged from 8 to 12 (mean 9.15). They were given course credit for their participation.

Table 1. Design of the study

Participants		Pre-Test (T1: October 2006)	Phonetic Training (November-December 2006)	Post-Test (T2: December 2006)	N
NNS	Experimental	✓	✓	✓	18
	Control	✓	×	✓	11
NS Control		×	×	✓	7
Total					36

2.2 Phonetic training

The experimental group participated in six two-hour training sessions specifically dealing with the articulatory and distributional properties of English oral stops (/p t k b d g/) and the English vowel system, particularly the spectral and durational features distinguishing /iː/-/ɪ/, /æ/-/ʌ/-/ɑː/ and /uː/-/ʊ/. Intensive practice based on various perception and production tasks was preceded by an introductory theoretical part consisting of articulatory-visual description, exposure to NS models and contrastive analysis. The learners received *immediate* or *trial-by-trial* feedback during the sessions, *cumulative* feedback at the end, and *weekly* feedback. Finally, group sessions were complemented with individual 15-minute working sessions based on computer-based visual feedback.

The training sessions were administered on days 1 to 6 and consisted of one-hour practice on English oral stops (aspiration and voice onset time as a cue for contrasting voiceless vs. voiced stops in English; closure, hold and release phases for the articulation of plosives; contexts of aspiration and distribution of English stops; cross-linguistic differences; spectrographic feedback) and one-hour practice on English vowels (English vowel system; focus on the tense-lax (/iː/-/ɪ/; /uː/-/ʊ/) and front-central-back (/æ/-/ʌ/-/ɑː/) contrasts; description of the tongue movement and lips position).

A multiplicity of tasks were used (Logan & Pruitt, 1995: 351) in order to: (a) develop the perceptual and productive abilities of the participants; (b) modify their performance on certain pronunciation aspects (i.e., unaspirated stops in word-initial position, overuse of the length cue to distinguish the tense-lax vowel contrast); and (c) permit generalisation or transfer to novel stimuli or tasks outside the training (see Table 2). Some other features related to the stimuli used in the training were: use of multiple talkers and natural tokens in multiple acoustic and phonetic contexts (Pisoni & Lively, 1995); use of natural tokens rather than synthetic stimuli*;* gradual transitions from easily identified stimuli to more difficult stimuli; introduction to the IPA phonetic symbols; attention to individual differences through team work; and participants' familiarisation with technology (headphones, microphones, speech analysis software, etc.).

Table 2. Structure of the training sessions

Variety of tasks	
Perception tasks	Production tasks
▪ Identification	Articulatory (visual) description of sounds
▪ Discrimination	▪ Imitation
▪ Phonetic transcription	▪ Reading aloud (from word to sentence)
▪ Exposure to NS sounds	▪ Dialogues, tongue-twisters...
Input from multiple male & female NS talkers	
Natural tokens in word and sentence contexts	
Auditory & visual feedback	
Oral stops	Vowels
Spectrograms (VOT duration); Listening	Computer-based visual feedback

Subject-controlled stimulus presentation followed the mainstream training sessions. The main advantage is the learners' possibility of focusing on stimuli that are particularly difficult to perceive, or even have an increased number of presentations, but also keep a record of their performances. Individual 15-minute sessions took place once a week in a quiet room with the visual pronunciation software EyeSpeak (Chan, 2004; www.eyespeak.info), which provided learners with an opportunity to use a visual approach to learn and practice vowels by allowing them to see the position of the vowel on a graph representing a F1-F2 vowel space and its degree of height/backness, check the vowel length and obtain immediate feedback (score) and opportunities for self-correction. It was also useful for working on self-monitoring aspects of learning, going as further as possible according to one's level and interests, and taking one's own decisions during the learning process.

2.3 Perception and production tasks

2.3.1 Speech perception tasks

Two tests of speech perception were administered to participants. Learners' accuracy in oral stop and vowel perception was assessed by means of a forced-choice lexical identification task based on VOT continua and an AX vowel discrimination task, respectively.

In the identification task the participants were asked to perceptually identify one member of a minimal pair contrasting voicing. Two 15-step VOT continua per contrast (C1: p/b, C2: t/d) ranging from 0 to 70 ms were used to generate 15 modified instances of each word, which were randomly presented twice to participants for identification (see Table 3). The two VOT continua were made from natural speech and with the test consonant in word-initial position (e.g., *pack-back*) using Praat software (Boersma, 2007). Voiced-to-voiceless VOT continua (e.g., *bin* to *pin*) were obtained by inserting a 70-ms period of voiceless breath between the release burst of a voiced oral stop and the onset of the following vowel at 5 ms steps. The result was 15 different VOT values from 0ms to 70ms voicing lag in 5ms increments for each VOT continuum, forming continua of identifiable words (see Table 4). Participants were thus presented with 120 randomized stimuli for identification (2 contrasts x 2 continua x 15 5-ms steps x 2 repetitions), produced by a female and a male speaker of British English, at 1-second intervals distributed into eight 15-stimuli blocks separated by 10-second pauses. Trial items were presented only once and in random order, and were preceded by 15 practice items from a k/g VOT continuum (*coat-goat*).

