THE EFFECTS OF COCHLEAR IMPLANTS ON SPEECH PRODUCTION IN POSTLINGUALLY ACQUIRED DEAFNESS

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ABSTRACT

Acoustic analyses were made of speech recordings from 75 deafened subjects before and after cochlear implantion, and 51 controls, using the ASSESS system. Pre-implant speech was abnormal in timing, intensity range, pitch height and change, frication, and spectral balance. Implantation reduced some anomalies, left some unchanged, and aggravated others. Many effects were sex-related.

INTRODUCTION

This paper reports part of a large-scale evaluation of cochlear implantation in the UK, co-ordinated by the MRC Institute of Hearing Research. We studied effects of implantation on speech production.

Our evaluation involved three phases. Two were auditory. Phoneticians rated speakers on a range of dimensions: and naive listeners' impressions were studied. This paper describes the third phase, which used the ASSESS system to obtain objective acoustic measurements.

ASSESS develops previous work on properties which can be measured automatically and which appear to reflect disorders of speech [1],[2]. It is based on standard descriptors - spectrum, intensity contours, and pitch contours. It forms a rich description by breaking these into significant units. Preprocessing finds inflections in the contours (points where volume or pitch stops rising and starts falling, or vice versa). Contours can then be described as a series of rises and falls. Blocks which correspond at least roughly to natural units are also found - silences, sound blocks, tunes, and fricative bursts. Sound blocks are defined by the way intensity rises after a silence, peaks, and falls to the next silence. Tunes are defined by the way pitch moves between two silences long enough to be considered pauses. Fricative bursts are defined by energy in the upper spectrum.

ASSESS generates a systematic statistical summary of these elements and higher order attributes derived from them. A fuller description is given in [3].

METHOD

The study considered 51 normal hearing and 75 deafened subjects. All of the latter were recorded pre-implant and 9 months after, and 29 were also recorded 18-24 months after. The reading material analysed was the "Rainbow passage".

After processing through ASSESS data were inspected graphically and a few gross 'outliers' were removed - usually about two or three per passage.

Absolute level measurements were unavailable, and intensity measures were normalised by setting median intensity at the start of each passage to 60dB. This is reasonable given that in auditory ratings controls and pre-implant patients scored almost identically on average volume, and post-implant speakers' ratings showed a significant but small trend towards lowered volume.

RESULTS AND DISCUSSION

The main statistic used was analysis of variance. Independent variables were speakers' sex and hearing status - pre-implant, 9 months post, 24 months post, and control. Hearing status was treated as a between groups variable. This is conservative - if anything it tends to underestimate effects of implantation.

Timing

Table 1 shows that deafened speakers spoke more slowly than controls. The effect is significant ($F3, 213 = 8.8$, $p<.0001$). Implantation does not reduce the problem: if anything it worsens it.

Table 1: Reading time excluding pauses (in seconds)

	total duration		n of pauses	
	fem	male	fem	male
pre implant	36.5	35.2	62.5	48.2
9 mths post	36.8	35.9	63.9	53.9
24 mths post	37.9	36.8	68.5	60.2
controls	29.4	30.0	53.6	46.2

The effect is not due to pausing. However the number of silences is high in deafened speakers, and significantly higher after implant ($F2,170= 4.1$, $p=.018$). No significant change was found in the duration of silences.

Deafened speakers show too many discontinuities in general - not only silences, but also inflections in the intensity and pitch contours. Table 2 shows two relevant measures, numbers of rises in the two contours. With pitch, the overall contrast including the controls is highly significant ($F\ 3, 211=9.5$, $p=.0001$), but implants do not affect the anomaly significantly ($F\ 2,170=0.4$, $p=.67$). With intensity as with silences, the effect worsens significantly post implant ($F\ 2,170=4.3$, $p=.016$).

Table 2: Numbers of rises

	Intensity		Pitch	
	female	male	female	male
pre implant	93.7	87.1	57.7	54.7
9 mths post	97.3	91.2	59.6	56.2
24 mths post	102	98.1	55.8	60.5
controls	81.3	79.8	46.7	45.1

Some aspects of timing do improve with implant, though. Rises and falls in intensity tend to last too long in deafened speakers, as is seen in median durations of rises and falls for each speaker (Table 3). Improvement after implantation seems marginal when the measures are analysed separately, but analysing them together shows a robust effect ($F\ 2,173= 4.1$, $p=0.018$). Improvement is essentially complete 9 months post implant.

