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Effect of hearing loss in electrocochleographic investigation of endolymphatic hydrops using tone-pip and click stimuli

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Abstract

Extratympanic electrocochleography (ECochG) was performed on 37 patients referred to the Evoked Potential Clinic with suspected Ménière's disease. The patients were classified according to their hearing impairment and audiometric configuration. Click and tone-pip stimuli with tone frequencies of 1 and 4 kHz were presented at a rate of 10 per second. Amplitude, latency and general waveform characteristics of the summation potential (SP) and action potential (AP) were analysed for each averaged response with respect to the level and configuration of the hearing loss. The highest incidence of abnormal percentage SP was in patients with average hearing loss in the range of 40–64 dB HL using the click stimulus. In low tone hearing loss, hydrops was identified from an enhanced SP in significantly more patients using the click and 4 kHz tone-pip than the 1 kHz stimulus. Measurement of the width of the 1 kHz tone-pip response waveform was abnormal in some patients even though the click and 4 kHz responses were normal. The optimum stimulus for identification of hydrops from an enhanced SP is dependent on the level and configuration of the hearing loss.

Key words: Ménière's disease; Audiometry, evoked response, electrocochleography; Hearing loss, sensorineural

Introduction

Ménière's disease is characterized by paroxysmal attacks of vertigo, tinnitus, aural fullness and sensorineural hearing loss (Gibson and Prasher, 1983). Many authors have noted that the hearing loss associated with the early stages of Ménière's disease affects primarily the low tones, and that as the disease progresses higher frequencies are also affected (Goodman, 1965; Eliacher *et al.*, 1973). A flat configuration to the audiogram is seen most frequently (Green *et al.*, 1991). Hearing in patients with Ménière's disease is characterized by a fluctuating loss, which is dependent on the stage of the disease (Ferraro *et al.*, 1985). The disease manifests itself as a result of endolymphatic hydrops. There is relatively little destruction of the sensory elements in the early stage of the disease except perhaps in the apical cochlear turn (Gibson *et al.*, 1983). There is a large SP/AP amplitude ratio (percentage SP) in these patients which is influenced by the level of hearing loss. Sufficient residual hearing must be present in order to record a reliable response waveform (Campbell *et al.*, 1992a).

There is a choice of which stimulus to employ in ECochG. Although the SP can be recorded using tone-pip stimuli, which may help in the differentiation of the SP and AP, most workers have only used the click stimulus (Eggermont, 1979; Coats, 1981; Kitahara *et al.*, 1981). The click gives the best neural synchrony and hence the largest response amplitude. However, it is not frequency specific and activates wide regions of the basilar membrane particularly at the basal turn of the cochlea. A tone-pip stimulus should improve the frequency specificity of the ECochG investigation.

The relative effect of enhancement of the SP on the response waveform, arising from endolymphatic hydrops is likely to be dependent on hearing threshold and the type of stimulus employed for ECochG. In the present study click and tone-pip stimuli were presented to patients referred to the Evoked Potentials Clinic at the Department of Medical Physics at Queens Medical Centre, Nottingham, with suspected Ménière's disease and the presence of endolymphatic hydrops was assessed with respect to the audiometric configuration of the hearing loss.

Material and methods

Subjects

The patient group comprised 37 subjects having symptoms suggestive of Ménière's disease (16 males and 21 females) with ages from 32 to 85 years (mean = 48 years). Twenty normal-hearing subjects (9 males and 11 females) with ages ranging from 18 to 23 years (mean = 21 years) were used as a control group. These control subjects had normal pure tone audiometry with no history of Ménière's type symptoms. The patients were classified into three subgroups firstly according to the level of hearing impairment and then with respect to the configuration of the hearing loss (Katz, 1978). Table I shows the distribution

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TABLE I

THE NUMBER AND PERCENTAGE OF PATIENTS WITH RESPECT TO THE AUDIOMETRIC CONFIGURATION FOR HEARING LOSS OF TYPE 1, 2 AND 3

	Flat		High tone		Low tone		Total
	No.	%	No.	%	No.	%	No.
Type 1 (0–39 dB HL)	12	52	8	35	3	13	23
Type 2 (40–64 dB HL)	4	44	2	23	3	33	9
Type 3 (> = 65 dB HL)	4	80	1	20	0	0	5
Total	20	54	11	30	6	16	37

of the numbers of patients according to the following classification.