Table 3. VOT duration values (ms) for each of the stimuli forming the b/p and t/d continua

VOT continua															
Number of stimuli	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
Stimuli created by modifying VOT duration (ms)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70
C1	*back – pack* (2)														
	bin – pin (2)														
C2	*Dan – tan* (2)														
	deans – teans (2)														

Table 4. Items in the oral stops identification test

PERCEPTION: forced-choice lexical identification task					
VOT continua		Items for ID	Repetitions	Steps	Total
C1	/p/-/b/	*pack/back*	2	15	30
		pin/bin	2	15	30
C2	/t/-/d/	*tan/Dan*	2	15	30
		teans/deans	2	15	30
Stimuli for identification					120

In the AX discrimination task (see Table 5), learners were presented with 3 repetitions of 24 monosyllabic minimal pairs (e.g., *feel-fill*) and 6 distractors (e.g., *wheel-wheel*) containing the vowel contrasts /iː-ɪ; æ-ʌ/ in a variety of phonetic environments (CVC, CVCC, CCVC and CCVCC), after a previous familiarization phase. The participants' task was to indicate whether the two stimuli in each of the randomized 90 word-pairs distributed in 6 sections of 15 trials were the *same* or *different.*

Table 5. Items in the AX vowel discrimination test

PERCEPTION: AX discrimination task				
Minimal pairs		Distractors	Repetitions	Items
/iː/	11	3	3	42
/ɪ/	(*feet-fit*)	(*chip-chip*)		
/æ/	13	3	3	48
/ʌ/	(*cap-cup*)	(*run-run*)		
Word-pairs for discrimination				90

2.3.2 Speech production tasks

Accuracy in production was assessed by measuring VOT durations in oral stops and formant frequency and length in vowels in words elicited through a delayed repetition technique (Flege *et al.*, 1995) where elicited target words are embedded in mini-dialogues, as in Mora and Fullana (2007) (See Table 6).

Table 6. Items in the production test

PRODUCTION: Delayed Sentence Repetition Task					
Word-initial oral stops + Vowels			Words	Repetitions	Total
voiceless	/p/	/iː ɪ æ ʌ/	2	3	24
	/t/	/iː ɪ æ ʌ/	2	3	24
voiced	/b/	/iː ɪ æ ʌ/	2	3	24
	/d/	/iː ɪ æ ʌ/	2	3	24
Elicited oral stops and vowels					96

2.3.3 Target sounds

Early and late learners of English in immersion contexts whose L1 has short-lag voiceless stops (VOT of 0-30 ms, such as Catalan and Spanish) have been found to produce English voiceless stops inaccurately, with values that fall short of the typical 40-80ms VOT range of English monolinguals (Flege & Eefting, 1987; Flege *et al.*, 1998). Studies using VOT continua in a perceptual identification task have also found robust cross-linguistic differences. For example, Spanish-English bilinguals have been found to identify stimuli as instances of the /p/ category at shorter VOT durations than English monolinguals, suggesting that the VOT-based category boundaries of NSs and NNSs are placed at different locations along a VOT continuum (Flege & Schmidt, 1995; Flege *et al.*, 1996). It has also been shown that short-term laboratory training may be effective in modifying NNS VOT-based perceptual boundaries between English voiced and voiceless oral stops (Bohn & Flege, 1993). To better quantify oral stop identification data, studies on the development of phonemic categorization (e.g., Hazan & Barrett, 2000) and language deficits and speech perception (e.g., Joanisse *et al.*, 2000) have reported modified slopes in logistic curve functions as a result of training or experience, where lower b1 values represent steeper slopes, indicating higher degree of categoriality in perception, whilst the location of the category boundary is a useful measure for assessing the effect of VOT duration on stimuli categorization.

The target contrasting vowels were selected on the basis of their relative difficulty for Catalan/Spanish learners of English. On the one hand, L1 Catalan and Spanish lack a tense-lax distinction for high vowels /iː/-/ɪ/ and have a vowel (/i/) closer to English /iː/ (Flege & Mackay, 2004). On the other hand, a front-back distinction for open/low vowels /æ/-/ʌ/ is also lacking in the L1 of participants, and therefore substituted by a relatively front /a/. The difficulty is further explained by the prejudice induced by the frequent orthographic spelling with <u> or <o> (Cruttenden, 2001). The quality generally obtained is thus a too fronted and lip-rounded vowel modified in the direction of the back sound /ɑː/.

Given the L1-L2 differences in vowel space and the language-specificity characterising speech perception, cross-language research has documented L2 learners' failure to detect subtle spectral differences between contrasting vowels which overlap a single L1 category and, consequently, their tendency to produce them without substantial durational or spectral difference, resulting in a merged L1-based category (single-category assimilation) (Best, 1995; Best & Tyler, 2007; Flege, 1995). Other studies have shown, however, non-native's overreliance on durational cues non-existing in the L1 as a non-native stategy to perceive and produce vowel contrasts (Cebrián, 2006; Escudero, 2000), along with L2 vowels produced with formant frequency values intermediate to the values of NSs of the L1 and L2 (Flege *et al.*, 1997).

Based on this evidence, the present study sets out to explore the extent to which accuracy in the perception and production of oral stops and vowel contrasts by Catalan/Spanish late learners of English may be improved through a six-week phonetic training. On the one hand, the training was predicted to: (1) improve learners' accuracy in oral stop production through increased VOT durations, (2) shift the learners' perceptual boundary locations (between voiced and voiceless stops) towards longer durations along a VOT continuum and (3) show higher degree of categoriality of the responses and heightened sensitity to VOT through a steeper slope of the identification curves. On the other hand, the training was also hypothesized to improve learners' accuracy in: (1) vowel discrimination through increased English-like cue weighting and (2) the production of vowels through new phonetic categories formation and proper use of spectral/durational cues.

3. Results

3.1 Perception and production of /p/-/b/ and /t/-/d/

3.1.1 Effects of training on perception

The participants' performance on the forced-choice lexical identification task was assessed by computing an identification function for each VOT continuum (C1: b-p and C2: t-d) that plots the percentage of one of the two alternative responses, particularly the voiceless stop response (e.g., *pack* or *tan*), for each of the stimuli making up the 15-step continua. A decrease in percent /p/ and /t/ identification after training, particularly in the stimuli with a VOT duration ranging between 25 and 35 ms, suggests that phonetic training seems to have increased participants' sensitivity to VOT as a voicing cue because longer VOT durations are necessary to obtain a /p/ or /t/ response from participants at T2.

To better quantify the identification data, each participant's categorization curve was fitted to a logistic function using the Logistic Curve Fit function in SPSS (Figure 1), yielding mean slope coefficients (b1 values between 0 and 1 per stimulus) for each group and continuum (see Table 7) as a mesure of degree of categoriality of responses, with lower values representing less shallow slopes, meaning more precision, that is, more categorical perception of oral stops. Since training was expected to have a positive effect on the categorical perception of the target contrasts, the participants undergoing the treatment were expected to obtain steeper logistic curves than untrained listeners.