Table 3: median durations of rises and falls in intensity (in milliseconds)

	Rises		Falls	
	female	male	female	male
pre implant	79.1	79.2	90.1	86.6
9 mths post	75.9	78.0	82.3	85.6
24 mths post	75.0	78.9	82.9	87.5
controls	74.9	75.0	81.1	80.0

Pitch shows a partially similar trend (Table 4). For the deafened as a whole, median pitch falls are too long. Fall length reduces with implantation ($F\ 2,170 = 3.5$, $p=0.03$). But sex complicates the trend. Pre-implant females already have shorter pitch falls than control females, but the reduction in fall length occurs for both sexes. This is an improvement for the males, but the effect on females is that 24 months post implant, their pitch fall is considerably too short.

Table 4: Median pitch fall duration (ms)

	female	male
pre implant	95.5	106.6
9 months post	91.9	91.0
24 months post	82.4	95.9
controls	101.8	92.2

These findings emphasise the need to be wary of global statements about timing. Anomalous shortening may occur because deafened people with implants have a rather undiscriminating sense that they should liven up their speech.

Intensity

The clearest intensity effects involve spread measures, particularly interquartile range (IQR), which spans the middle 50% of observations. IQR is too high in pre-implant patients and falls following implantation (Table 5). The fall is significant with $F\ 2,172= 6.8$, $p=.001$. It may continue after 9 mths post implant.

Table 5: Intensity IQR (in dB)

	female	male
pre implant	11.56	12.94
9 mths post	10.67	11.17
24 mths post	9.98	11.05
controls	9.96	9.30

Table 6 clarifies the effect by showing the limits of speakers' usual range, the 10% point (below which intensity falls less than 10% of the time) and the 90% point (analogously defined).

The 90% point is strikingly stable, but pre-implant subjects have a low 10% point - i.e.they overuse rather low levels. Post implantation the 10% points rise significantly ($F\ 2,172= 6.8$, $p=.001$) - i.e. implants narrow intensity range by raising the lower limit.

Table 6: Intensity extremes (in dB)

	10% point		90% point	
	female	male	female	male
pre implant	48.4	46.9	67.2	67.0
9 mths post	49.9	48.7	67.5	67.1
24 mths post	50.9	48.8	67.7	66.5
controls	49.6	50.6	66.6	66.9

The large rises and falls which begin and end sound blocks are distinctive. Table 7 shows that they are much longer than rises and falls in general, as would be expected. They are also a case of change which continues after 9 months post implant. Considering patient performance on rises and falls together shows an effect of time (F 2, 171=4.6, p=.011). Post hoc tests show that the significant contrast (p<0.01) is between pre implant and 24 months post.

As with pitch falls, the changes are appropriate for males. But they leave 24 month post implant females with shorter rises and falls than control females.

Table 7: Durations of rises and falls which begin and end blocks (in ms)

	opening rises		closing falls	
	female	male	female	male
pre implant	151	153	187	202
9 mths post	143	152	171	193
24 mths post	140	144	162	182
controls	151	135	171	166

Pitch

There are no strong, straightforward pitch effects, partly because of occasional extreme values, but measures which bypass these extremes show effects of hearing loss and of implantation.

One such measure comes from the midpoints of quadratic curves which are fitted to tunes. The interaction between sex and hearing status falls short of significance in the full analysis (F 3, 212 =2.4, p=.067) but reaches it in the analysis which considers only pre-implant and control subjects (F 1, 117 =5.7, p=.019). As table 8 shows, female pitch is never far from normal, but male pitch is high pre-implant and remains so.

Table 8: Fitted midpoints of tunes (in Hz)

	female	male
pre implant	192.6	140.5
9 mths post	192.19	132.7
24 mths post	186.2	144.1
controls	198.0	115.5

Extreme pitch changes also show a sex-related pattern, as shown in Table 9. Significant sex*hearing status interactions occur with all these measures - 10% points for rises (F 3, 213=3.9, p=.01) and falls (F 3, 213 =4.0, p=.008) and 90% points for both (rises F3,213=3.2, p=.023, falls F3, 213 =2.9, p=.035).

