The Effect of Time and Frequency Manipulation on Syllable Perception in Developmental Dyslexics

Ken I. McAnally[1], Peter C. Hansen, Piers L. Cornelissen[2] & John F. Stein

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1) Present address: Air Operations Division, Aeronautical and Maritime Research Laboratory, PO Box 4331, Melbourne 3001, Australia.

2) Present address: Psychology Department., Ridley Building, Newcastle University, Newcastle upon Tyne, NE1 7RU, UK.

ABSTRACT

Many people with developmental dyslexia have difficulty perceiving stop consonant contrasts as effectively as other people and it has been suggested that this may be due to perceptual limitations of a temporal nature. Accordingly, we predicted that perception of such stimuli by listeners with dyslexia might be improved by stretching them in time - equivalent to speaking slowly. Conversely, their perception of the same stimuli ought to be made even worse by compressing them in time - equivalent to speaking quickly. We tested 15 children with dyslexia on their ability to identify correctly consonant-vowel-consonant (CVC) stimuli which had been stretched or compressed in the time domain. We also tested their perception of the same CVC stimuli after the formant transitions had been stretched or compressed in the frequency domain. Contrary to our predictions, we failed to find any systematic improvement in their performance with either manipulation. We conclude that simple manipulations in the time and frequency domains are unlikely to benefit the ability of people with dyslexia to discriminate between CVCs containing stop consonants.

The Effect of Time and Frequency Manipulation on Syllable Perception in Developmental Dyslexics

Many children fail to acquire competent reading skills despite adequate educational opportunity. A surprising number of these poor readers have normal or above normal abilities in other areas, so their reading problems are unexpected. Rutter and Yule (1975) attempted to capture this sense of unexpected reading failure by using statistical criteria. They defined children as specifically retarded readers (i.e. developmental dyslexics) if their reading ability was significantly lower than that predicted on the basis of age and IQ. Stanovich (1991) has criticized IQ discrepancy measures of developmental dyslexia because of the fact that poor reading ability tends to be correlated with poor performance on IQ tests. Consequently, some authors have suggested that a mismatch between reading and spoken comprehension might provide a better measure (Gough & Tunmer, 1986). Nevertheless, the majority of published research has used some version of the IQ discrepancy measure to define developmental dyslexia. For the sake of consistency, therefore, we have used the same definition.

Many people with developmental dyslexia have difficulty perceiving consonant contrasts. Both single case and group studies have shown that people with dyslexia confuse the identity of a range of fricatives in spoken consonant-vowel (CV) syllables (Cornelissen, Hansen, Bradley & Stein, 1996; Masterson, Hazan & Wijayatilake, 1995). Furthermore, at least six studies have been published in which categorical perception of speech sounds was investigated in dyslexic individuals by using synthetic CV continua (/ba/-/da/ and /da/-/ga/ which differ in the frequency of the second formant transition; /bath/-/path/ and /sa/-/sta/ which differ on voice onset time) (Brandt & Rosen, 1980; Godfrey, Syrdal-Lasky, Millay & Knox, 1981; Manis, McBride, Seidenberg, Doi & Custodio, 1993; Reed, 1989; Steffens, Eilers, Gross-Glenn & Jallad, 1992; Werker & Tees, 1987). While people with dyslexia demonstrate categorical perception of synthetic CV continua containing stop consonants, the slopes of the boundary curves for the listeners with dyslexia tend to be less steep than normal. This suggests that the categorical boundaries between different speech sounds may be blurred in people with dyslexia. Thus they may confuse phonetically similar speech sounds more readily than normal.

It has been proposed that people with dyslexia have deficits in temporal processing of acoustic information (Tallal, 1980) which may limit the accuracy of their identification of consonant-vowel F2 and F3 transitions (Tallal & Stark, 1981). In support of temporal processing deficits in dyslexia, Watson (1992) showed that reading-disabled college students were impaired in their ability to detect differences in the duration of tones but not in their ability to detect changes in frequency. If people with dyslexia have temporal processing deficits, their perception of speech stimuli might be improved by stretching these stimuli in time. Conversely, their perception of the same stimuli might be made even worse by compressing them in time. We examined the ability of dyslexic and non-dyslexic children to identify synthetic stop consonant CVC stimuli which were compressed or expanded in time, while retaining the original frequency content.

Watkins, Baldeweg, Richardson & Gruzelier (1995) and McAnally & Stein (1996) have shown that adult dyslexics are more impaired in their discrimination of frequency than of either tone or gap duration. Therefore, we also investigated identification of synthetic CVC stimuli in which the range of the formant frequency transitions was compressed or expanded.

METHOD

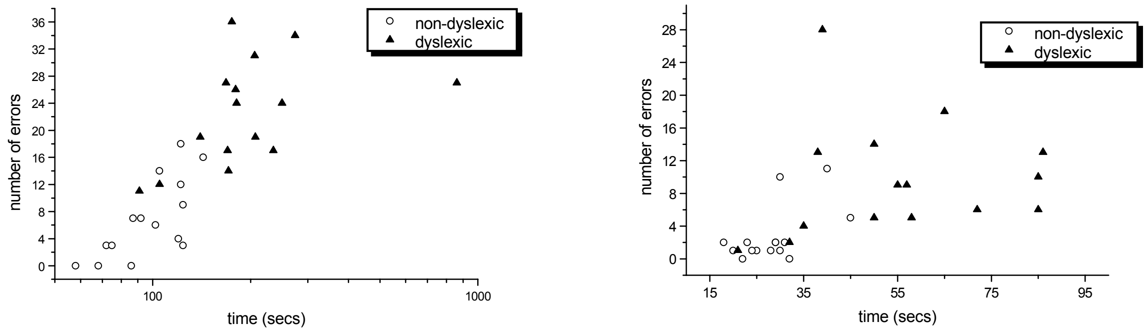
Participants

Fifteen dyslexic boys who had been assessed by the same educational psychologist participated in the experiment (mean age was 182 months, standard deviation (sd) 11.8; mean IQ [British Ability Scales, BAS] was 108, sd 8.1). Diagnosis was based on standard IQ discrepancy criteria where reading age is two or more standard deviations below the mean for children of similar age and IQ. Fifteen boys from the same school with no history of reading problems also participated (mean age was 183 months, sd 10.8; mean IQ [BAS] 124, sd 11.3). All participants had normal hearing thresholds to pure tones between 125 Hz and 8 kHz. Independently from the psychologist's assessments, we administered two reading tests. Subjects were given a list of real words (Schonell, 1950) or nonsense words (Castles & Coltheart, 1993) and were instructed to read the lists as quickly and as accurately as possible. The participants with dyslexia made more errors and took longer to read both the word and non-word lists than did participants with no history of reading problems (Figure 1 and Table 1).