Level of hearing loss (average across 0.5, 1, 2 and 4 kHz) was assessed as: Type 1 (average = 0 to 39 dB HL) a mild to moderate hearing loss in 23 patients; Type 2 (average = 40 to 64 dB HL) a moderate to severe hearing loss in nine patients; Type 3 (average > = 65 dB HL) a severe to profound hearing loss in five patients.

Audiometric configuration across 0.5, 1, 2 and 4 kHz was assessed as: Flat loss (average of 0.5 + 1 kHz) − (average of 2 + 4 kHz) less than 20 dB in 20 patients; High tone loss (average of 2 + 4 kHz) − (average 0.5 + 1 kHz) > 20 dB in 11 patients; Low tone loss (average of 0.5 + 1 kHz) − (average of 2 + 4 kHz) > 20 dB in six patients.

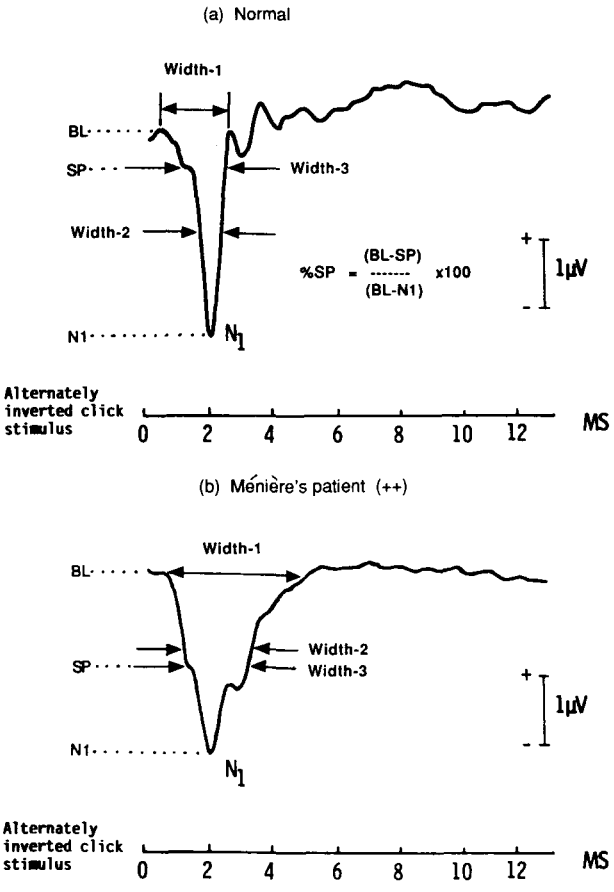

FIG. 1

Measurement of the percentage SP, Widths (1, 2 and 3) and AP latency in the normal waveform (a) and in a Ménière's patient (b) with enhancement of the SP component.

Test procedure

An extratympanic technique for ECochG was performed on the control subjects and patients as described previously (Mason *et al.*, 1980). Subjects were tested in a soundproofed room, while lying comfortably on a couch. A silver ear canal electrode was positioned in the postero-inferior quadrant of the ear canal close to the tympanic annulus with the aid of a microscope and was held in place with bentonite electrode paste. The reference electrode was placed on the ipsilateral earlobe with a guard electrode on the forehead. The resultant signal was amplified (10 000) and filtered (5 Hz–5 kHz) before being averaged (2000 sweeps) and analysed. The AP and SP components were evoked by alternately inverted click and tone-pip stimuli (1 and 4 kHz) presented at 10 per second. The clicks were generated using 100 μs electrical pulses and the tone-pip had a two cycle rise/fall time and four cycle plateau. Stimulus intensity was expressed in decibels relative to normal hearing threshold (dB nHL). Levels of 80, 90 or 100 dB nHL were employed depending on the degree of hearing loss present and the clarity of the SP and AP potentials. Analysis was carried out on response waveforms which had been recorded with the same intensity level for both the click and tone-pip stimuli. All stimuli were presented to the patients through an electrically shielded (mu-metal) TDH39 headphone.

