Apparent auditory deprivation effects of late onset: The role of presentation level

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(Received 11 October 1988; accepted for publication 3 July 1989)

Silman and colleagues [J. Acoust. Soc. Am. **76**, 1347–1362 (1984)] have reported an apparent effect of late auditory deprivation; this presents as loss of discrimination over time in the unaided ear of individuals using a single hearing aid fitted in middle age. In a replication of the basic effect, the influence of presentation level was examined in 24 monaurally aided subjects. The effect was reversed at presentation levels below about 75 dB SPL. The ear that is normally aided performs better at high presentation levels, while, at lower presentation levels, the converse is true. Thus it appears that a form of selective adjustment takes place in a particular part of the dynamic range, at least in ears with a dynamic range limited by a sensory hearing loss. If this interpretation is correct, there are important implications for research on perceptual learning and for the time course of evaluation in hearing aid provision.

PACS numbers: 43.71.Ky, 43.71.Pc, 43.66.Ts

INTRODUCTION

In two previous studies (Silman *et al.*, 1984; Gelfand *et al.*, 1987), the speech identification ability of adults with bilateral sensorineural hearing impairment has been investigated as a function of the uni- or bilaterality of amplification supplied over varying time periods. Both of these studies incorporated a degree of control for the absolute characteristics of the individual ears involved and showed 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.

The authors have offered an interpretation of these findings in terms of a deprivation effect leading to loss of discriminatory capacity in the normally unaided ear (or at levels of the auditory system prior to afferent binaural interaction) relative to the normally aided ear, but have been appropriately cautious before pressing such an interpretation. In both of those studies, the speech recognition scores were obtained using CID W-22 words presented in quiet at a presentation level of 40 dB SL relative to the speech reception threshold of the ear under test. The mean speech reception thresholds of the various groups ranged from 43.8–53.1 dB HL at the final assessment, and so the presentation level at which the speech identification scores were derived would be in the range approximately 80–90 dB HL.

An alternative interpretation of these results could be offered in terms of acclimatization. When any systematic shift occurs in the speech cues presented, the auditory system could adapt to that changed pattern of cues. This can occur in a very short time (Haggard, 1974) for adjustment to parameters such as individual speaker, frequency shift, and even noise level; such adjustments are likely to involve a central process (Haggard, 1974), although, in the case of noise level, peripheral auditory adaptation may also facilitate the task.

In addition, over a longer time course, repeated stimulation by some types of speech sound causes a selective adaptation, presumed to occur in analyzers for pattern features (Ganong, 1978; Samuel, 1988). The phenomenon involves a shift in phonemic responses with more extreme auditory parameter values being required to evoke a particular response after adaptation. This is also thought to be at least partly central, but can show some dependence on intensity and implies that, in the normal auditory system, some aspects of the analysis of particular features are intensity dependent. Physiologically, there is evidence of different, or at least graded, subpopulations of auditory nerve fibers for different portions of the dynamic range (Liberman and Kiang, 1978). Evidence is mounting (Palmer, 1987) that a considerable amount of feature extraction takes place in the cochlear nucleus, i.e., before afferent binaural interaction. The linkage between the subpopulations of auditory filters and the neurons responsible for the extraction of pattern features may occur at a peripheral level prior to binaural interaction. As such linkage does not normally need to be modified, any modification would very probably require a lengthy "adaptation" period.

This hypothesis of habituation may offer an alternative explanation to that of feature analyzers going out of condition through lack of input. Inputs from each ear reach all levels of the auditory system above the cochlear nucleus; so, unless there were specific physiological evidence on *late* deprivation effects in the cochlear nucleus (which we have been unable to find), the present alternative hypothesis would be more economical than a deprivation hypothesis.