The effect of training on the participants' identification of oral stops was also assessed by means of another measure: mean category boundaries (the 50% crossover points of the fitted labeling curve) were computed for each subject, group and continuum using the formula –Ln(b0)/Ln(b1), where b0 is the constant value of the logistic curve (Keating, 2004). Because the experimental group was expected to label a greater proportion of stimuli as b/d rather than p/t after training, it was hypothesized that /b/-/p/ and /t/-/d/ category boundaries would be located at higher VOT duration on the continuum at T2. Table 7 displays data from the two parameters extracted to characterize each identification function: the slope of the fitted curve, taken as an indication of degree of categoriality in identification, and the phonetic category boundary, showing the effect of VOT duration on categorization.

Table 7. Identification data: slope coefficient (between 0 and 1) and boundary values (stimuli 1-15)

	p/b VOT continuum			**t/d VOT continuum**		
	T1	T2	Wilcoxon	T1	T2	Wilcoxon
Experimental group	boundary = 0.60 slope = 0.552	boundary = 2.44 slope = 0.495	* p =.016 * p =.020	boundary = 6.19 slope = 0,334	boundary = 6.84 slope = 0.315	*p = .031 p = .84
Control group	boundary = -0.41 slope = 0.549	boundary = 6.32 slope = 0.530	p = .477 p = .929	boundary = 1.66 slope = 0.387	boundary = 6.99 slope = 0.328	p = .477 p = .075
NS group	boundary = 1.15 slope = 0.514			boundary = 7.24 slope = 0.278		

When Catalan/Spanish speakers' identification responses were compared across continua, C1 and C2 were found to yield very different curves. Whereas the /t/-/d/ continuum produced the expected semi-categorical S-shaped curve, the curve obtained for the /b/-/p/ continuum did not conform to the behaviour typically triggered by this type of identification task based on acoustic continua (where stimuli at both ends of the continuum have 0% or 100% identification rate) (Figure 1). It is worth noting, however, that a similar trend for both C1 and C2 indicated that perceptual accuracy was slightly affected by training in both cases: NNS curves at T2 were found to be slightly steeper than at T1 and aproximated the NS curve in steepness.

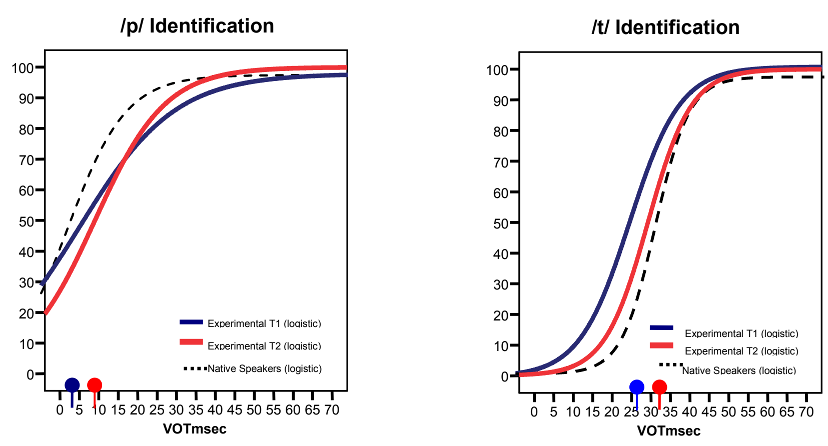

Figure 1. Logistic curves showing the experimental group's percent identification of /p/ and /t/, before and after training, as compared to that of native-speakers

In order to further explore the effect of training on the identification of the /p/-b/ and /t/-/d/ contrasts, planned comparisons were performed on the mean slope coefficients and mean boundary values between and within groups using non-parametric tests, Mann-Whitney and Wilcoxon. Examination of the average logistic curves of the participants indicated steeper slopes for the /t/-/d/ than for the /p/-/b/ contrast (see Figure 2), suggesting that /t/-/d/ was labeled more sharply than /p/-/b/ along the VOT continuum.

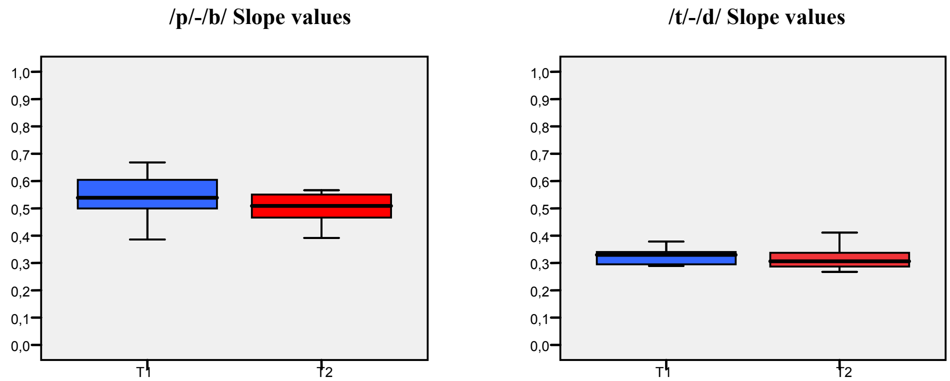

Figure 2. Box plots showing mean slope values of the experimental group for b/p (left) and t/d (right) identification before and after training: slope values at T1 (blue), slope values at T2 (red)

Comparisons between the mean slopes at T1 and T2, separately assessed for each participant and contrast, yielded no significant differences between experimental and control groups ($p > .05$). However, within-groups comparison revealed significant effects of the training on the slope values for the /p/-/b/ contrast (Z=-2.330, p= .020), but not for /t/-/d/ (p>.05). After phonetic training, the experimental group displayed significantly lower slope values for b/p identification, resulting in a less shallow slope indicating a slight increase in degree of categoriality in perception. Although the /t/-/d/ contrast is characterized by higher degree of categoriality of responses at both T1 and T2 than the /p/-/b/ contrast, the slightly steeper slope obtained after training for /t/-/d/ did not reach statistical significance. Whereas the slope of the /p/-/b/ identification function of the experimental group increased significantly in steepness, no significant increase was observed for the NNS control group from T1 to T2 for none of the contrasts (p>.05).

