ACCLIMATISATION AND AUDITORY DEPRIVATION AS EXPLANATIONS FOR CHANGES IN SPEECH IDENTIFICATION ABILITIES IN HEARING AID USERS

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INTRODUCTION

Previous studies [1,2,3] of speech identification ability in adults with bilateral sensorineural hearing impairment have shown that subjects using monaural amplification exhibit a relative decrement in speech identification scores for the normally unaided ear relative to the normally aided ear. In contrast, individuals using no amplification, or using binaural amplification, showed no such interaural discrepancies. In addition, it has been shown [4] that in some subjects these decrements may be reversed by the provision of a second hearing aid. The authors of these studies have offered an interpretation of these findings in terms of a deprivation effect leading to loss of discriminatory capacity in the normally unaided ear relative to the normally aided ear.

More recently it has been shown [5] that for monaurally aided individuals, the ear that is normally aided performs better than the normally unaided ear at high presentation levels, while at lower presentation levels the converse is true. This intensity dependence suggests that an ear which is used to receiving a high level of stimulation will "acclimatise" to the pattern of speech cues presented and be most efficient at analysing at high presentation levels. At lower presentation levels, the normally unaided ear receives its familiar pattern of cues and so performs better than the normally aided ear. This interpretation reasonably assumes in turn that some non-linearity or variation across frequency in loudness functions characterises impaired ears, leading to variation in spectral patterns across presentation levels and requiring a degree of perceptual (re-)learning.

This study aims to document prospectively any changes in speech identification ability in either the normally aided or normally unaided ear of monaural hearing aid users with symmetric sensorineural hearing impairment, with a view to resolving further the conflicting claims of the deprivation and acclimatisation hypotheses. Further details of the justification, methodology and results from the investigation outwith the scope of this article may be found in Gatehouse [6].

METHODS

The intensive experimentation required a small group of reliable and motivated subjects. Four subjects with symmetric bilateral sensorineural hearing impairment were selected.. Pure tone thresholds for air and bone conduction were obtained using a standard clinical method [7]. All four subjects had asymmetry in air conduction thresholds $\leq$10 dB at each frequency from

250 Hz to 8000 Hz and air-bone gaps ≤10 dB for frequencies 250 Hz to 2000 Hz. On a standard clinical procedure for determining speech identification ability in quiet [8], all subjects had symmetric maximum discrimination scores (asymmetry <5%) and symmetric speech reception thresholds (asymmetry ≤5 dB). In an attempt to ensure that the subjects had no further subtle asymmetry in peripheral auditory function, an abbreviated assessment of frequency resolution was performed [9] and showed symmetric slopes (asymmetry ≤2.5 dB) for the low and high frequency portions of the psychoacoustical tuning curves. An abbreviated gap detection procedure [10] showed no asymmetry in gap detection threshold >3 ms. The four subjects thus exhibit symmetric peripheral auditory function. One ear was chosen at random and fitted with a post-aural hearing aid and earmould, whose insertion gain characteristic determined by a probe microphone system rose at approximately 6 dB per octave up to 2000 Hz and was flat thereafter to 6000 Hz.

Prior to hearing aid fitting, each subject had their speech identification performance assessed using single words in a background of noise via a variant of the Four Alternative Auditory Feature test (FAAF). This is a forced-choice word identification test based on the rhyme test principle [11, 12]. The test was administered in noise monaurally over headphones using an adaptive strategy [5, 10] and for each ear yielded, via a 2-up 1-down adaptive procedure [13], the signal-to-noise ratio for 70.7% correct identification. Within each subject, the maximum interaural difference for this signal-to-noise ratio was 1.1 dB, and the average across the two ears for each subject provided the signal-to-noise ratio for further administration of the FAAF test. Each subject was then tested in 11 conditions at week 0 (prior to hearing aid fitting) and at 1, 2, 3, 4, 5, 6, 8, 10 and 12 weeks post-fitting. The conditions tested are summarised in Table 1.