Applied to monaural amplification, the intensity dependence suggests that an ear which is use to receiving a high level of stimulation (and hence the associated pattern of speech cues) will "adapt" to the pattern of cues presented and be most efficient at analyzing at high presentation levels. At the high levels of stimulation used in the previous studies, the normally aided ear was presented with a pattern of speech cues for which it would be efficiently adapted, whereas the normally unaided ear was not. Such intensity-dependent effects might have gone unnoticed previously because particulary stressing conditions of perceptual adaptation experiments, or the limited dynamic range and/or loss of neural redundancy via sensory hearing loss, are required to demonstrate them. A test of the intensity-dependence hypothesis against the deprivation hypothesis involves lower stimulation levels: Here, the normally unaided ear should be receiving its familiar pattern of cues, and so the normally unaided ear would be expected to perform better than the normally aided ear. This hypothesis was tested in a group of hearing-impaired individuals with symmetric sensorineural hearing impairments who have been regular users of monaural amplification.

I. METHOD

A. Speech test materials

Speech identification performance was assessed using single words in a background noise via a variant of the Four Alternative Auditory Feature (FAAF) Test. This is a forced-choice word identification test based on the rhyme test principle, described by Foster and Haggard (1979 and 1987). The material consists of 20 sets of 4 binarily and minimally paired words, giving an 80-item vocabulary. Two examples of these sets are (i) MAIL, BAIL, NAIL, DALE and (ii) ROSE, ROVE, ROBE, RODE. Nine sets vary the initial consonant and 11 the final consonant. The test was administered monaurally over headphones in noise using an adaptive strategy as described by Lutman and Clark (1986). A fixed speech intensity was used and the level of filtered noise with the same long-term spectrum as the FAAF test items adjusted to achieve criterion performance. In the adaptive mode, only a subset of the full 80-item FAAF test was used, which contained 29 items previously determined to have monotonic psychometric response functions between signal-to-noise ratio and percent correct identification. A further six items were presented, but not scored, to ensure that at least two of the four alternatives were used for each four-word set. Presentation levels were 50, 60, 70, 80, and 90 dB SPL for the normally hearing subjects, and levels of 65, 70, 75, 80, 85, and 90 dB SPL for the hearing impaired subjects, both in the ear normally aided and in the ear normally not aided. The presentation level was defined from a 1-kHz calibration tone, which had a sound pressure level equal to the mean of the peaks of the test words measured in a 9-A coupler from a TDH39 headphone in MX-41/AR cushions. The overall level of the noise was measured as the A-weighted sound level in the coupler. The test was configured to follow a two-up–two-down procedure described by Levitt (1971), converging on the 50% correct identification point on the psychometric function. Items from the test vocabulary were selected at random. The adaptive FAAF test started at a signal-to-noise ratio of + 20 dB and proceeded with a step size of 2 dB. The test continued until ten reversals of signal-to-noise ratio occurred, and the last eight reversals were averaged to produce a mean signal-to-noise ratio for 50% correct identification.

II. SUBJECTS

Two groups of subjects were recruited: (i) a group of eight normally hearing individuals to assess the properties of the adaptive FAAF test as a function of presentation level and (ii) a group of 24 hearing-impaired individuals. The hearing-impaired individuals were identified from the records at the Audiology Department of Glasgow Royal Infirmary as having symmetric bilateral sensorineural hearing impairment at the time of hearing aid issue. Table I describes these 24 subjects and shows symmetric mean pure-tone thresholds both at aid issue and at time of assessment. All subjects were users of UK National Health Service BE10 series post-aural aids with maximum gains of ~45 dB and saturation sound-pressure level ~130 dB SPL. No speech performance measures are routinely available from these subjects at the time of hearing aid issue. However, as the subjects display similar pure-tone thresholds in the normally aided and normally unaided ears both at time of issue and at the time of assessment, there is no reason to suspect any other form of systematic asymmetry between the ears, except small divergences random in relation to the experimental design. It is common practice in the issuing clinic to allow the patient to choose the side of amplification on the basis of ease of use. The patients were interviewed about the degree and frequency of aid use, and all reported a high degree of use, with a mean reported duration of 8.6 h per day.