Similarly, between-group comparisons performed on the boundary values of experimental and control group did not reach significance. The within-group analysis showed, however, significant differences in the boundary values of the trainée group between T1 and T2, for both /p/-/b/ (Z=-2.417, p= .016) and /t/-/d/ (Z=-2.154, p= .031) identification (Figure 3). As expected, the perceptual boundaries of Catalan/Spanish learners –located at lower VOT values when compared to NSs– were shifted to longer VOT values at T2, meaning that phonetic training had a slight effect on the modification of non-native patterns of perceptual identification towards more English-like use of VOT as a cue for word-initial stop identification. Tests conducted for the NNS control group showed no significant differences overall between their mean boundary values at T1 and T2.

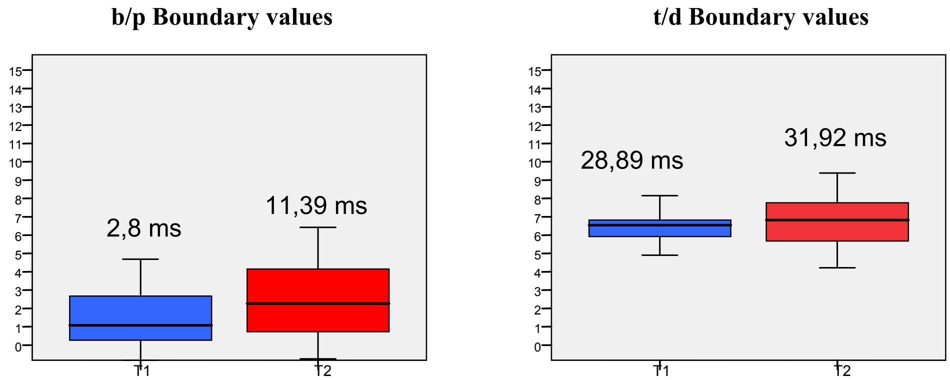

Figure 3. Box plots showing mean slope boundary values of the experimental group for b/p (left) and t/d (right) identification before and after training: boundary values at T1 (blue), boundary values at T2 (red)

All in all, Catalan/Spanish learners in the present study did not exhibit equal sensitivities to VOT in the perception of the contrasts /p/-/b/ and /t/-/d/. Whereas the alveolar stops were categorized far more consistently than the bilabial stops, significant differences between experimental and NS control groups as regards the slope of the /t/-/d/ function at T1 (Z=-4.237, p= .000) persisted at T2 (Z=-3.187, p= .001). Paired comparisons between the experimental and the NS groups revealed NSs had mean boundaries located at longer VOT durations and steeper slopes than NNSs. As opposed to NSs, NNSs do not perceive English stops with the same accuracy at different places of articulation, they tend to have mean ID boundaries at shorter VOT locations, and mean boundaries are less sharp and subjected to more variability. However, modified boundary and slope values after training suggest the Catalan/Spanish learners acquired a slightly higher sensitivity to VOT as a cue for identifiying /p/-/b/ and /t/-/d/ as a result of phonetic training.

3.1.2 Effects of training on production

Accuracy in learners' production of /p/-/b/ and /t/-/d/ was assessed by means of VOT duration measures (2 words x 4 contexts x 3 repetitions x 2 data collection times x 3 subject groups = 864 VOT measurements per oral stop). VOT values (in ms) were obtained by measuring the distance between the onset of the release burst and the onset of vocal fold vibration in wide-band spectrograms. When /b d/ were prevoiced, *lead* VOT was measured from the beginning of low-frequency periodicity to the onset of the release burst, and assigned negative values.

Mean VOT values obtained at T2 were higher than those at T1 (see Table 8). Paired-samples t-tests revealed no significant T1-T2 differences for the control group, but the experimental group showed a significant increase in VOT for /p/. The significant differences found between the experimental and the NS group at T1 as regards /p/ (t(23)=-6.24, p= .000) and /t/ (t(23)=-3.38, p= .003) had disappeared after training according to the t-tests performed on the T2 data (p> .05), which confirms the positive impact of phonetic training upon mean VOT duration. Production of alveolar /t/ −which is dentialveolar in the learners' L1 and therefore more dissimilar to English /t/ than Catalan/Spanish /p/ is to English /p/− showed less improvement at T2, as it was already pronounced more accurately before training. The fact that English and Catalan/Spanish /t/ do not share the same place of articulation probably prevents learners from directly assimilating English /t/ to their L1 /t/, thus promoting the formation of a new phonetic category for English /t/, which allows learners to produce English /t/ with more native-like VOT values. However, the mean VOT values obtained at T2 are still far from the NS average. The mean VOT for /p/ and /t/ in the present study was almost intermediate to the means observed for monolingual Spanish adults in Caramazza's (1973) study (26 ms) and the NS values from the present study.