Table 1
Participant characteristics

	Dyslexic n=15		Non-dyslexic n=15	
	Mean	(sd)	mean	(sd)
Word list: errors	22.3	(7.8)	6.8	(5.9)
Word list: time (s)	227.6	(181.8)	100.0	(25.4)
Nonword list: errors	9.5	(6.9)	2.7	(3.4)
Nonword list: time (s)	55.2	(20.4)	28.4	(7.1)
Chronological age (months)	182.4	(11.8)	182.6	(10.8)
IQ (BAS)	107.8	(8.1)	124.4	(11.3)

Fig. 1



Real word reading (Schonell)

Nonword reading

Figure 1. Two plots of the total number of reading errors that each subject made against the time it took them to complete the reading lists. The first plot is for the real word reading test and the second plot for the nonword reading test. Participants with dyslexia are represented by solid triangles while non-dyslexic participants are represented by open circles.

In view of the group difference in IQ, we carried out an analysis of covariance on the reading error data taking both age and IQ into account. The children with dyslexia were significantly poorer readers than those without, even when age and IQ were taken into account (Table 2). It is clear from these data that the children with dyslexia had persistent reading problems.

Table 2
Analysis of covariance for word and nonword reading errors.

	Explanatory variable	F ratio (df)	p value
Word errors	Participant group	22.1 (1,26)	$p<0.0005$
	Chronological age	3.4 (1,26)	$p>0.05$
	IQ (BAS)	0.1 (1,26)	$p>0.5$
Nonword errors	Group	7.8 (1,26)	$p<0.05$
	Chronological age	6.7 (1,26)	$p<0.05$
	IQ (BAS)	0.3 (1,26)	$p>0.5$

The ease of identification of the baseline and manipulated synthetic speech stimuli was assessed using four adults who were ignorant of the aims of this study.

Experimental stimuli

We used a speech synthesiser (Klatt, 1980) at a sample rate of 10 kHz to generate a baseline set of consonant-vowel-consonant (CVC) stimuli. Synthesizer parameters were generated by the IPOX interface (Dirksen & Coleman, 1995) to synthesise an adult male voice. The stimuli contained all the stop consonants in either onset or rime positions separated by the vowel sound / / (/b k/, /p k/, /d k/, /t k/, /g k/, /k k/, /k g/, /k b/, /k p/, /k d/ and /k t/). An example of the synthesizer parameters for the stimulus /d k/ is given in Appendix A. Differences from the default output from IPOX are listed in Appendix B for /k b/ and /k p/. We applied a uniform stretch or compression to the time-course of all synthesiser parameters, allowing us to generate a time-stretched (x1.6) and a time-compressed (x0.6) version of each stimulus. This algorithm did not alter the frequencies of the fundamental or the formants but altered their rate of change. Informal listening showed the effect of this algorithm; it made the CVC syllables sound like someone speaking either very quickly (time compression) or very slowly (time stretching).

We also generated stimuli in which the range of the transitions of formant frequency was either stretched or compressed, but the steady-state formant frequency of the vowel remained unchanged. However, their duration remained unchanged. We applied a frequency stretch or compression algorithm (around the steady-state value) to the formant frequencies of the same baseline set of synthesizer parameters to generate a frequency-stretched (x1.4) and a frequency-compressed (x0.5) version of each baseline stimulus. Informal listening showed that the effect of this algorithm was similar to the difference between someone enunciating clearly (frequency stretch) or lazily (frequency compression). Spectral plots of the 4 kinds of manipulated stimuli are shown in Figure 2 below.