III. RESULTS

The results from the eight normal-hearing subjects are shown in Table II. For an adaptive procedure, a lower signal-to-noise ratio to achieve criterion performance represents better word identification. The signal-to-noise ratio for 50% performance can be thought of as a speech recognition threshold in noise (SRTN). Performance is relatively stable over the presentation levels of 60, 70, and 80 dB SPL, but is

TABLE I. Mean (and standard deviations) of the characteristics for the 24 impaired subjects in the study.

	Ear normally aided	Ear not normally aided
At time of aid issue		
Pure-tone average (dB HL) (500, 1000, 2000, and 4000 Hz)	46.6 (3.5)	46.3 (3.3)
At time of test		
Pure-tone average dB HL (500, 1000, 2000, and 4000 Hz)	50.7 (2.8)	50.8 (3.9)
Pure-tone thresholds dB HL		
500 Hz	36.2 (4.1)	37.8 (3.1)
1000 Hz	43.1 (3.4)	41.9 (3.7)
2000 Hz	55.3 (7.8)	55.6 (5.9)
4000 Hz	68.3 (9.2)	67.9 (8.8)
Age (years)	59.3 (5.0)	
Time from issue to test (years)	4.8 (1.1)	
Reported aid use (hours/day)	8.6 (2.2)	

TABLE II. Mean (and standard deviation) of the signal-to-noise ratio to achieve 50% performance on the FAAF test for the eight normal subjects as a function of presentation level.

	S/N ratio for 50% performance (dB)
50 dB SPL	1.9(0.4)
60 dB SPL	0.5(1.2)
70 dB SPL	0.6(0.7)
80 dB SPL	0.1(0.8)
90 dB SPL	2.9(0.6)

poorer (higher SRTN) at 50 and 90 dB SPL. At 50 dB SPL it is likely that the less intense high-frequency cues in the speech material will become unavailable to the listener, whereas at 90 dB SPL, a high level of presentation for normal-hearing listeners, the speech cues may have become distorted or subject to upward spread of masking.

The results from the hearing impaired subjects are shown in Table III. As expected, for both the normally aided ear and the normally unaided ear, there is an improvement in performance from 65 to 90 dB SPL. However, Table III shows a fundamental divergence in performance/intensity function in the 65- to 75-dB SPL range between the normally aided ear and the normally unaided ear; the SRTN value is significantly higher (for a paired t test, $t = 7.96$, $df = 23$, $p < 0.001$) for the normally aided ear at 13.2 dB compared to 10.0 dB for the unaided ears. At presentation levels of 70, 75, and 80 dB SPL, there are no significant differences ($p < 0.01$) between the SRTN values for the two ears. However, at 85 and 90 dB SPL, the normally aided ear has superior performance (for the paired t test, $t = 5.57$, $df = 23$, $p < 0.001$, and $t = 9.54$, $df = 23$, $p < 0.001$, respectively). The magnitudes of effect involved are appreciable; 3–4 dB in SRTN equates to approximately 20% for this material around the 50% point (Foster and Haggard, 1987).

IV. DISCUSSION

The results from the two highest presentation levels (85 and 90 dB SPL) replicate the earlier reports from Silman *et al.* (1984) and Gelfand *et al.* (1987). However, at the 65 dB SPL, the contrary finding is obtained, whereby the normally aided ear performs more poorly than the normally unaided ear. It is parsimonious to explain both the present data and the previous reports in terms of an acclimatization effect rather than a deprivation effect. At the descriptive level, acclimatization to intensity involves an ear performing more efficiently at the presentation level to which it has typically been exposed for the material in question. In isolation poorer performance in the normally aided ear at 65 dB SPL could be interpreted as an asymmetry in auditory function between the two ears that was not reflected in the pure-tone thresholds; indeed, given the choice, patients will choose to wear monaural amplification on the ear that functions more poorly from a general disability point of view (Swan *et al.*, 1987). However, that interpretation cannot be applied here, given the better performance at the higher presentation levels of 85 and 90 dB SPL for the normally aided ear. The contrary findings at the low and high presentation levels lend credence to the interpretation in terms of acclimatization.