Table 9: Extremes of pitch change per rise or fall (in Hz)

		10% point		90% point	
		female	male	female	male
pre implant	R	1.39	1.49	22.6	23.0
	F	1.65	1.80	32.0	33.0
9 mths post	R	1.36	1.29	21.8	18.6
	F	1.66	1.45	32.1	23.1
24 mths post	R	1.38	1.32	21.2	19.4
	F	1.51	1.50	30.2	24.5
controls	R	1.51	1.22	29.1	16.3
	F	1.80	1.40	37.8	21.5

As with mid pitch, sex differences are reduced pre-implant. Both extremes are high in pre-implant males and low in pre-implant females. Implants reduce change, taking males towards control norms and females away from them.

Pitch variability, both within and between individuals, is strongly reduced by implantation. Within individuals, variability shows in the movements which open and close tunes. Table 10 shows the standard deviation of the slopes of these movements. This reflects the extent to which patients vary the pitch movements which begin and end tunes. Analysis of variance considering the patient groups on both measures shows a significant effect of time (F 2,170=3.1, p=.047). Post hoc tests show that the only significant difference is between pre-implant and 24 mth groups.

Table 10 : variability of initial and final pitch movements in a tune (Hz/sec)

	initial pitch movements		final pitch movements	
	female	male	female	male
pre implant	95.7	86.0	93.4	84.3
9 mths post	87.4	73.3	96.7	68.0
24 mths post	77.9	72.1	77.2	66.1
controls	99.9	76.3	99.9	58.7

Again, reductions in variability mark a move towards normality for the males and away from it for females.

In several measures variance within the pre-implant group is abnormally high because some individuals lie beyond the normal range. Pre-implant males show too wide a range of pitch variability,

which narrows post implant. Females show no consistent change in variability. Females pre-implant show an abnormal range of movements at the beginnings and ends of tunes: there is marked narrowing post-implant. The male pattern is probably similar, but less consistent.

Males also show an abnormally wide range of values for properties involving tunes' mean height and shape. The range of mean heights is wide before implant and remains so. The shape measures reflect two patterns which are uncommon among controls: tunes which start low then rise steadily in pitch, and tunes which drop pitch in the middle. At 24 months post implant, half of the males showed at least one of these patterns.

Frication and the spectrum

Pre-implant patients show under-frication on all measures - number of bursts, average duration of a burst, and level of fricative energy in a burst. There are significant effects of hearing status on all three variables (respectively F3, 210 =3.4, p=.019, F3, 209=4.1, p=.007, and F3, 208=5.0, p=.002).

Implantation has an effect. When only patients are considered, all three variables show effects of hearing status which are significant or nearly so (F2,169 =3.2, p=.042, F2,168 =3.0 p=.053, and F2, 167 =3.0, p=.054 respectively). Energy level changes towards the control pattern, but for number and duration of bursts, initial change is in the wrong direction.

Subspectra for fricative bursts and peaks in the intensity contour (the best simple approximation to vowel centres) are summarised by the slope the profile of energy against frequency, and the mean, marking the spectrum's centre of gravity.

Table 11 gives slopes and means for fricative spectra. Hearing status affects both (slope F3,127 =4.6, p=.004, mean F3, 127=4.1, p=.008). Essentially patients show too little energy in the upper spectrum, before and after implant.

Table 11: shapes of fricative spectra

	slopes (dB/8ve)		means (Hz)	
	female	male	female	male
pre implant	-.175	-.156	861	866
9 mths post	-.050	-.147	909	873
24 mths post	-.111	-.079	879	892
controls	-.009	+.012	920	924

Table 12: shapes of intensity peak spectra

	slopes (dB/8ave)		means (Hz)	
	female	male	female	male
pre implant	-0.94	-0.97	630	608
9 mths post	-1.11	-1.00	588	605
24 mths post	-0.99	-0.94	626	619
controls	-0.90	-0.83	636	663

Table 12 shows that deafened speakers also lack energy in the upper intensity peak spectrum. Again hearing status has significant effects (slope F3, 127=3.8, p=.011, mean F3,127 =2.8, p=.043), but implantation does not. The parallel with frication suggests that speakers may have a general problem with the upper spectrum rather than frication as such.

There is evidence that deafened speakers fail to distinguish fricatives spectrally [4]. ASSESS provides a related measure, variation in the centre of fricative energy in bursts. Hearing status has an effect in the expected direction (F3, 202=4.1, p=.008). Implantation has no significant effect.

CONCLUSION

Objective measures show that speech production changes after implantation, but not always in the right direction. This may not be surprising given the level of input that current devices provide. Speech production may be a sensitive monitor of improvements in implant technology.

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