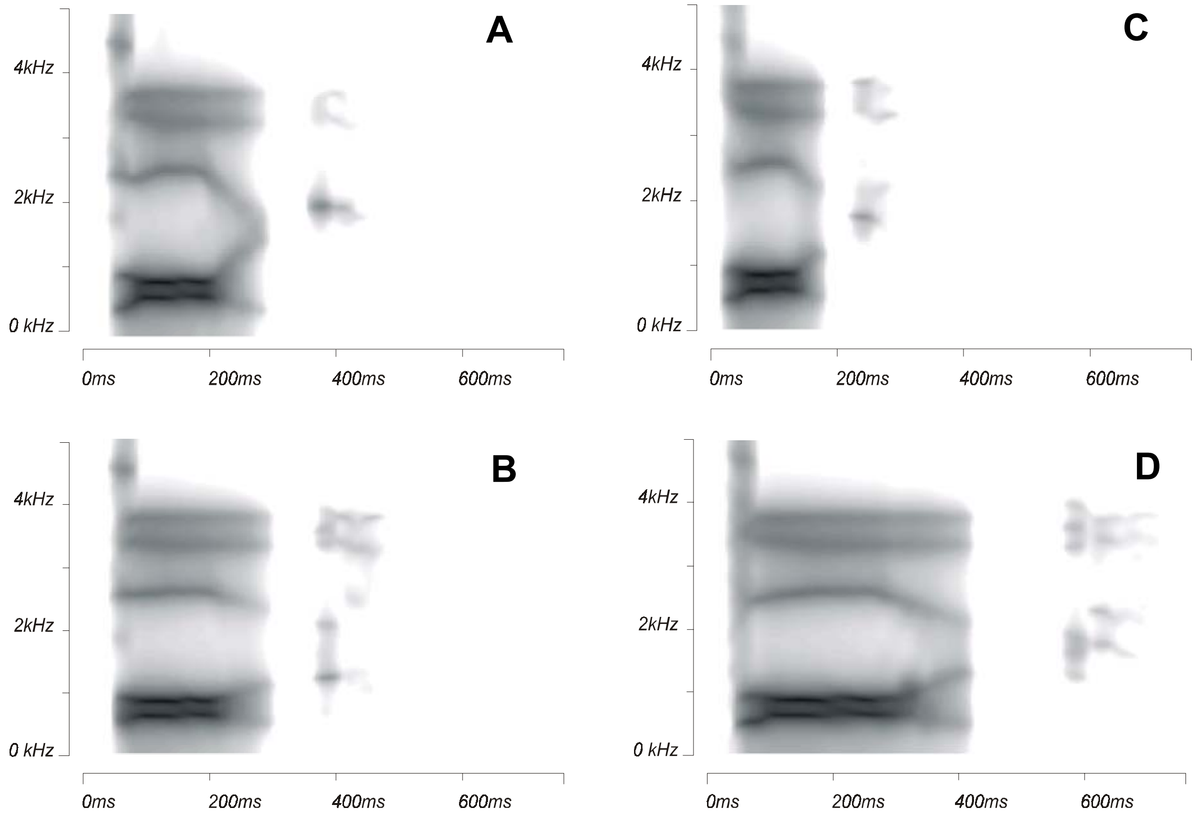


Figure 2. A: Frequency expanded version of /b k/. B: Frequency compressed version of /b k/. C: Time compressed version of /b k/. D: Time expanded version of /b k/. Darker shading represents increasing amplitude.

Synthetic speech stimuli were played by an IBM compatible PC equipped with a 16-bit sound card (Sound Blaster 16, Creative Labs.) and presented diotically through headphones (Sennheiser HD520II) at a sound pressure of 70dB (with respect to 20μPa).

Data collection

Each trial was comprised of a single interval in which a stimulus was chosen randomly (without replacement) from the set of stimuli. Listener responses were recorded using a multiple choice window presented on a computer monitor. The possible responses were represented on screen in a vertical array of 11 boxes, each of which contained one of the letter strings (bok, pok, dok, tok, gok, kok, kog, kob, kop, kod and kot). Once participants had decided which of the stimuli they had heard, they selected the appropriate response box with the mouse. The computer logged the stimulus and the response. The positions of the letter strings in the array of boxes were randomized on every trial to control for any tendency for participants to prefer selecting particular box locations.

Before the experiment, participants were asked to read aloud the letter strings within each response box and occasionally they made mistakes. Participants who made mistakes were asked to repeat the task until they could read through the letter strings perfectly.

The experiment was run in 12 blocks under computer control (Canadian Speech Research Environment). The first block was a training condition during which subjects were familiarized with the synthetic speech stimuli. Participants listened to five repetitions of each of the 11 baseline CVC stimuli, presented in random order. Visual feedback was provided about whether the responses were correct. The next 10 blocks of trials provided the main experimental data. Each block comprised a presentation of each of the five versions of each CVC (baseline, time stretched, time compressed, frequency stretched and frequency compressed) in random order without replacement in a background of white noise (signal-to-noise ratio of 15 dB). Low-level noise was used to reduce the children’s performance enough for us to measure any potential benefit from the time or frequency manipulations. If we had not added white noise, many children’s performances might have been close to ceiling even with the baseline stimuli.

To control for possible difficulties that the children with dyslexia may have had reading the letter strings in each response box, the stimuli were presented visually as letter strings in the final block. Each of the 11 letter strings was presented 10 times. On each trial, the stimulus letter string appeared on screen for 500 ms before the response boxes were presented.

RESULTS

Table 3 shows the proportion of correct responses in the visual control task, the noise free training condition and the experimental condition for the baseline stimuli only. The high scores on the visual control task show that dyslexic and non-dyslexic children were able to at least recognize the visual stimuli.

Table 3 Correlations between IQ and the percentage correct responses in the speech task.

Stimulus type	Correlation coefficient	p value
Baseline	0.36	$p>0.05$
Frequency compressed	0.29	$p>0.1$
Frequency stretched	0.31	$p>0.1$
Time compressed	0.41	$p>0.5$
Time stretched	0.28	$p>l.1$

The fact that performance was so good on the visual control task and that the children were able to read the visual stimuli aloud suggest that participants' responses were unlikely to be confounded by the problem of reading from the multiple choice response box. For the auditory stimuli presented in quiet, the adults scored 94.1 % correct, showing the baseline stimuli to be well discriminable and identified. Chance performance in the task would have resulted in 9 % correct identification. The time and frequency modified syllables in noise were all also well identified by the adult listeners (baseline 84.1%, time compressed 63.6 %, time stretched 69.1 %, frequency compressed 75.2 % and frequency stretched 73.6 %), suggesting that these syllables did not cross perceptual boundaries following modification.

Both dyslexic and non-dyslexic children scored less well than the adults for the auditory stimuli presented in quiet and as expected, the performance of both groups of children was impaired by the combination of white noise masking and the removal of feedback.

Table 1 showed that the mean IQ of the children with dyslexia was lower than the mean IQ of the controls. However, Table 4 shows that the correlation between IQ and the performance in the speech task (for the five kinds of stimuli) was always weak and insignificant. Therefore IQ was excluded from the following analyses.

Table 4
Percent correct scores on the speech tasks (baseline stimuli only) and visual control task

	CHILDREN			ADULTS
	Visual control	Spoken CVC in quiet with feedback	Spoken CVC in noise without feedback	Spoken CVC in quiet with feedback
Dyslexic	91.8%	70.4%	54.9%	N/A
Non-dyslexic	96.1%	76.5%	63.9%	94.1%

As a first step towards analyzing the effects of our interventions, we carried out separate repeated measures analyses of variance (ANOVA) of responses to the time and frequency modified stimuli, comparing responses of participants with or without dyslexia. Fig. 3 shows a plot of the means and standard deviations for the ANOVAs.