Measurement of the waveform

Amplitude of the SP (nanovolt = nV) was measured from the baseline (onset of response) to the notch on the descending limb of the response waveform. The AP amplitude (nV) was measured from the baseline (BL) to the maximal negative peak of the response. The percentage SP was then calculated as $(BL - SP/BL - N_1) \times 100$ per cent.

Three measurements of the width of the SP/AP response waveform were carried out as shown in Figures 1a and b for the normal and enhanced SP waveform respectively. Width 1 was measured as the time interval (ms) from the onset of the response to the same amplitude on the ascending limb of the AP. Width 2 was a similar measurement at the 50 per cent amplitude point of the response waveform. Width 3 was measured from the SP

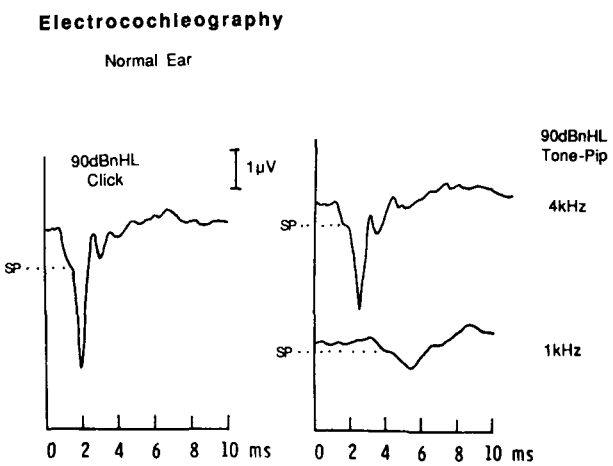

FIG. 2

An example of the click and tone-pip response waveforms in the normal ear.

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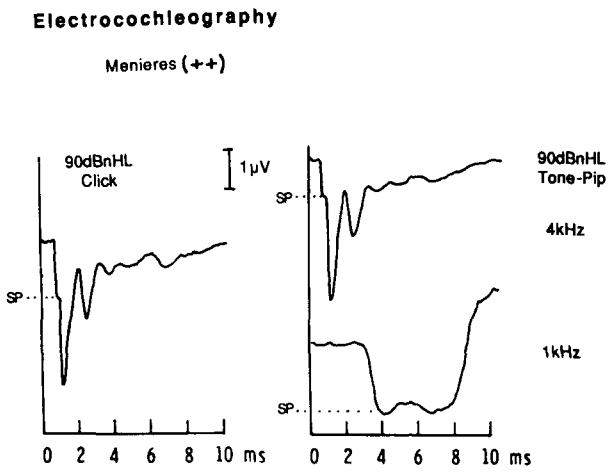

FIG. 3

Click and tone-pip response waveforms in a Ménière's patient with hearing loss in the Type 1 category with a flat audiometric configuration. Enhancement of the SP component is particularly evident on the 1 kHz tone-pip response waveform in contrast to the click and 4 kHz tone-pip stimuli.

notch to the same amplitude point on the ascending limb of the AP.

The AP latency (ms) was measured from the onset of the waveform to the peak negative deflection.

Results

Examples of click and tone-pip response waveforms in the normal ear and in a Ménière's patient are shown in Figures 2 and 3 respectively. Recordings in Figure 3 are in a patient with hearing loss in the Type 1 category with a flat audiometric configuration. Enhancement of the SP component is particularly evident on the 1 kHz tone-pip response waveform in contrast to the click and 4 kHz tone-pip stimuli. Results are presented for percentage SP, width measurements and AP latency which are independent of the absolute amplitude of the response waveform. This reduces the effects of inter-subject differences in response amplitude arising from the extratympanic recording technique and from possible loss of hair cell activity in patients with hearing impairment.