Table 8. Mean VOT duration (ms) at T1 and T2 (*SD* in parenthesis) and significant differences (*) at α=.05

	Mean VOT (ms)											
	/p/			/b/			/t/			/d/		
	T1	T2	*p*=	T1	T2	*p*=	T1	T2	*p*=	T1	T2	*p*=
Experimental group	33.68 (14.59)	55.79 (30.16)	*.037	-54.69 (34.89)	-62.47 (24.56)	.413	59.11 (19.41)	68.96 (27.21)	.069	-42.72 (24.52)	-55.82 (26.18)	.071
Control group	33.46 (17.90)	32.70 (19.31)	.704	-34.64 (42.10)	-33.86 (28.52)	.937	45.87 (10.74)	54.78 (15.32)	.259	-57.18 (59.79)	-56,63 (57.27)	.957
NS group	76 (10.20)		-	-39.75 (49.06)		-	86.18 (13.71)		-	-21.86 (45.72)		-

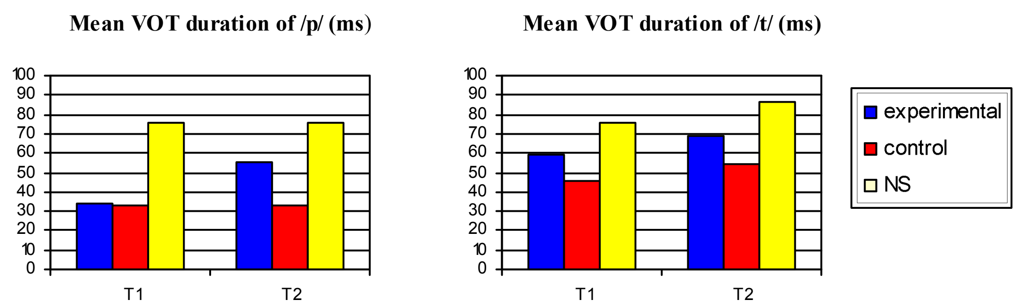

Figure 4. Mean VOT (ms) of /p/ and /t/ at T1 and T2

A paired-samples t-test confirmed that the production of /b d/ did not benefit from training (cf. Mackay *et al.*, 2001). The experimental group showed a higher amount of prevoicing in /b/ and /d/ than NSs at T2, and the mean VOT durations of /b/ and /d/ at T1 and T2 (see Table 8) were not significantly different. Similarly, independent-samples t-tests showed no significant advantage of the experimental group over the control group in this respect.

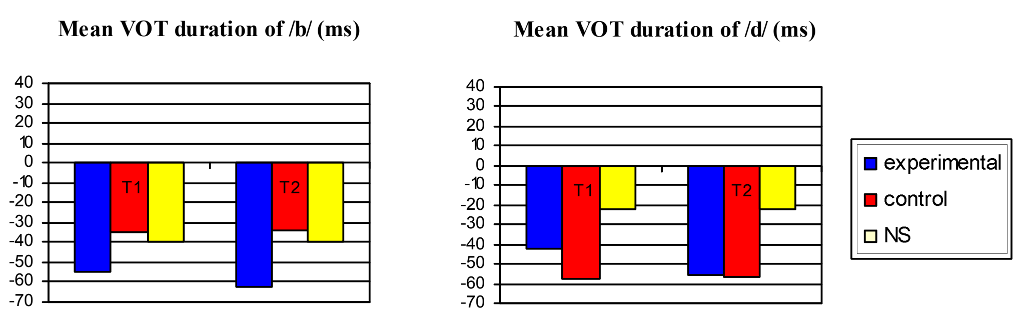

Figure 5. Mean VOT (ms) of /b/ and /d/ at T1 and T2

3.2 Perception and production of /iː/-/ɪ/ and /æ/-/ʌ/

3.2.1 Effects of training on perception

Mean percent correct vowel discrimination scores were computed for each subject and vowel contrast (see Table 9). As expected, overall significant T1-T2 differences were observed in the discrimination scores of the experimental group ($t(17)=-3.64$, $p=.002$), but not the control group, for both /iː/-/ɪ/ ($t(17)=-2.66$, $p=.017$) and /æ/-/ʌ/ ($t(17)=-3.32$, $p=.005$), which suggests that phonetic training had significantly affected learners' discrimination ability positively. A more detailed statistical analysis conducted for each of the vowel contrasts independently indicated a similar amount of significant increase for the /iː/-/ɪ/ contrast (8.75%) and the /æ/-/ʌ/ contrast (9.65%) from T1 to T2, although /æ/-/ʌ/ was discerned at higher discrimination rates than /iː/-/ɪ/.

Despite the fact that the experimental group improved significantly in their ability to discern the vowel contrasts, the significant differences between NSs' and NNSs' performance observed at T1 ($t(23)=-6.27$, p=.000) persisted at T2 ($t(23)=-4.22$, $p=.000$), suggesting that Catalan/Spanish learners of English continued to perceive /iː ɪ æ ʌ/ in a nonnative-like manner after training (see Figure 6).

Table 9. Mean percent correct vowel discrimination (*SD* in parenthesis) and significant differences (*) at α=.05

PERCEPTION % Correct discrimination		Total		/iː/-/ɪ/		/æ/-/ʌ/	
		T1	T2	T1	T2	T1	T2
NNS	Experimental group	70.45 (9.85)	*79.71 (9.07)	64.82 (12.26)	*73.57 (9.63)	75.21 (10.74)	*84.90 (11.19)
	Control Group	69.32 (9.87)	75.52 (7.89)	62.26 (14.04)	69.15 (9.56)	75.29 (11.60)	80.89 (8.06)
NS		95.04 (4.66)		95.67 (4.90)		94.51 (5.00)	