Fig. 3

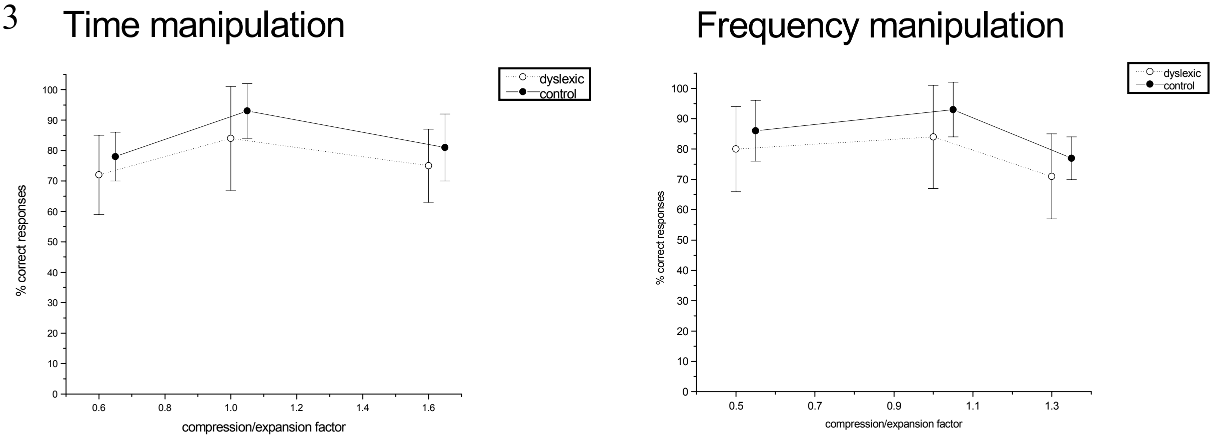


Figure 3. Plots of the percentage correct responses comparing children with and without dyslexia when listening to the time and frequency compressed or expanded stimuli, embedded in white noise. Error bars represent 1sd. The x-axis represents the expansion factor so a value of 1.0 is equivalent to the baseline stimulus.

It is clear from these plots that neither expansion nor compression of time or frequency resulted in an improvement over baseline in either group of participants. The appropriate probability distribution for proportionate data is binomial because we were calculating the proportion of errors made. We therefore applied an arcsine transform (Snedecor & Cochran, 1967) to the data. For the time manipulated stimuli, while the main effect of stimulus-type was significant ($F_{2,56} = 32.6$, $p < 0.0005$) neither the main effect of group (i.e. dyslexic versus non-dyslexic) nor the interaction between group and stimulus-type was significant ($\underline{F}_{1,28} = 2.9$, $\underline{p} > 0.1$ and $\underline{F}_{2,56} = 0.56$, $\underline{p} > 0.5$ respectively). For the frequency manipulated stimuli we found similar results. While the main effect of stimulus-type was significant ($\underline{F}_{2,56} = 64.7$, $\underline{p} < 0.0005$) neither the main effect of group (i.e. dyslexic versus non-dyslexic) nor the interaction between group and stimulus-type was significant ($\underline{F}_{1,28} = 2.7$, $\underline{p} > 0.1$ and $\underline{F}_{2,56} = 0.64$, $\underline{p} > 0.5$ respectively). Both time and frequency manipulation affected CVC identification, but contrary to our hypothesis they reduced performance. Moreover, these effects were the same whether children had dyslexia or not.

Our baseline stimuli varied over two dimensions: place of articulation and voice onset time (VOT). Similarly, in the studies of the categorical perception of CV sounds in people with dyslexia (see earlier), both place of articulation and VOT were varied. These studies showed that people with dyslexia exhibited categorical boundaries which were less sharp than normal. Hence, in our study, it is possible that time stretching might have improved the perception of isolated pairs of CVCs which were differentiated by a single phonetic feature like VOT (e.g. /b k/ versus /p k/). Yet such an effect could have been masked in the above analysis by being averaged together with the more common effect of degraded performance for the majority of CVCs. Therefore, we sought isolated effects of this kind by looking at the consequences of our manipulations on the identification of the individual phonetic features: place of articulation and VOT. For place of articulation, we counted the percentage of correct responses within six phonetic categories: labial onsets (/b k/ and /p k/), alveolar onsets (/d k/ and /t k/), palatal onsets (/g k/ and /k k/), labial rimes (/k b/ and /k p/), alveolar rimes (/k d/ and /k t/) and palatal rimes (/k g/ and /k k/). For VOT, we counted the percentage of correct responses within four phonetic categories: voiced onsets (/b k/, /d k/ and /g k/), unvoiced onsets (/k k/, /p k/ and /t k/), voiced rimes (/k b/, /k d/ and /k g/) and unvoiced rimes (/k k/, /k p/ and /k t/). Within each category, we plotted the percentage of correct responses as a function of stimulus compression or expansion as shown in Figures 4, 5, 6 and 7. In each plot, a value on the x-axis of one represents the baseline stimuli, values less than one represent compression and values greater than one represent expansion. We looked for improvement in performance over the baseline as a consequence of time or frequency manipulation.

As can be seen in Figures 4, 5, 6 and 7 we could find none for either dyslexic or non-dyslexic listeners. Instead, both time and frequency stretching tended to have a detrimental effect on identification of these CVCs.