Hearing loss

Table II shows the mean values and two standard deviation upper limits (+2 SD) for measurements of the SP/AP waveform with respect to hearing loss (Types 1, 2, 3) and in the normal group. The most consistent abnormal features across all levels of hearing loss were the percentage SP and Width 2 measurements for both the click and tone-pip stimuli. The group mean percentage SP measurement for the click was only significantly different from normal in those patients with a mid-range hearing loss (Type 2). The 4 kHz tone-pip produced significant differences in the group mean percentage SP measurements across all levels of hearing loss when compared to normal, in contrast to the 1 kHz stimulus where no percentage SP results were significantly different.

Table III shows the number and percentage of patients exceeding the normal range (+2 SD) with respect to hearing loss (Types 1, 2, and 3). The click stimulus in patients with mid-range hearing loss (Type 2) gave the highest incidence of abnormal percentage SP and Width 2 measurements. The incidence of abnormal measurements for the 1 kHz tone-pip was low for the percentage SP, but high for the width measurements across all levels of hearing loss.

Configuration of the audiogram

Table IV shows the mean values and two standard

TABLE II

MEAN VALUES AND TWO STANDARD DEVIATION UPPER LIMITS (+2 SD) OF ECOCHG PARAMETERS IN EACH HEARING LOSS GROUP, TYPE 1, 2 AND 3, AND IN THE NORMAL SUBJECTS. THE LEVEL OF STATISTICAL SIGNIFICANCE OF THE DIFFERENCE IN THE GROUP MEANS BETWEEN THE PATIENTS AND NORMAL SUBJECTS IS PRESENTED

	Type 1 (0–39 dB HL) (23 patients)			Type 2 (40–64 dB HL) (9 patients)			Type 3 (> 65 dB HL) (5 patients)			Normal (20 subjects)	
	Mean	+2 SD	Sig.	Mean	+2 SD	Sig.	Mean	+2 SD	Sig.	Mean	+2 SD
Click											
% SP	28	55	NS	46	110	$p<0.05$	36	74	NS	24	40
Width 1 (ms)	3.3	7.7	NS	2.9	7.6	NS	3.4	6.1	NS	2.8	8.3
Width 2 (ms)	0.9	1.7	$p<0.001$	1.2	2.8	$p<0.05$	0.8	1.5	NS	0.6	0.9
Width 3 (ms)	1.3	2.5	NS	1.2	2.1	NS	1.1	1.7	NS	1.1	1.7
AP latency (ms)	1.8	2.4	$p<0.01$	2.1	2.7	$p<0.001$	2.1	2.7	$p<0.02$	1.7	2.0
4 kHz											
% SP	26	37	$p<0.05$	40	103	$p<0.05$	40	82	$p<0.05$	20	37
Width 1 (ms)	2.9	6.6	NS	2.8	7.5	NS	3.7	9.1	NS	2.6	4.1
Width 2 (ms)	0.9	1.7	$p<0.01$	1.3	2.8	$p<0.01$	1.0	1.7	$p<0.05$	0.6	0.8
Width 3 (ms)	1.4	3.3	NS	1.1	2.1	NS	1.2	1.9	NS	1.4	2.8
AP latency (ms)	2.2	2.7	NS	2.3	9.7	NS	2.5	3.5	NS	1.7	2.0
1 kHz											
% SP	28	76	NS	20	63	NS	26	90	NS	31	67
Width 1 (ms)	5.2	9.6	NS	5.9	12.4	NS	7.1	12.6	$p<0.02$	4.2	7.4
Width 2 (ms)	2.7	6.2	$p<0.01$	3.7	8.6	$p<0.02$	4.0	9.1	$p<0.05$	1.6	3.0
Width 3 (ms)	2.6	6.8	NS	3.4	10.4	NS	2.9	9.3	NS	2.5	5.6
AP latency (ms)	4.1	6.4	NS	4.8	7.6	NS	5.2	7.6	$p<0.001$	3.0	4.0

Sig. = significance; NS = not significant.