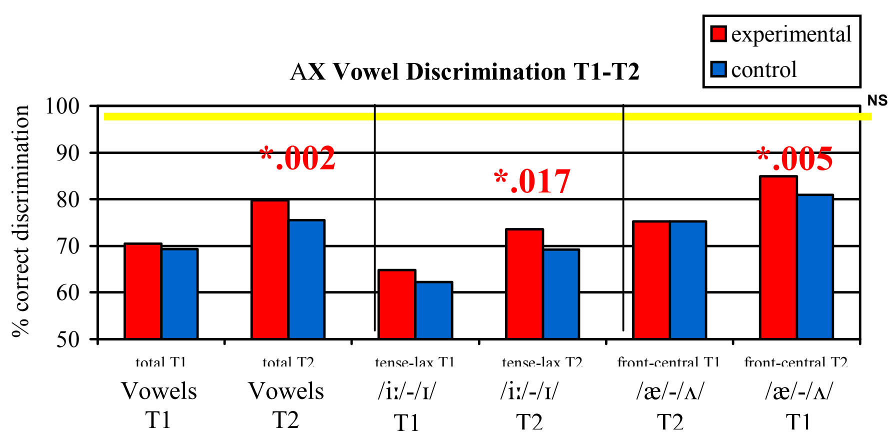

Figure 6. Mean percent correct vowel discrimination

3.2.2 Effects of training on production

Accuracy in L2 vowel production was assessed by means of F1 and F2 frequency (Hz) and duration measures (ms) (8 words x 3 repetitions x 2 data collection times x 3 subject groups = 1708 F1-F2 frequency and duration measurements). Formant frequencies were measured by obtaining the mean F1 and F2 frequency of a 20 ms window placed at the midpoint of the steady state of the vowel. Spectral contrasts were then calculated by measuring the distance between the F1 and F2 values of the contrasting vowels, independently. Vowel duration was measured (ms) from the first positive peak in the periodic portion of the signal to the onset of the following consonant, for each vowel and environment. Formant frequency analysis was expected to reveal significant differences between groups since training was likely to affect the degree of tongue height (F1) and the degree of tongue frontness/backness (F2), making learners produce the target vowels with more English-like frequency values (lower F1 values). The analysis of F1 and F2 differences between the two members of each vowel pair was expected to yield a larger distance between the contrasting vowels /iː/ and /ɪ/, and between /æ/ and /ʌ/, for the experimental group than for the control group at T2.

Formant frequency analysis showed no significant differences overall in L2 vowel production as a result of phonetic training (see Table 10), and revealed significant differences between experimental and NS control groups at T1 and T2, especially for the tense-lax contrast. In general, learners produced the target vowels with significantly higher F1 values than NSs, indicating that tongue position for L2 vowels was too low in the mouth. A closer inspection of F1 and F2 values revealed, however, modest gains as regards the production of the tense-lax contrast on the part of the experimental group, but not the control group. Paired-samples t-tests showed that, in all cases, NNSs produced /iː/ ($t(16)=2.74$, $p=.015$) and /ɪ/ ($t(16)=2.38$, p=.030) with significantly lower F1 values, indicating that vowels were produced with greater vowel height after training. On the other hand, no significant T1-T2 differences were found for the F1 and F2 values of /æ/ and /ʌ/ ($p>.05$).

Table 10. Mean F1-F2 measures of vowels and significant differences (*) at α=.05

Mean F1-F2		**/iː/**		**/ɪ/**		**/æ/**		**/ʌ/**	
		F1	**F2**	**F1**	**F2**	**F1**	**F2**	**F1**	**F2**
Experimental	T1	541.34	1590.17	553.86	1617.22	928.66	1401.03	803.21	1350.85
	T2	*515.41	1623.22	*525.03	1555.67	908.33	1353.83	787.96	1326.73
Control	T1	547.52	1647.18	546.99	1691.54	890.47	1420.49	816.47	1337.45
	T2	*495.79	1745.44	503.03	1787.44	879.85	1394.31	*773.97	1350.02
NS		376.36	2260.67	476.07	1648.54	814.83	1404.33	657.93	1223.74

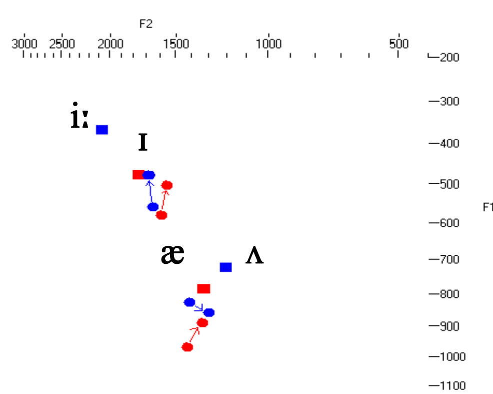

Figure 7. F1-F2 vowel formant plot for the English vowels pronounced by NSs (■ ■) and NNSs (● ●) at T1 and T2, with arrows showing amount and direction of change

Statistical analysis of the quality differences between the target vowel categories revealed significant differences between the experimental and NS groups for the F1 ($t(23)=-4.03$, $p=.001$) and F2 ($t(7.07)=-2.47$, $p=.043$) values of /iː/-/ɪ/, suggesting that, unlike NSs, Catalan/Spanish learners did not rely on quality differences to implement the /ɪ/-/iː/ contrast but did it in a non-native way to produce /æ/-/ʌ/ (see Table 11 and Figure 8).

Table 11. Distance between the F1-F2 measures of /iː/-/ɪ/ and /æ/-/ʌ/

Differences between phonetic categories		/iː/-/ɪ/		/æ-/ʌ/	
		F1	**F2**	**F1**	**F2**
Experimental	T1	22.74	96.67	125.44	86.02
	T2	29.94	180.32	120.37	105.62
Control	T1	37.06	103.54	82.22	143.54
	T2	30.78	118.73	105.88	67.11
NS		99.70	612.13	165.90	200.26

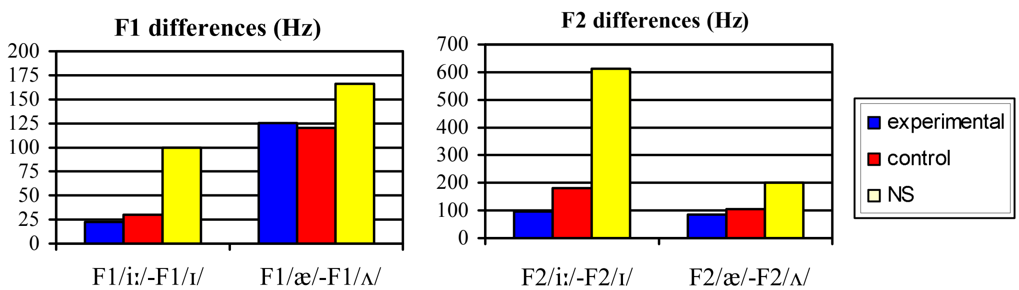

Figure 8. Spectral contrast (F1 and F2 differences) in /iː/-/ɪ/ and /æ/-/ʌ/

On the other hand, length was consistently used as a vowel differentiation cue by learners, especially for /iː/-/ɪ/. In all cases, the experimental and control groups produced L2 vowels with significantly larger contrasting duration than NSs and t-tests revealed no significant differences between L2 production at T1 and T2, which suggests that phonetic training did not affect learners' over-reliance on durational cues in L2 vowel production in the direction of a more English-like cue weighting (see Table 12 and Figure 9).