DYSLEXICS

Fig. 4

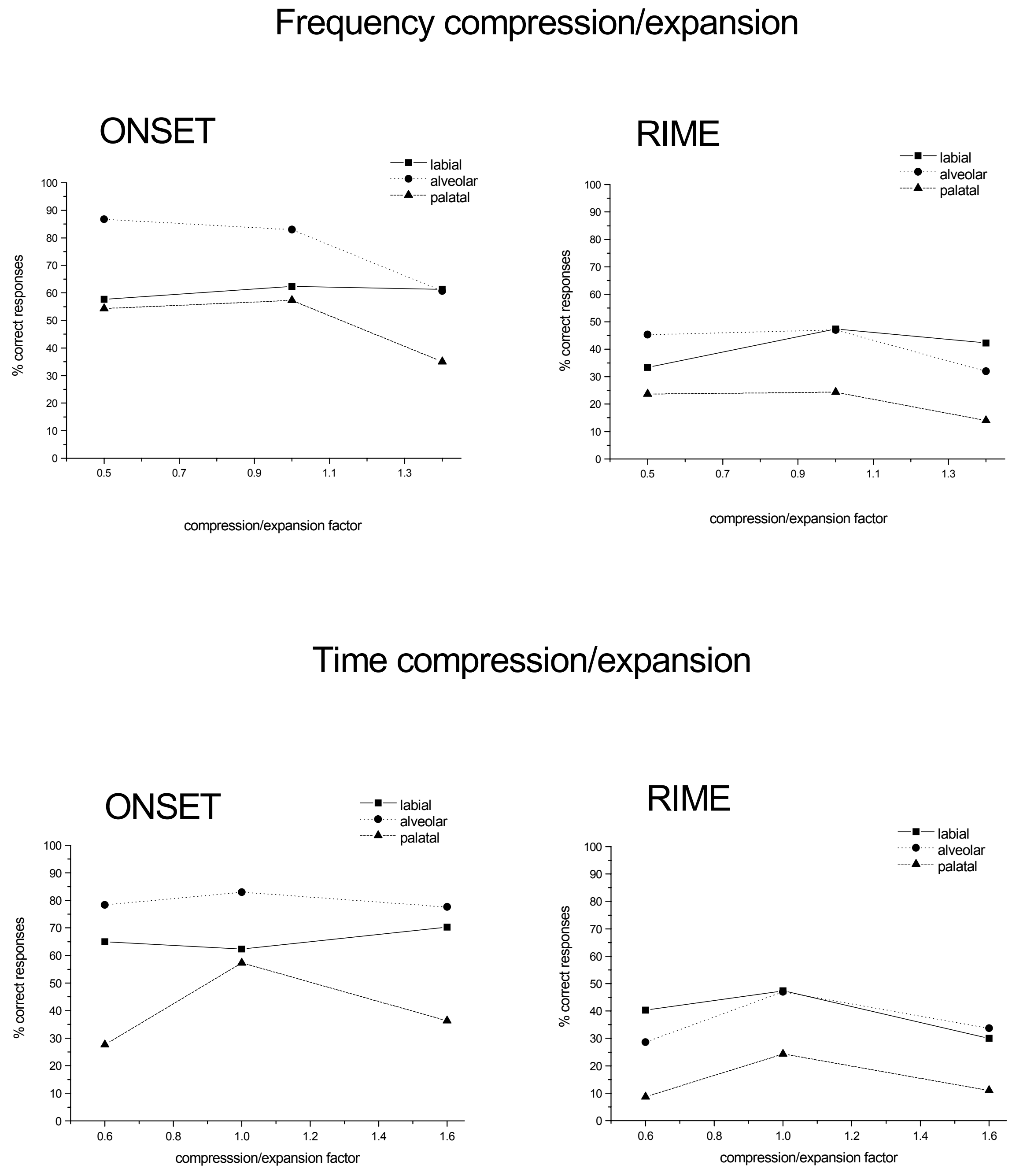
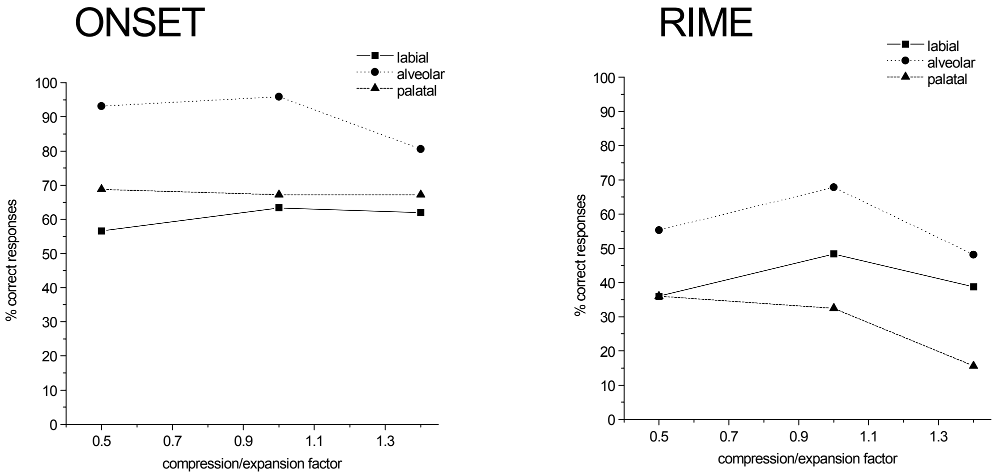


Figure 4. Plots of the percentage correct responses of the children with dyslexia when listening to the time and frequency compressed or expanded stimuli, embedded in white noise. The data are plotted separately for the phonetic features: labial onsets (/b k/ and /p k/), alveolar onsets (/d k/ and /t k/), palatal onsets (/g k/ and /k k/), labial rimes (/k b/ and /k p/), alveolar rimes (/k d/ and /k t/) and palatal rimes (/k g/ and /k k/). The x-axis represents the expansion factor so a value of 1.0 is equivalent to the baseline stimulus.