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TABLE III

THE NUMBER AND PERCENTAGE OF PATIENTS EXCEEDING THE NORMAL RANGE (+2 SD) WITH RESPECT TO HEARING LOSS USING CLICK AND TONE-PIP STIMULI

	Type 1 (0–39 dB HL) (23 patients)		Type 2 (40–64 dB HL) (9 patients)		Type 3 (>65 dB HL) (5 patients)		Total (37 patients)	
	No.	%	No.	%	No.	%	No.	%
Click								
% SP	4	17	4	44	1	20	9	24
Width 1	1	4	0	0	0	0	1	3
Width 2	8	35	5	56	1	20	14	38
Width 3	6	26	1	11	0	0	7	19
AP latency	7	30	4	44	3	60	14	38
4 kHz								
% SP	6	26	2	22	2	40	10	27
Width 1	3	13	2	22	1	20	6	16
Width 2	8	35	5	56	2	40	15	41
Width 3	2	9	0	0	0	0	2	5
AP latency	1	4	3	33	2	40	6	16
1 kHz								
% SP	2	9	0	0	1	20	3	8
Width 1	3	13	4	44	3	60	10	27
Width 2	8	35	4	44	2	40	14	38
Width 3	3	13	4	44	1	20	8	22
AP latency	11	48	6	67	5	100	22	59

deviation upper limits (+2 SD) of waveform features for patients with flat, high tone and low tone hearing loss. The only significant differences for the percentage SP measurements between patients and normal subjects, was in the click and 4 kHz tone-pip responses in the flat hearing loss group. The Width 2 measurements had a generally higher incidence of significant differences than the percentage SP.

Table V shows the number and percentage of patients exceeding the normal range (+2 SD) in the flat, high tone and low tone hearing loss groups. There were no patients where measurement of the percentage SP or width of the waveform for the 1 kHz tone-pip exceeded the normal range in cases of low tone hearing loss.

Discussion

Electrocochleography provides valuable information in the diagnosis and the status of endolymphatic hydrops in Ménière's disease (Ferraro *et al.*, 1983). The outcome of the investigation however is influenced by many factors such as the episodic nature of the disease and factors related to the methodology. A combination of hearing loss and aural fullness or pressure at the time of the test is

TABLE IV

MEAN VALUES AND TWO STANDARD DEVIATION UPPER LIMITS (+2 SD) OF ECOCHG PARAMETERS IN PATIENTS WITH FLAT, HIGH TONE AND LOW TONE AUDIOMETRIC CONFIGURATION AND IN NORMAL SUBJECTS. THE LEVEL OF STATISTICAL SIGNIFICANCE OF THE DIFFERENCE IN THE GROUP MEANS BETWEEN THE PATIENTS AND NORMAL SUBJECTS IS PRESENTED

	Flat (20 patients)			High tone (11 patients)			Low tone (6 patients)			Normals (20 subjects)	
	Mean	+2 SD	Sig.	Mean	+2 SD	Sig.	Mean	+2 SD	Sig.	Mean	+2 SD
Click											
% SP	38	88	$p<0.05$	31	62	NS	21	37	NS	24	40
Width 1 (ms)	3.0	6.7	NS	3.6	9.7	NS	2.4	17.4	NS	2.8	8.3
Width 2 (ms)	0.9	2.2	NS	0.9	1.9	$p<0.01$	0.8	1.5	$p<0.001$	0.6	0.9
Width 3 (ms)	1.2	2.0	NS	1.4	2.7	NS	1.2	2.4	NS	1.1	1.7
AP latency (ms)	2.0	2.3	$p<0.001$	2.0	2.4	$p<0.05$	1.8	2.0	$p<0.01$	1.7	2.0
4 kHz											
% SP	36	85	$p<0.01$	27	49	NS	24	40	NS	20	37
Width 1 (ms)	3.1	7.1	NS	3.3	8.5	NS	2.2	3.3	NS	2.6	4.1
Width 2 (ms)	0.9	2.1	$p<0.02$	1.0	3.0	$p<0.01$	1.0	2.2	$p<0.05$	0.6	0.8
Width 3 (ms)	1.2	1.9	NS	1.6	4.2	NS	1.2	2.5	NS	1.4	2.8
AP latency (ms)	2.2	2.9	NS	2.3	9.9	$p<0.05$	2.1	2.4	NS	1.7	2.0
1 kHz											
% SP	31	79	NS	21	75	NS	16	54	NS	31	67
Width 1 (ms)	5.8	11.4	$p<0.05$	6.3	11.3	$p<0.02$	4.1	5.9	NS	4.2	7.4
Width 2 (ms)	3.5	6.0	$p<0.001$	2.8	6.1	$p<0.02$	2.1	3.9	NS	1.6	3.0
Width 3 (ms)	3.8	9.1	NS	1.8	6.3	NS	1.6	5.3	NS	2.5	5.6
AP latency (ms)	4.5	6.9	$p<0.001$	4.2	6.8	$p<0.01$	3.6	4.8	$p<0.02$	3.0	4.0