At this stage, however, some caution must be exercised in interpreting the findings. No direct evidence is available that the upper intensity tested (90 dB SPL) represents the aided intensity levels for these subjects. A study containing similar subjects with sensorineural impairments fitted from the same range of hearing aids (Carlin and Browning, 1989) showed that the mean gain used measured in a 2-cc coupler was 19 dB. Despite potential differences between coupler gain and real ear gain, this would imply that the intensity range covered, of 25 dB above 65 dB SPL (representing unaided speech), did encompass the subjects aided listening levels.

A more difficult problem is the lack of any speech identification measures, either in quiet or in noise, prior to fitting of the aid. Despite the previous argument of a reverse effect at low and high intensities, it cannot be shown that there is no asymmetry of function between the normally aided and unaided ears. We argue, however, that any *systematic* asymmetry or idiosyncracy between the performance-intensity functions is unlikely. Only a truly prospective study can resolve the issue and determine both the relative and absolute shifts in performance for the aided and unaided ears, and compare their performance as a function of presentation level both with normal subjects and also unaided hearing-impaired individuals.

If the interpretation in terms of an acclimatization or habituation effect to the level of presentation of speech holds up across differences in subjects, speech materials, and degree of amplification used, it would be worth applying it to broad frequency regions, as well as for the speech spectrum as a whole. 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 acclimatization, calling into question short-term methods of hearing aid evaluation and selection. Thus the benefits from providing a particular frequency spectrum might not be apparent immediately, but might take time to develop. If so, practical hearing aid fitting would require not only the overcoming of initial preferences with respect to frequency response, but rather a requirement for a longer term prediction of overall benefit. If acclimatization effects of clinically material magnitude do occur, their time course will need to be charted. They may provide a partial explanation for some of the past difficulties

TABLE III. Mean (and standard deviation) of the signal-to-noise ratio to achieve 50% performance on the FAAF test for the 24 hearing-impaired subjects as a function of presentation level.

	S/N ratio for 50% performance (dB)	
	Ear normally aided	Ear not normally aided
65 dB SPL	13.2 (1.5)	10.0 (1.4)
70 dB SPL	9.8 (1.8)	8.9 (1.2)
75 dB SPL	7.9 (1.3)	7.1 (1.8)
80 dB SPL	6.4 (1.4)	7.9 (1.7)
85 dB SPL	4.2 (1.3)	6.8 (1.9)
90 dB SPL	2.8 (1.4)	6.5 (1.3)

in demonstrating the benefits of a theoretically advantageous frequency reponse; evaluation of outcome may have taken place prior to the completion of the adaptation process and at different points on it, introducing random variance.

While this study suggests that late auditory deprivation is not a parsimonious explanation of the results of Silman *et al.* (1984) and Gelfand *et al.* (1987) it does not deny the existence of deprivation effects developing over time. The search for them—though perhaps not on a monaural basis—is still very relevant to life-span developmental psychology and to the fitting of hearing aids. There does exist the possibility that the performance of the normally aided ear has been depressed at all intensities due to the use of an unfamiliar frequency response (i.e., the unaided spectrum) to which it is not optimally adapted. This would in no way undermine the adaptation hypothesis as it merely substitutes a frequency adaptation effect for an intensity effect to explain the result.

ACKNOWLEDGMENTS

I would like to thank Professor M. P. Haggard for several suggestions during the preparation of the manuscript, and particularly for drawing attention to the feature adaptation literature, and also the two anonymous reviewers for many valuable comments on an earlier version of the manuscript.

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