Table 12. Mean duration of /iː ɪ æ ʌ/

Mean Duration (ms)		/iː/			/ɪ/			/æ/		/ʌ/	
		/p_s/	**/t_m/**	**/b_ tʃ/**	**/p_g/**	**/t_k/**	**/t_m/**	**/p_k/**	**/t_g/**	**/p_n/**	**/t_k/**
Experimental	T1	254.17	190.54	155.03	172.3	132.82	160.94	187.37	217.30	171.63	153.90
	T2	234.56	*209	153.87	176.52	131.03	160.26	188.72	221.59	180.43	145.43
Control	T1	200.43	196.12	146.20	149.87	124.83	157.71	176.79	199.94	177.18	139.62
	T2	206.37	202.64	153.26	162.57	134.11	162.44	198.20	219.19	192.62	144.31
NS		131.75	181.60	119.23	126.56	87.95	110.62	98.48	180.13	123.72	86.16

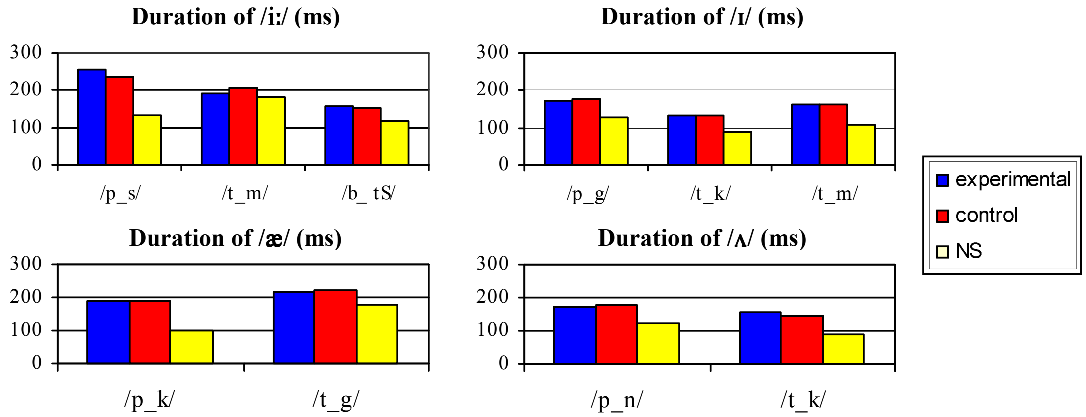

Figure 9. Mean duration (ms) of /iː/, /ɪ/, /æ/ and /ʌ/

4. Discussion and conclusions

The present study investigated the effects of phonetic training on the perception and production of four L2 sound pairs by bilingual Catalan/Spanish learners of English. Two of the target L2 sound pairs examined were consonant phonemes (/p/-/b/ and /t/-/d/) contrasting voicing in word-initial position through the presence/absence of closure voicing and VOT duration, contrasts that are relatively difficult to master for Catalan/Spanish learners because VOT duration is not used contrastively to implement the voicing contrast in their L1. The other two target L2 sound pairs were vowel phonemes contrasting primarily in quality (/iː/-/ɪ/, /æ/-/ʌ/), but also exhibiting durational differences (/iː/ and /æ/ are longer than /ɪ/ and /ʌ/, respectively) and are also known to present difficulty for Catalan/Spanish learners of English because these contrasting vowel pairs occupy each an area of the vowel space that is filled by a single vowel category in Catalan and Spanish (/i/ and /a/) and because neither Spanish nor Catalan make use of vowel duration contrastively. The main aim of the present study was to measure the effect of six two-hour especially designed phonetic training sessions on learners' accuracy in the perception and production of these English sound contrasts. Learners' gains in perceptual competence were assessed by measuring the degree of categoriality in their identification of /p/, /b/, /t/, /d/ stimuli drawn from VOT continua and the percent correct discrimination scores of /iː/-/ɪ/ and /æ/-/ʌ/ obtained in an AX minimal-pair discrimination task. Learners' accuracy gains in the production of the sound pairs /p/-/b/ and /t/-/d/ were assessed by measuring the VOT durations of /p/, /b/, /t/ and /d/ productions elicited in a variety of phonetic contexts by means of an imitation task using a delayed repetition technique. Accuracy gains in the production of /iː/, /ɪ/, /æ/ and /ʌ/ were assessed by measuring the F1 and F2 frequency values of learners' vowel productions (also obtained in the same imitation task) and comparing the size of the difference between the contrasting vowels in each pair with respect to their F1 and F2 frequency values obtained before (T1) and after (T2) the phonetic training sessions.

The results do not reveal overall significant gains in perceptual and productive competence for all the sound pairs examined, but learners were found to either perceive or produce some of the target sounds examined significantly more accurately after training, suggesting that the six two-hour phonetic training sessions administered to the experimental group were successful in achieving improvement in pronunciation accuracy. In particular, after training the degree of categoriality in the identification of /p/ and /b/ was found to increase significantly, and a significant shift towards longer VOT durations in the location of the /p/-/b/ and /t/-/d/ category boundaries was also observed. Percent correct discrimination scores for /iː/-/ɪ/ and /æ/-/ʌ/ were found to increase significantly after training. In production, learners were found to produce /p/ with significantly longer VOT after training and the increase in VOT duration in /t/ approached significance (p=.069), but the negative VOT duration of their voiced counterparts (/b/, /d/) did not shorten after training. Accuracy in vowel production, as measured through F1 and F2 frequency values, did not improve significantly as a result of training, which was found not to have an effect either on learners' reliance on duration differences to produce the /iː/-/ɪ/ and /æ/-/ʌ/ vowel contrasts.