Sig. = significance; NS = not significant.

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TABLE V

THE NUMBER AND PERCENTAGE OF PATIENTS EXCEEDING THE NORMAL RANGE (+2 SD) IN FLAT, HIGH TONE AND LOW TONE HEARING LOSS

	Flat (20 patients)		High tone (11 patients)		Low tone (6 patients)		Total (37 patients)	
	No.	%	No.	%	No.	%	No	%
Click								
% SP	6	30	3	27	0	0	9	24
Width 1	0	0	1	9	0	0	1	3
Width 2	7	35	4	36	2	33	13	35
Width 3	2	10	4	36	1	17	7	19
AP latency	9	45	5	46	0	0	14	38
4 kHz								
% SP	6	30	3	27	1	17	10	27
Width 1	3	15	3	27	0	0	6	16
Width 2	7	35	5	46	3	50	15	41
Width 3	0	0	2	18	0	0	2	5
AP latency	4	20	2	18	0	0	6	16
1 kHz								
% SP	2	10	1	9	0	0	3	8
Width 1	7	35	3	27	0	0	10	27
Width 2	9	45	4	36	0	0	13	35
Width 3	7	35	1	9	0	0	8	22
AP latency	14	70	6	54	1	17	21	57

a strong predictor of a positive outcome for endolymphatic hydrops on the ECochG (Ferraro *et al.*, 1985; Campbell *et al.*, 1992b). Ferraro *et al.* (1985) reported that severe to profound high-frequency hearing loss precludes the recording of reliable click-evoked ECochG responses. In the presence of mid-frequency hearing, tone-burst stimuli can be used, but the specificity of the response becomes tenuous for frequencies below 1000 Hz. The click stimulus has been favoured in most extratympanic ECochG techniques and tone-pip stimuli have been used in only a few studies. Terkildsen *et al.* (1975) performed ECochG using click and 4 kHz tone-pip stimuli in normal subjects and reported that the most reliable and consistent measurement of the SP and AP components was achieved with the tone-pip stimulus. Mori *et al.* (1987) studied patients with Ménière's disease using click and 1, 2, 4 and 8 kHz tone bursts. They reported that the SP elicited by mid to low frequency tone bursts were more stable than the click. Campbell *et al.* (1992b) reported that the SP/AP amplitude ratio in a small series of 10 Ménière's patients was not significantly different from normal subjects both for the click stimulus and a 6 kHz tone burst. Separation of the two groups was not improved even when symptoms at the time of the test and hearing threshold were taken into consideration. The SP and AP have been measured in a number of different ways (Coats, 1981; Goin *et al.*, 1982; Ohashi *et al.*, 1991). The absolute amplitude of the SP and AP and the SP/AP ratio (percentage SP) are commonly used to identify the presence of endolymphatic hydrops. Gibson *et al.* (1977) quantified the SP magnitude by measuring the duration of the response in the waveform. However the relationship of measurements like Widths 1, 2 and 3 combined with the percentage SP have not been related to different stimuli and the audiometric configuration.

