A Japanese nationwide survey for evaluation of the comprehensibility of alternative audiometry display formats: Insight into otolaryngologists’ cognitive processes

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A Japanese nationwide survey for evaluation of the comprehensibility of alternative audiometry display formats: Insight into otolaryngologists' cognitive processes

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ABSTRACT

Objective: The present study aimed to elucidate opinions regarding comprehensibility of audiometry display formats among otolaryngologists in Japan, and to identify the characteristics of otolaryngologists' cognitive processes for audiometry.
Methods: We conducted a cross-sectional nationwide questionnaire-based mail survey regarding the comprehensibility of audiometry display formats among 543 Japanese otolaryngologists. Of 543 otolaryngologists to whom the questionnaires were mailed, 137 replied to the questions. For the analysis, the sample size used was 112 participants. The questionnaire contained questions regarding the otolaryngologists' occupational characteristics, and assessed their opinions of four comprehensibility aspects of five display formats.
Results: Otolaryngologists in clinics indicated that the passage of time and changes in thresholds of each frequency in numeric tables were ordinary or incomprehensible. More than 60% of otolaryngologists with extensive experience in using electronic medical records indicated that both, the passage of time and change in the thresholds in overlaid thresholds on a chart were comprehensible.
Conclusions: Display formats in audiometry influenced the comprehension of pure tone audiometry data. Our results suggest that overlaid thresholds on a chart rather than numeric table or multi-dimensional charts are the primary choice for computerized audiometry display formats in most aspects of audiometry.

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1. Introduction

For otolaryngologists, the examination of a patient's hearing ability is a fundamental clinical practice. Recent advances in electronic technologies, such as computed tomography and magnetic resonance imaging, have enabled anatomical observation of the entire conductive pathway of sound, which includes the ear canal, tympanic membrane, ossicles of the middle ear cavity, endolymph of the cochlea, inner hair cells, inner ear nerve, and brain [1-3]. However, identifying hearing disorders requires assessment of the physiological function of sound conductance, which has led to the invention of audiometry, a basic functional test for hearing ability.

Since the invention of audiometry more than 100 years ago [4], its display formats have been improved by efforts to improve the quality of hearing threshold recording [5]. These efforts were reported by Hughson and Westlake [6] in 1944, Bekesy [7] in 1947, Carhart and Jerger [8] in 1959, the American National Standards Institute [9-11] in 2004, and the American Speech–Language–Hearing Association [12] in 2005. Following these efforts, an audiogram that presents the pure tone threshold in the vertical axis and tone frequency in the horizontal axis has become common worldwide as the audiometry display format. However, simplifying audiometry display format is a major concern among otolaryngologists because of the complexity caused by the presentation of numerous thresholds data in a single view. Furthermore, the sophisticated presentation of data in accumulated audiograms repeated for a single patient is a critical challenge, which has led to the use of other types of display formats for audiometry [13-15].

Recent advances in information technology have enabled the use of a wide variety of audiograms to present the results of audiometry on a computer screen. These audiograms include the piled view, two-dimensional view, and three-dimensional view. Computer technology is strongly believed to improve data presentation for audiometry. However, the diversity of audiometry display formats is problematic in that it limits the comprehensibility of audiograms for otolaryngologists. In order to improve audiometry usability, it is necessary to identify audiometry display formats that enable optimal comprehension for otolaryngologists.

One of the major reasons for this problem derives from the fact that cognitive analysis and design has not been adequately applied to audiometry displays as in various healthcare information systems [16]. The responsibility for the construction of healthcare information systems has often been left to information technologists, who are not always familiar with the complexity of healthcare work processes, as clinicians have limited expertise in the development and evaluation of devices [17,18]. In order to improve audiometry usability, it is necessary to identify audiometry display formats that enable optimal comprehension among otolaryngologists, thereby elucidating and presenting their cognitive process of audiometry usage to system administrators and software engineers.