Taken together, the results suggest that the size of the effect of phonetic training on learners' perceptual and productive competence differs greatly according to phonetic dimension and sound contrast and appears to be different also in perception and production. However, the positive effects of the phonetic training observed in oral stop perception and production and vowel discrimination strongly suggest that a short phonetic training treatment may enhance L2 pronunciation accuracy in the short term provided L2 sound-specific perception and production training tasks are used. Follow up studies are necessary to test how effective phonetic training is in achieving the long-term retention of phonetic knowledge and in enhancing the development of pronunciation strategies and skills for the perception and production of L2 sounds. Further research is also needed in order to devise effective phonetic training methods capable of enhancing the formation of phonetic categories for L2 sounds and thus improve learners' pronunciation in the L2. In particular, the differential effects of audio-visual and articulatory training methods on learners' perceptual and productive competence in the L2 may prove to be a very fruitful research area leading to findings that could usefully be applied to L2 pronunciation instruction.

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Appendix 1

AX Vowel Discrimination Task

Section 1

1	C2	/mæd-mʌd/
2	C1	/tɪm-tiːm/
3	C1	/fiːl-fɪl/
4	C2	/drʌg-dræg/
5	C2	/kʌt-kæt/
6	C2	/pʌn-pæn/
7	C2	/læmp-læmp/
8	C1	/wiːl-wiːl/
9	C1	/biːtʃ-bɪtʃ/
10	C2	/tʌb-tæb/
11	C1	/fiːt-fiːt/
12	C2	/dæn-dʌn/
13	C1	/pɪk-piːk/
14	C2	/læk-lʌk/
15	C2	/kæt-kæt/

Section 2

16	C1	/liːv-lɪv/
17	C2	/piːl-pɪl/
18	C1	/lɪst-liːst/
19	C1	/slɪp-sliːp/
20	C1	/tʃiːk-tʃɪk/
21	C1	/dɪp-diːp/
22	C1	/riːtʃ-rɪtʃ/
23	C2	/rʌn- rʌn/
24	C2	/kæp-kʌp/
25	C2	/bæt-bʌt/
26	C2	/drʌnk-drænk/
27	C2	/kæm-kʌm/
28	C1	/tʃɪp-tʃɪp/
29	C2	/krʌʃ-kræʃ/
30	C1	/bɪt-biːt/

Section 3

31	C1	/slɪp-sliːp/
32	C1	/wiːl-wiːl/
33	C2	/kæm-kʌm/
34	C1	/fiːt-fiːt/
35	C1	/fiːl-fɪl/
36	C1	/riːtʃ-rɪtʃ/
37	C1	/dɪp-diːp/
38	C2	/kæt-kæt/
39	C2	/drʌg-dræg/
40	C2	/læk-lʌk/
41	C1	/biːtʃ-bɪtʃ/
42	C2	/pʌn-pæn/
43	C2	/krʌʃ-kræʃ/
44	C2	/rʌn- rʌn/
45	C1	/bɪt-biːt/

Section 4

46	C1	/pɪk-piːk/
47	C2	/kʌt-kæt/
48	C1	/tʃɪp-tʃɪp/
49	C1	/tʃiːk-tʃɪk/
50	C2	/tʌb-tæb/
51	C1	/lɪst-liːst/
52	C2	/kæp-kʌp/
53	C1	/piːl-pɪl/
54	C2	drʌnk-drænk/
55	C2	/mæd-mʌd/
56	C2	/læmp-læmp/
57	C2	/dæn-dʌn/
58	C2	/bæt-bʌt/
59	C1	/tɪm-tiːm/
60	C1	/liːv-lɪv/

Section 5

61	C1	/pɪk-piːk/
62	C1	/dɪp-diːp/
63	C1	/wiːl-wiːl/
64	C1	/fiːt-fiːt/
65	C1	/riːtʃ-rɪtʃ/
66	C2	/læk-lʌk/
67	C2	/læmp-læmp/
68	C2	/rʌn- rʌn/
69	C1	/piːl-pɪl/
70	C2	/pʌn-pæn/
71	C1	/fiːl-fɪl/
72	C2	/bæt-bʌt/
73	C2	/kʌt-kæt/
74	C1	/tʃɪp-tʃɪp/
75	C2	/kæt-kæt/

Section 6

76	C2	/drʌnk-drænk/
77	C2	/mæd-mʌd/
78	C2	/tʌb-tæb/
79	C2	/drʌg-dræg/
80	C1	/liːv-lɪv/
81	C1	/biːtʃ-bɪtʃ/
82	C1	/tʃiːk-tʃɪk/
83	C1	/bɪt-biːt/
84	C2	/kæp-kʌp/
85	C2	/dæn-dʌn/
86	C1	/tɪm-tiːm/
87	C2	/kæm-kʌm/
88	C1	/slɪp-sliːp/
89	C2	/krʌʃ-kræʃ/
90	C1	/lɪst-liːst/

Appendix 2

Sentence Repetition Task

A	What is the the next word?
B	*BEACH* is the next word.
A	What is the the next word?
You	_____ *is the next word.*

Part 1

but	pig	peel	Dan
dad	dean	bat	big
bag	team	duck	deep
peace	tea	pun	pan
din	bees	tub	Tim
bitch	tag	bunch	punch
pill	dinner	done	tick
beach	pack	tuck	tab

Part 2

pan	bat	but	peel
beach	bag	pun	Dan
done	Tim	tab	team
tag	din	peace	bunch
duck	dean	tick	tuck
punch	deep	dinner	tub
big	dad	pig	bitch
tea	bees	pack	pill

Part 3

pan	tea	tub	bees
dean	bitch	duck	done
pig	tab	tag	tick
din	bag	pill	deep
dinner	but	pack	beach
Dan	bunch	big	peace
punch	team	peel	Tim
tuck	bat	pun	dad