There is some disagreement about the generation of the SP in Ménière's disease and its association with hearing loss. Coats (1981) reported that previous studies by Dallos *et al.* (1972) suggest that SP enlargement in Ménière's patients with ascending audiogram shapes was not specifically related to endolymphatic hydrops, but was instead a nonspecific consequence of a selective low-frequency deficit. However Gibson and Prasher (1983) believed that amplitude of the SP could be directly related to the presence of endolymphatic hydrops. The absolute amplitude of the SP seen in Ménière's disease indicates to some extent the survival of hair cell function (Eggermont, 1979; Ohashi *et al.*, 1991). During an hydropic attack, the basilar membrane is under abnormal pressure at rest and during stimulation (Ferraro *et al.*, 1985) resulting in a change in the functioning of the hair cells and the organ of Corti. Eggermont (1979) believed that the large SP merely indicated the relatively intact hair cells during the early stages of the disorder. Some authors (Gibson and Prasher, 1983; Ferraro *et al.*, 1985) reported that the degree of hearing loss influenced the relative enhancement of the SP/AP amplitude ratio, whereas others (Coats, 1981 and 1986; Campbell *et al.*, 1992b) showed little association particularly for hearing loss below 50 dB HL. Eggermont (1979) compared the SP seen in Ménière's disease and sensory neural hearing loss and reported that the larger SP amplitude was obtained from Ménière's patients during active periods when their hearing was poor. He also reported that SP amplitude decreased with increasing hearing loss in the sensory neural group but not in the Ménière's group. The SP/AP ratio in those Ménière's patients with hearing loss of less than 40 dB HL was not significantly different from the normal subjects. In studies of patients with hearing loss between 40 and 80 dB HL (Gibson *et al.*, 1983) the absolute SP amplitude and the SP/AP ratio was significantly different from normals at the one per cent significance level. These results are similar to our findings where a high incidence of abnormality was observed in the Type 2 hearing loss group (40 to 64 dB HL). Kumagami *et al.* (1982) classified patients with Ménière's disease according to the degree of their hearing impairment and audiometric configuration and choose an SP/AP ratio of 30 per cent as diagnostic. They found that 50 per cent of patients with mild to moderate hearing loss (mean loss of 35 dB across 0.25 through to 4 kHz) exceeded this value. This diagnostic level of SP/AP ratio is relatively low compared to our two standard deviation limit for the click waveform

(40 per cent) and may explain their high incidence of abnormal findings in patients with mild to moderate hearing loss. Gibson and Prasher (1983) reported that the SP/AP ratio was larger in moderate or severe hearing loss (often with a marked high frequency loss exceeding 60 dB HL at 4 to 8 kHz) when compared to low frequency hearing loss of around 40 dB HL for the frequencies 0.25 to 2 kHz) or flat moderate losses of about 60 dB HL. They suggested that diagnostic use of ECochG was more appropriate for patients with hearing loss of moderate to severe levels with associated high frequency loss. In our study, five patients had severe hearing impairment and 11 patients had high tone hearing loss. There was a flat or high tone hearing loss in 84 per cent of all patients and all those with severe loss (Type 3) had this audiometric configuration. These findings are consistent with studies reported by Ferraro *et al.* (1983) and Campbell *et al.* (1992b).

In this study the Width 2 and percentage SP were generally the most effective measurements in the identification of an enhanced SP. Occasionally the measurement of widening due to an enhanced SP rather than neural effects required careful analysis, particularly for the 1 kHz tone-pip stimulus. The use of a fast stimulus repetition rate, in order to adapt the AP component could be useful in this situation. In patients with only mild to moderate hearing loss (Type 1) there was a consistently higher incidence of abnormal measurements for Width 2 compared to the percentage SP across all three types of stimuli. The optimum diagnostic performance for the click stimulus was observed in patients with a mid-range hearing loss (Type 2) or a flat/high tone audiometric configuration. The performance of the 4 kHz tone-pip stimulus was on the whole less dependent on hearing loss and the audiometric configuration than the click. High frequency stimuli, such as the click and 4 kHz tone-pip, identified more cases of endolymphatic hydrops in low tone hearing loss than the 1 kHz tone-pip. The Width 2 measurement for the 1 kHz tone-pip response was abnormal in some patients even though the click and 4 kHz reponses were normal.

Conclusion

The optimum stimulus for identification of endolymphatic hydrops from an enhanced SP is dependent on the threshold and configuration of the hearing loss. Both click and tone-pip stimuli (1 and 4 kHz) should be employed in order to improve the diagnosis efficiency of ECochG in the assessment of patients with Ménière's disease.

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