Fig. 5

NON-DYLEXICS

Frequency compression/expansion



Time compression/expansion

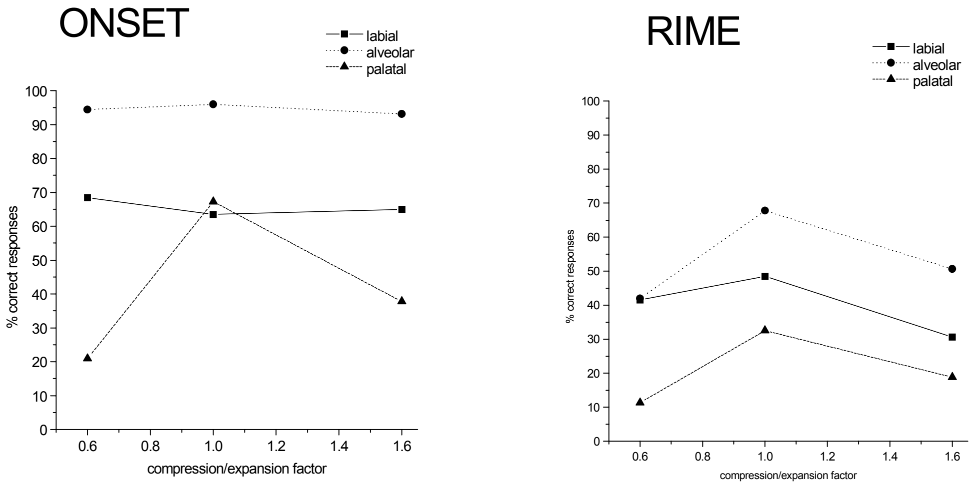
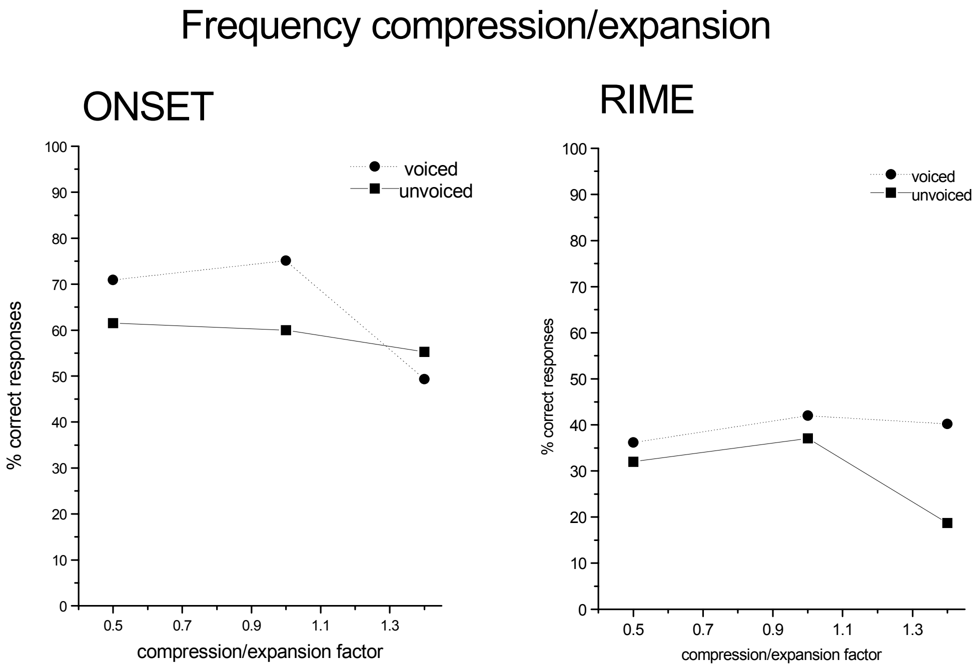


Figure 5. Plots of the percentage correct responses of the non-dyslexic children when listening to the time and frequency compressed or expanded stimuli, embedded in white noise. As in Figure 3, the data are plotted separately for the phonetic features: labial onsets (/b k/ and /p k/), alveolar onsets (/d k/ and /t k/), palatal onsets (/g k/ and /k k/), labial rimes (/k b/ and /k p/), alveolar rimes (/k d/ and /k t/) and palatal rimes (/k g/ and /k k/). The x-axis represents the expansion factor so a value of 1.0 is equivalent to the baseline stimulus.

DYSLEXICS

Fig. 6



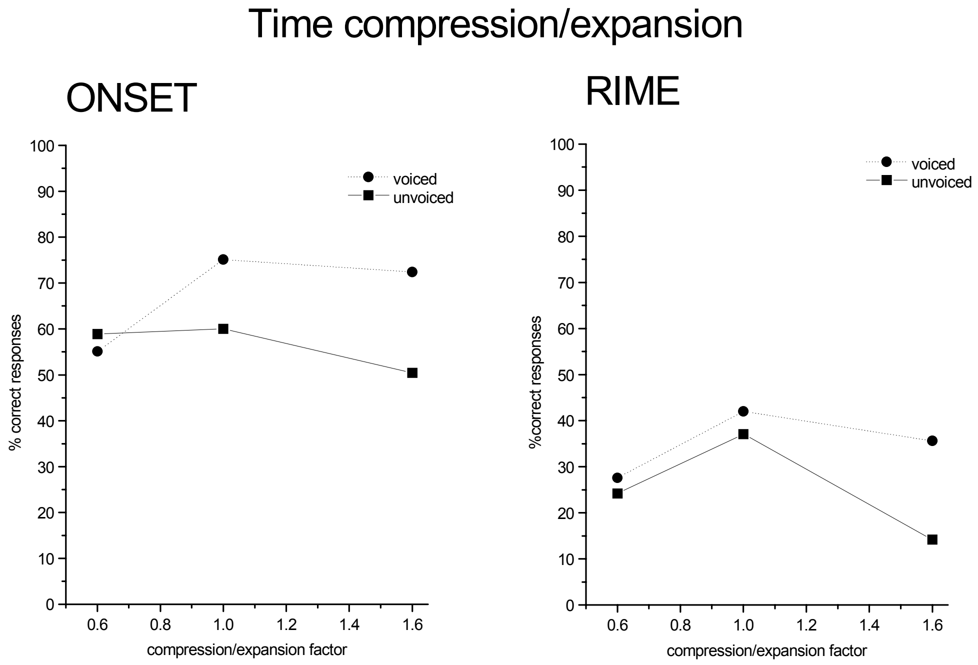


Figure 6. Plots of the percentage correct responses of the children with dyslexia when listening to the time and frequency compressed or expanded stimuli, embedded in white noise. The data are plotted separately for the phonetic features: voiced onsets (/b k/, /d k/ and /g k/), unvoiced onsets (/k k/, p k and /t k/), voiced rimes (/k b/, /k d/ and /k g/) and unvoiced rimes (/k k/, /k p/ and /k t/). The x-axis represents the expansion factor so a value of 1.0 is equivalent to the baseline stimulus.