TABLE 1

Conditions tested for each of the 4 subjects, at each visit from Week 0 to Week 12

Condition	Presentation Mode	Test Ear	Presentation level	Frequency Response
(i)	Headphones	Fitted ear	65 dB SPL	Flat
(ii)	"	"	65 dB SPL + Aid Gain	Flat
(iii)	"	"	65 dB SPL	Aid Processed
(iv)	"	"	65 dB SPL + Aid Gain	Aid Processed
(v)	"	Control ear	65 dB SPL	Flat
(vi)	"	"	65 dB SPL + Aid Gain	Flat
(vii)	"	"	65 dB SPL	Aid Processed
(viii)	"	"	65 dB SPL + Aid Gain	Aid Processed
(ix)	Free Field	Binaural - no aid	-	-
(x)	"	Binaural - aid in fitted ear	-	-
(xi)	"	Binaural - aid in control ear	-	-

Conditions (i) to (iv) were performed over headphones in the fitted ear, with (i) corresponding to no aid and (iv) corresponding to the aided condition. Conditions (ii) and (iii) allow separate investigation of presentation level [(ii)] and frequency response [(iii)]. Conditions (vi) to (viii) were the corresponding tests in the control (normally unaided) ear. In addition to the headphone testing, three assessments were performed using an actual aid in free-field stimulation, with condition (ix) being potential binaural stimulation with no hearing aid, (x) potential binaural stimulation with the aid in the fitted (normally aided) ear and (xi) with the aid in the control (normally unaided) ear.

The order of presentation of these conditions was balanced across subject and visit, following the use of one initial condition selected at random to minimise any practise effects.

RESULTS

The results were analysed separately for each of the four subjects using GLIM [14]. The dependent variable was the benefit of amplification in the fitted ear (the difference between the score in condition (iv) and the score in condition (i)) in a repeated-measures analysis of variance.

TABLE 2

Summary of the GLIM analysis performed separately on each of the 4 subjects using a repeated measures analysis of variance to investigate the interaction between post-fitting time (Week 0, Week 1, etc.) and the benefit of amplification. The procedure yields a parameter estimate for the interaction term and the associated standard error.

Subject	Parameter Estimate	S.E. of Estimate	t	df	Significance Level
1	.0870	.0305	2.85	16	p<.02
2	.0761	.0302	2.52	16	p<.05
3	.0794	.0301	2.64	16	p<.02
4	.0625	.0303	2.06	16	N.S.

Table 2 summarises the results and for three of the four subjects shows a significant interaction between the benefits of amplification and the post-fitting time (week 0, week 1, etc). For the fourth subject the results are statistically marginal. Benefit of amplification increases as a function of post-fitting time.

When the results are aggregated across the four subjects, it is possible to investigate each of the 11 conditions independently using a repeated measures analysis of variance and covariance via the BMDP2V program [15]. Each procedure yields an orthogonal polynomial as a function of post-fitting time (Table 3). Effects are only regarded as significant if the overall effect achieves $p<.05$, but all of the effects evident are predominantly linear.

TABLE 3

Summary of the analysis for each condition separately using BMDP. Post-fitting time (Week 0, Week 1, etc) is treated as a repeated measure in an analysis of variance, and the procedure yields an orthogonal polynomial breakdown. The table contains the F value and associated significance level for the overall effect of post-fitting time on each condition.

Condition	F (df = 9,27)	Significance Level	Direction
(i)	8.10	p<.0001	Decrease
(ii)	0.53	N.S.	-
(iii)	6.42	p<.0001	Increase
(iv)	11.84	p<.0001	Increase
(v)	2.01	N.S.	-
(vi)	3.08	p<.02	Decrease
(vii)	2.53	p<.05	Decrease
(viii)	2.09	N.S.	-
(ix)	0.61	N.S.	-
(x)	7.30	p<.0001	Increase
(xi)	1.33	N.S.	-

Inspection of Table 3 shows that the initial results in Table 2 on the benefit of amplification arise from two components, the decrease in performance in the unaided condition {(i)} and an increase in performance in the aided condition {(iv)}. The significant increase in performance with the aid in the fitted ear for free-field stimulation {(x)} is not mirrored by any increase with the aid in the unfitted ear {(xi)}, or in the unaided condition {(ix)}. Thus any changes in the speech identification abilities, and in particular increases, cannot be attributed to any long-term practice effects on the FAAF test. For the tests in the control (normally unaided) ear, conditions (vi and vii) exhibit significant decreases with post-fitting time, while conditions (v) and (viii) are statistically marginal but in the same direction.

