Development of Frequency Selectivity Map (FSMap) depiction system for hearing impairment

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Abstract

Background: An audiological assessment of hearing impairments and the fitting of hearing aids require an accurate measurement for auditory profiles which can express loudness recruitment, reduced frequency selectivity and reduced temporal resolution. Since, it is difficult to express the complicated auditory characteristic of sensorineural hearing loss using the profile of only the audiogram. A system that can measure these auditory profiles has been needed at the practical clinic and the fitting of hearing aids.

Method: It is known that frequency selectivity is related to the bandwidth of auditory filters. In order to investigate the reduced frequency selectivity, a system that enables the measurement of an individual auditory filter of a hearing impairment in 3 minutes has been developed. The measured auditory filters are utilised to draw Frequency Selectivity Map (FSMap) with colored gradation. Actually, data of auditory filters with respect to several frequencies and sensation levels are employed to draw a FSMap. The system calculates the ratio between Equivalent Rectangular Bandwidth (ERB) of an individual hearing-impaired listener and averaged ERB of normal-hearing listeners. Auditory filters of 31 hearing impairments were measured using the proposed system.

Results: Results showed that the frequency selectivity of sensorineural hearing loss was reduced as comparing with that of the normal hearing. Different degrees of frequency selectivity for individuals who had the similar contour in audiogram were seen in the obtained FSMaps. There was no relation between FSMap and the audiogram.

Conclusion: Reduced frequency selectivity, i.e. how much your frequency selectivity is poorer than normal hearings, is quantitatively and intuitively showed with FSMap. Results of this study suggested that FSMap had a potential to be a new practical auditory profile.

Introduction

An audiological assessment of hearing impairments and the fitting of hearing aids require an accurate measurement for auditory profiles of the individual hearing impairments. Sensorineural hearing loss shows several perceptual differences from normal hearings, such as loudness recruitment, reduced frequency selectivity, reduced temporal resolution, etc. Reduced frequency selectivity has an important implication to understand the communication difficulties of hearing impairments [1]. Speech intelligibility in noisy environments is also reduced due to the loss of frequency selectivity [2]. The reduced frequency selectivity has been investigated on a basis of the measurement of auditory filters [3, 4]. Frequency selectivity of hearing impairments has the following characteristics; (1) Different among individuals and (2) Varied with respect to the centre frequencies and the sensation levels of input signal [5, 6]. Therefore, frequency selectivity for hearing impairments may be needed to measure depending on the frequencies and the sensation levels. However it is difficult to measure auditory filter, since measurement takes long time. If the system which can measure accurately auditory filter in a short time would be developed, the degree of the reduced frequency selectivity for individual hearing impairments may estimate the loss of the speech intelligibility ability and also in noisy environments. Our goal is to develop a system that can depict the variations of frequency selectivity depending on the frequencies and the sensation levels. To make use of the frequency selectivity as an auditory profile, it would be necessary to satisfy the following conditions;

(1) Measuring time must be short.

(2) Measuring procedure must be simple.

(3) Outcome should be easily understood. (User-friendly)

According to these three conditions, a system that can measure the frequency selectivity practically as an auditory profile has been developed. In this paper, auditory filters were measured for 31 hearing-impaired subjects using the system, and the practicality of this system was evaluated.

Frequency Selectivity Map depiction system

2.1 Measurement of auditory filters

FSMap is aimed to express frequency selectivity. Auditory filters, which are assumed to be symmetric at a centre frequency, are measured at various centre frequencies and sensation levels. Measuring procedure is called “Simplified measurement method” of auditory filters based on the notched noised method [7], which takes only 3 minutes to measure one auditory filter [9]. Measuring time expected to depict one FSMap is about 45 minutes in total, because one FSMap is composed of 15 auditory filters. Moreover, the automatic system that can perform the task of measurements for the auditory filters was developed for a practical use. That is, an auditory filter is measured only by a task that subjects response using a push button, whether a probe signal was perceived.

2.2 Frequency selectivity map (FSMap)

Figure 1 shows an example of FSMap [9]. In the figure, “O” marks indicate points that have an actual measured auditory filter. Other areas are estimated using interpolation technique between data on the "O" marks. FSMap is depicted by colored gradation using the ratio between ERB of a hearing impairment and averaged ERB of normal hearings where *Rb* stands for Ratio of Bandwidth. f_c and x denote center frequency and sensation level of auditory filter respectively. The *Rbs* are plotted with respect to fc and x as observational points on FSMap.

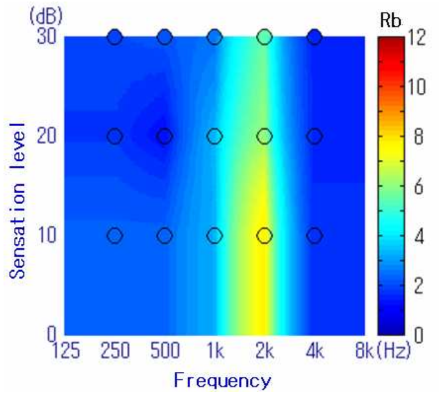

Figure 1: An example of FSMap and its audiogram

$$Rb(f_c, x) = ERB_i(f_c, x) / ERB_n(f_c, x), \quad (1)$$

Experiment

To evaluate the efficacy and the reasonability of FSMap depiction system, the experiments were conducted using the automated measuring system.