Nevertheless, no study has surveyed the comprehensibility of audiometry display formats among otolaryngologists. A survey of otolaryngologists regarding the comprehensibility of various types of audiometry display formats is therefore needed to guide the development of information technology. Moreover, clarification of the characteristics of otolaryngologists who use audiograms most often in clinical practice will improve audiometry usability. Therefore, the present study aimed to elucidate opinions regarding the comprehensibility of audiometry display formats among otolaryngologists in Japan, and to identify the characteristics of otolaryngologists' that impact such opinions.

2. Materials and methods

2.1. Study design and participants

We conducted a cross-sectional nationwide survey of otolaryngologists in Japan. The sample consisted of 543 otolaryngologists who were selected at random from a membership list of the Oto-Rhino-Laryngology Society of Japan (Tokyo, Japan). The membership list was open to the public on the Internet in February 2016. The list of names of members and their practice offices were downloaded from the database on the homepage of the Oto-Rhino-Laryngology Society of Japan. The addresses of the offices were identified from Internet information resources. In March 2016, the questionnaire was mailed to the offices of randomly selected otolaryngologists. Questionnaires that were returned until the end of August 2016 were subjected to statistical analyses. The processed data of this study is available at Mendeley Data (http://dx.doi.org/10.17632/dty9shzbmv.3).

2.2. Questionnaire development

The questionnaire was first developed in draft form and applied to the research project members. The draft form responders included four physicians (including otolaryngologists), three nurses, one psychologist, and one healthcare service researcher. The final version of the questionnaire included the following items: years of experience as a physician; type of medical office; experience using electronic medical records (EMRs); and opinions regarding the comprehensibility of various types of display formats for audiometry.

With respect to years of experience as a physician, categories of "<15 years," "15–29 years," and "≥30 years" were used. With respect to type of medical office, categories of "clinic" and "hospital" were used. In the present study, a clinic constituted a medical practice with fewer than 20 beds for the admission of patients, in accordance with the official definition in Japan. With respect to experience using EMRs, categories of "No," "<5 years," and "≥5 years" were used. With respect to opinions regarding the comprehensibility of various types of display formats for audiometry, five formats were included: "numeric table," "piled chart," "overlaid thresholds on a chart," "two-dimensional progress chart," and "three-dimensional progress chart." These five types of representative display formats are shown in Fig. 1. For each of the five formats, otolaryngologists were asked to provide their opinion regarding comprehensibility based on the following four aspects: "passage of time," "change in thresholds,"