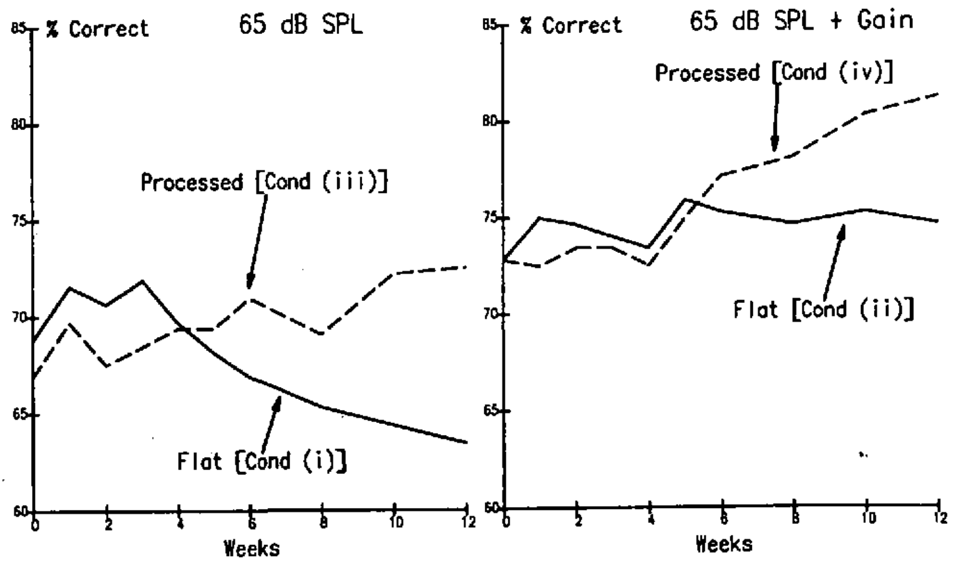
DISCUSSION

The results confirm changes in speech identification abilities in individuals fitted with a single hearing aid. The benefit from a single hearing aid in free-field increases with time (condition (x) in Table 3). When testing over headphones in each individual ear and assessing separately the contribution of presentation level and frequency response, at least two processes are present. In the aided condition for the fitted ear {(iv)}, there is the maximum increase in performance while in condition (i) there is a highly significant decrease. Thus the fitted ear's performance increases in the most familiar condition (with the hearing aid), while it decreases in the now unfamiliar condition. There is also an increase in condition (iii) (consisting of the hearing aid frequency response but at the lower presentation level), while there is no change for the flat frequency response at the higher presentation level, which corresponds closely to the conditions used in the experiments interpreted as supporting the deprivation hypothesis [1,2,3].

The pattern of results for the fitted ear contrasts with those for the control ear, where there are decreases in two of the four conditions (vi and vii) with changes in the same direction for the other two, but not achieving statistical significance at the p<.05 level. The magnitude and significance of these changes in the control ear are much less than those in the fitted ear, but could be interpreted as demonstrating the effects of auditory deprivation in the non-fitted control ear. The time-course of the present effects in the control ear is much shorter than those investigated in previous deprivation studies, and so further effects developing over time cannot be ruled out. The finding can be used as yet further potential justification for the provision of binaural amplification in individuals with symmetric sensorineural hearing impairment.

The more interesting results, however, are obtained from the fitted ear, which show substantial effects of acclimatisation to the hearing aid and its frequency response. Figure 1 shows the change in speech identification ability as a function of post-fitting time averaged over the four subjects for conditions (i)-(iv).

FIGURE 1



It is clear that testing at week 0 could not demonstrate any benefits, for the same overall presentation level, of a frequency response which emphasised the higher frequencies {(iv)} as opposed to a flat frequency response {(ii)}. After 6-12 weeks of hearing aid use however, performance in condition (iv) is markedly superior to that in condition (ii). Thus benefits from providing a particular frequency spectrum do not emerge immediately, but take time to develop. A valid choice of the best frequency response from the point of view of long-term discrimination might only be made after an appropriate period of acclimatisation. This calls into question short-term methods of hearing aid evaluation and selection. This finding provides a potential explanation for some of the past difficulties in demonstrating benefits of a theoretically advantageous frequency response, if evaluation of the outcome usually occurred prior to the complete acclimatisation. The potentially important implications for research on perceptual learning and for evaluation in hearing aid provision are being investigated on a wider range of subjects and speech materials.

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