NON-DYSLEXICS

Fig. 7

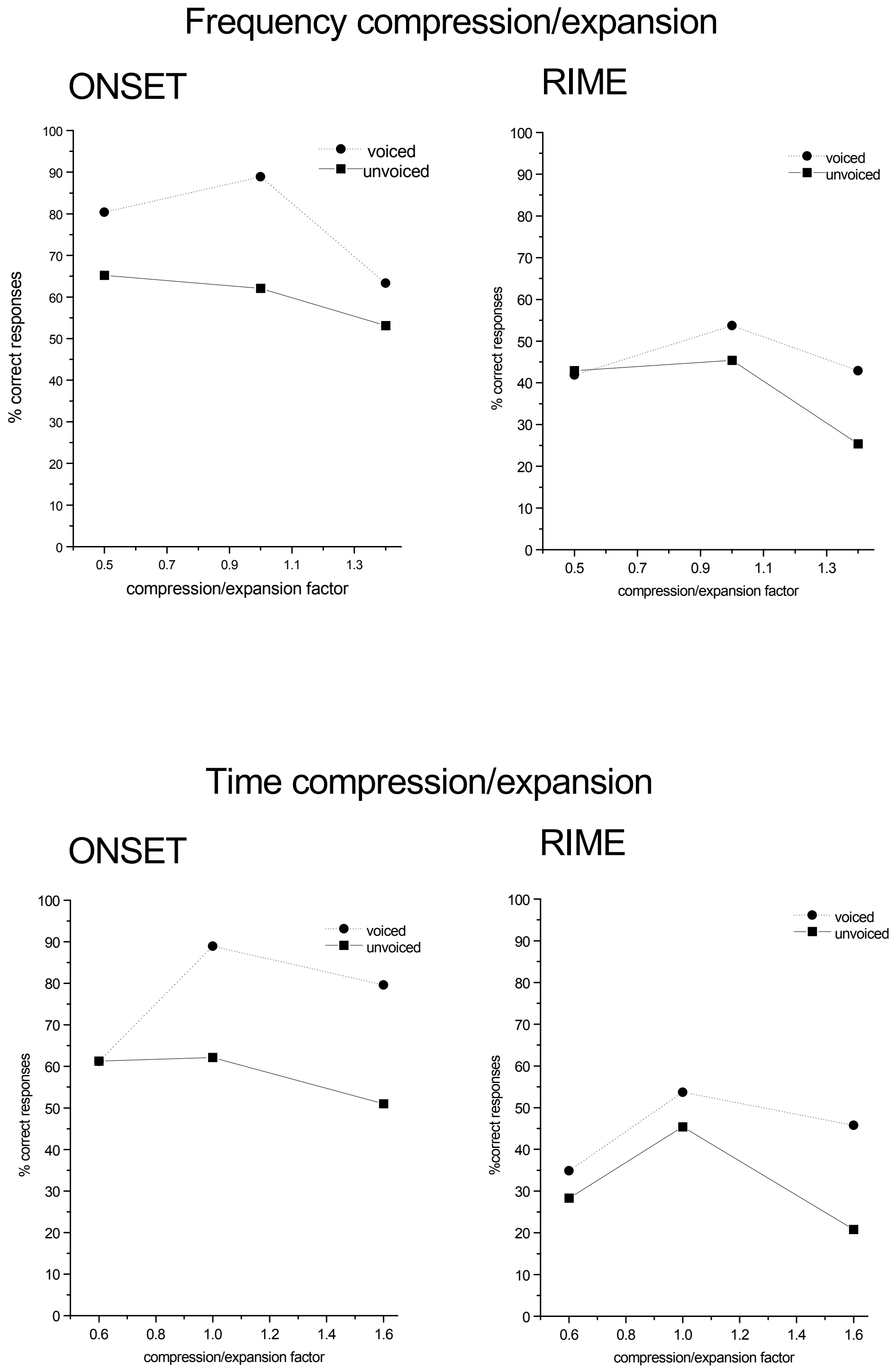


Figure 7. Plots of the percentage correct responses of the non-dyslexic children when listening to the time and frequency compressed or expanded stimuli, embedded in white noise. As in Figure 6, the data are plotted separately for the phonetic features: voiced onsets (/b k/, /d k/ and /g k/), unvoiced onsets (/k k/, p k and /t k/), voiced rimes (/k b/, /k d/ and /k g/) and unvoiced rimes (/k k/, /k p/ and /k t/). The x-axis represents the expansion factor so a value of 1.0 is equivalent to the baseline stimulus.

Finally, we analyzed the data individual by individual to try to find any children whose perception of CVCs may have benefited from time or frequency manipulation. We selected cases where time or frequency stretching produced an increase in the proportion of correct responses of 25% or more. Tables 5 and 6 show the instances where such improvement was recorded for place of articulation. For VOT, there was only one case of improved identification: the identification of unvoiced onsets was improved in one individual by time compression. To our surprise, compression as well as expansion in both the time and frequency domains produced examples of improvement in individuals from both listener groups. However, there did not seem to be any particular condition which was selectively beneficial to children with dyslexia.

Table 5
Individual analysis of data from children with dyslexia where improvement is >= 25%

		Compression		Expansion	
Mode	Phonetic Feature	Onsets	Rimes	Onsets	Rimes
Time	Labial	DXM	GHR	DXM, MJB	
	Alveolar		EMW		WJA
	Palatal				
Frequency	Labial			DXM	
	Alveolar	DXM, GHR, MJB	TJT		WJA
	Palatal	WRC			

Table 6
Individual analysis of data from children without dyslexia where improvement is >= 25%

		Compression		Expansion	
Mode	Phonetic Feature	Onsets	Rimes	Onsets	Rimes
Time	Labial	EWT,RMM,TCF	CMS	JMW,RMM	
	Alveolar				
	Palatal				
Frequency	Labial	EMB			EWT
	Alveolar				
	Palatal	SRH	CMS		

DISCUSSION

Based on the results from previous studies which show children with dyslexia to have difficulty in processing rapid acoustic stimuli (Tallal, 1980), we predicted that time expansion ought to improve the ability of such children to discriminate between phonetically confusable spoken syllables. However the present results fail to support these predictions for CVC syllables containing stop consonants. Stollman, Kapteyn, & Sleeswijk (1994) have measured the speech recognition threshold in noise (SRT) for children with language-impairment listening to normal and time manipulated speech. As expected, the SRT increased with time compression, but contrary to the prediction based on a temporal processing deficit in children with language impairment (Tallal & Piercy, 1973), the SRT was not improved with time expansion. Stollman et al.'s findings are consistent with those of the present study of children with dyslexia.