3.1 Subjects

31 hearing-impaired subjects (11 females and 20 males) participated (age: 20-91, hearing level: 25-75dBHL). 7 out of 31 subjects were measured for both ears (Total: 38 ears). Table 1 shows the individual profile and hearing thresholds for the hearing-impaired subjects.

sub.	age	sex	ear	frequency [Hz]				
				250	500	1000	2000	4000
				Hearing Level [dBHL]				
01	78	m	L	55	61	61	66	68
02	76	f	L	51	43	45	58	62
03	77	f	L	47	49	35	40	60
04	74	m	R	73	67	58	80	110
05	77	f	R	45	53	52	50	56
06	70	m	L	23	21	59	52	62
07	73	m	R	38	28	28	44	58
08	63	m	R	62	60	68	65	91
09	75	f	R	30	42	56	65	63
10	20	m	R	38	52	56	45	55
11	85	m	L	53	47	55	59	77
12	77	m	R	40	40	52	65	71
13	77	m	L	63	51	53	65	67
14	79	m	R	10	14	38	43	89
15	91	f	L	50	50	60	60	55
16	84	f	R	34	38	52	47	53
17	71	m	R	30	45	82	59	60
18	74	m	L	51	49	47	39	69
19	64	f	R	60	55	40	55	55
20	70	f	L	63	63	63	71	59
21	45	f	L	63	61	55	43	31
22	76	m	R	58	54	58	67	57
23	78	m	L	80	65	73	82	105
			R	90	80	60	83	113
24	72	m	L	51	39	43	62	88
			R	22	22	18	37	41
25	76	m	L	37	27	37	58	59
			R	30	18	28	53	55
26	73	m	L	45	40	40	50	40
			R	30	38	38	49	53
27	50	f	L	45	36	49	63	57
			R	30	40	44	71	69
28	80	m	L	55	55	57	57	69
			R	60	65	65	60	55
29	77	m	L	31	35	41	53	67
			R	44	50	52	67	71
30	39	m	L	31	35	53	53	47
			R	26	40	50	49	59
31	80	m	L	25	30	25	73	85
			R	43	27	25	80	80

Table 1: Profiles and hearing thresholds for the tested ears of individual subjects.

3.2 Measuring auditory filter

All measurements were conducted in a sound proof room. Across 5 centre frequencies (f_c =250, 500, 1000, 2000 and 4000 Hz), 3 sensation levels (x=10, 20 and 30dB) are the targeted parameters.

Results and discussion

4.1 Possibility of FSMap as an auditory profile

Figure 2 was resulted in the case that subjects who had a similar contour in audiogram to others showed different patterns of FSMap each other. Individual FSMaps showed different patterns and there was no relation between FSMap and the audiogram. It is well known that the speech intelligibility and the result of hearing aids fitting differ in each hearing-impairment which has similar contour in audiogram. A part of these phenomena may be resolved by FSMap. Further investigation, classification depending on the different types of FSMap might show some kind of tendency for frequency selectivity.

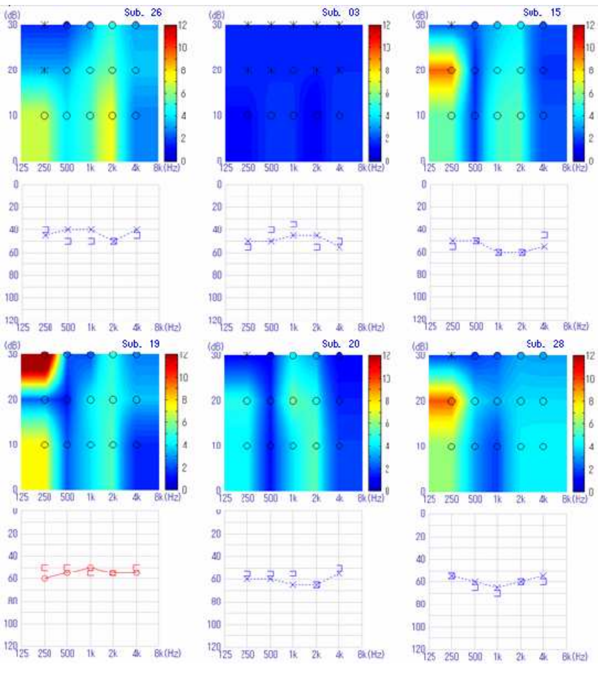

Figure 2: FSMaps and audiograms of subjects who had a similar contour in audiogram.

4.2 Possibility for the practical use

Asterisk mark in FSMap were unmeasured points due to the lack of maximum output level of the system, (Masker level: 120dBSPL), for example, 9 unmeasured points out of 15 for Subject 03 [Nakaichi2003]. It is expected that the measurement of auditory filters towards FSMap for severe or profound hearing loss can not be measured with this limitation of the system. The louder output level would be needed for those hearing losses to measure their auditory filters with taking account of hearing protection. Interpolation technique should be considered more carefully, especially for unmeasured points on FSMaps. It took about 50 minutes for actual measuring time. Shorter measuring time would be required to reduce subjects' test loadings. FSMap can be utilized for the evaluation at the practical clinic and the fitting of hearing aids, if the required improvements mentioned above are undertaken.

Conclusion

The degree of the reduced frequency selectivity is expressed by FSMap, in which the ratio between averaged ERB of normal hearings and ERB of hearing impairment are used. Result shows that (1) Individual FSMaps showed different patterns and (2) there was no relation between FSMap and the audiogram. These results suggested that FSMap has a big potential to be utilized for the evaluation at the practical clinic.

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