None of our manipulations (time or frequency, expansion or compression) improved overall CVC identification in either dyslexic or non-dyslexic children. Nevertheless, a more detailed analysis of our results showed that the perception of certain phonetic features was improved in some individuals not only by time compression or expansion, but also by frequency compression or expansion. Unfortunately, these results did not apply systematically to any one individual; while a particular manipulation may have improved the perception of some phonetic features, the same manipulation degraded the perception of other features. Moreover, we found isolated examples of improved performance in individuals from both listener groups. Therefore, it seems that manipulating either the time or the frequency domain as we have done is unlikely to lead to a dramatic improvement in the perception of stop consonant CVC syllables by listeners with dyslexia.

There was a significant difference in IQ (BAS) between the participant groups in the present study. This factor was statistically taken into account to ensure that the children with dyslexia were indeed worse readers than the group of non-dyslexic children. However, this difference was unlikely to have had any influence on the comparison between dyslexic and non-dyslexic individuals on CVC identification because there was no correlation between IQ and performance on the speech task.

Recently, Tallal and colleagues reported a significant improvement in the language comprehension abilities of children with language impairment who had been given extensive training with both adaptive temporal discrimination exercises as well as acoustically modified speech (Merzenich, Jenkins, Johnston, Schreiner, Miller, Tallal, 1996; Tallal, Miller, Bedi, Byma, Wang, Nagarajan, Schreiner, Jenkins, Merzenich, 1996). It is unclear which aspect of the training regime in their study (i.e. the temporal discrimination exercises or the modified speech) contributed to the improvement in the children's language ability. Furthermore, acoustic modification of the speech was a two stage process. The signal was initially slowed by 50 % and then amplitude modulations between 3Hz and 30Hz in the narrowband filtered signal were amplified. If long-term exposure to the acoustically modified speech had been responsible for improving speech perception, it is unclear which of these processing stages (i.e. time expansion or amplitude modulation) was the more potent. The results from the present study suggest that limited exposure of children with dyslexia to time-stretched synthetic CVC syllables did not improve their ability to identify the stimuli correctly. However, McAnally and Stein (1997) have shown that the scalp potential evoked by amplitude modulation of tones is significantly smaller in adults with dyslexia than in matched control listeners. Therefore, as with the amplitude manipulations of stimuli by Tallal et al. (1996), it is possible that the selective emphasis of narrowband AM may be more potent than slowing of the speech signal in improving speech perception in listeners with dyslexia.

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Address correspondence to Piers Cornelissen, Psychology Department, Ridley Building, Newcastle University, Newcastle upon Tyne, NE1 7RU, U.K.

APPENDIX A

Klatt parameter values for the baseline stimulus /d k/. The first number given is the parameter value and the second number, if present, is time (ms). Parameter labels are as in Klatt (1980).

SW	FGP	BGP	FGZ	BGZ	B4	F5	B5	F6	B6
0	0	100	1500	6000	250	3750	200	4900	1000

FNP	BNP	BNZ	BGS	SR	NWS	G0	NFC	AC
250	100	100	200	10000	50	48	5	0

AV	AF	AH	AVS
0,5	0,5	0,5	0,5
0,300	0,275	0,560	0,830
58,305	53,290	24,565	
58,485	45,295	54,585	
0,490	0,300	54,625	
	0,560	40,655	
	48,565	0,660	
	0,580		

F0	F1	F2	F3	F4	FNZ	AN
0,5	450,5	1450,5	2450,5	3300,5	250,5	0,5
0,205	450,250	1450,250	2450,250	3300,250	250,830	0,830
120,295	200,285	1380,285	2470,285	3050,285		
120,345	409,305	1400,305	2470,305	3050,305		
95,415	620,350	850,365	2570,395	3300,355		
60,475	620,435	850,420	2570,405			
0,485	461,485	1343,485	2018,485			
0,535	300,505	1720,505	2250,505			
55,540	300,565	1680,565	2250,570			
55,735	340,580	1680,590	2150,590			
0,740	230,640	1212,660	2258,660			
	203,645	1212,735	2258,735			
	203,735	1450,740	2450,740			
	450,740					

A1	A2	A3	A4	A5	A6	AB
0,5	0,5	0,5	0,5	0,5	0,5	0,5
0,830	0,560	0,260	0,260	0,260	0,260	0,830
	54,565	56,265	58,265	48,265	36,265	
	54,735	56,325	58,325	48,325	36,325	
	0,740	0,330	0,330	0,330	0,330	
		0,560	0,560	0,560		
		30,565	43,565	46,565		
		30,735	43,735	46,735		
		0,740	0,740	0,740		

B1	B2	B3
50,0	70,5	110,0
50,250	70,250	110,250
70,275	120,275	180,275
70,415	120,305	180,305
300,445	50,375	140,355
300,735	50,415	140,415
50,740	250,445	300,455
	250,735	300,735
	0,735	0,740

APPENDIX B

Synthesiser parameters for the baseline stimuli were identical to the default output from the IPOX interface (Dirksen & Coleman, 1995) with the exception of /k b/ and /k p/. For these stimuli, the following changes were made:

CVC	Klatt Parameter	Time point (ms)	Value
/k b/	AB	~650	0
	A2	650-700	20
	A3	650-700	30
	F2	430	850
	F2	830	700
/k p/	AB	~565	0
	A2	565-640	50
	A3	565-640	40