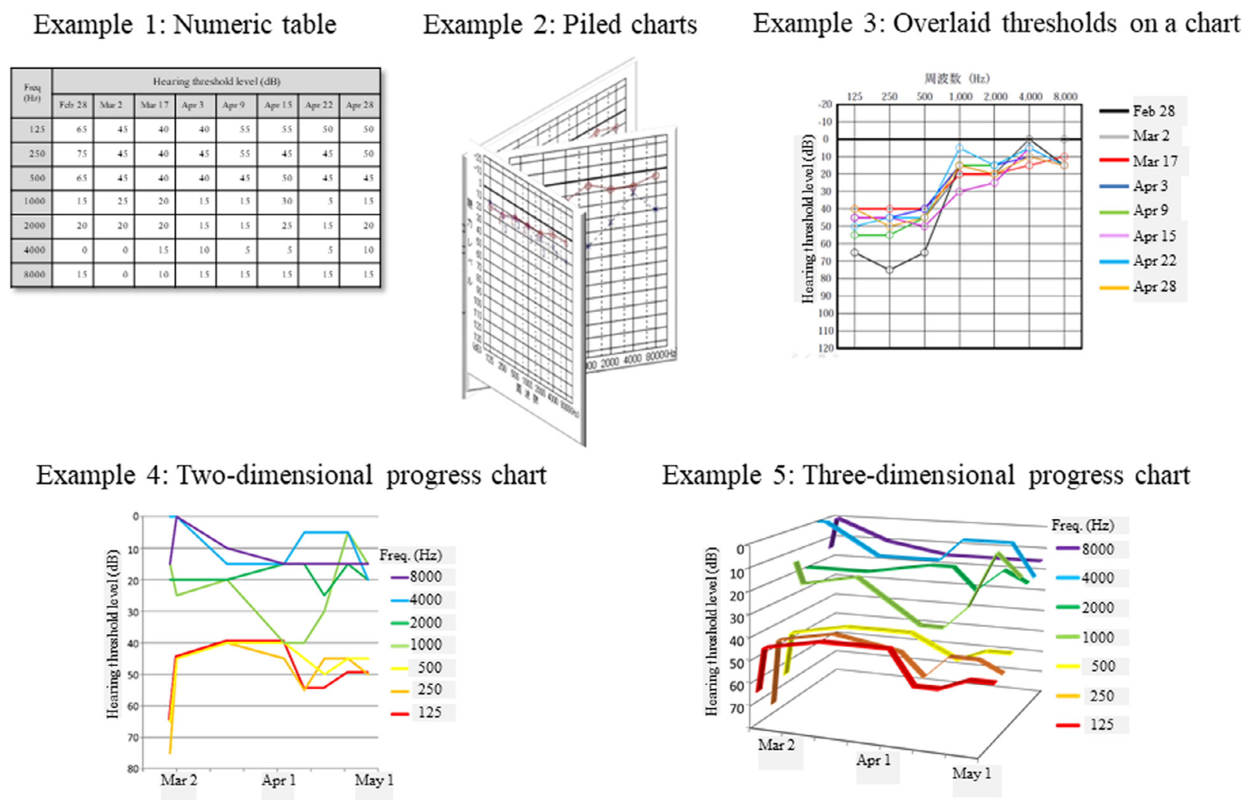

Fig. 1. Sample images of the five types of display formats.
Five types of representative display formats (Numeric table, Piled charts, Overlaid thresholds on a chart, Two-dimensional progress chart, and Three-dimensional progress chart) were shown as diagrams in the questionnaire.

"accuracy of threshold," and "notation of other medical practices." Specifically, otolaryngologists were asked the following question: 'For each of the five display formats for audiometry (numeric table, piled chart, overlaid thresholds on a chart, two-dimensional progress chart, and three-dimensional progress chart), do you think it easy to comprehend each of the four aspects (passage of time; change in thresholds; accuracy of threshold; and notation of other medical practices such as examination finding, checkup, and a prescription)?' Fig. 2 shows that the original questionnaire on the comprehensibility of the four aspects in the five display formats. With respect to these opinions, the following responses were obtained: "comprehensible," "ordinary," and "difficult to comprehend." In the analysis, these were regrouped into two categories: "Comprehensible" and "Ordinary or incomprehensible" (containing "ordinary" and "difficult to comprehend" responses) to determine whether otolaryngologists found the four aspects in each of the five display formats to be comprehensible.

2.3. Ethical considerations

The application form of the present research plan and the content of the questionnaire was submitted to the ethical review committee at Nihon University School of Medicine (Tokyo, Japan). Permission to conduct this study was issued on November 12, 2015 (approval no. 27-6). The purpose and the limitation of the usage of data was described on the first page of the questionnaire; therefore, only responders who accepted such usage could return the questionnaire with informed consent.

2.4. Statistical analysis

Descriptive statistics were used to summarize the otolaryngologists' characteristics. Then, relationships were examined between otolaryngologists' demographic characteristics and their opinions regarding the comprehensibility of all four aspects for each of the five display formats. To examine the statistical significance of the observations, chi-squared tests were conducted for all analyses. Data were analyzed using SPSS 24.0 (SPSS Inc., Chicago, IL). A P value less than 0.05 was considered to be statistically significant.

3. Results

3.1. Demographic characteristics of the otolaryngologists

Of 543 otolaryngologists to whom the questionnaires were mailed, 137 replied to the questions; this constituted an effective response rate of 25.2%. For the analysis, the sample size used was 112 participants. Participants were excluded if they did not respond to questions regarding the principal variables. The demographic characteristics of the respondents are summarized in Table 1. More than 65% of respondents had ≥15 years of experience as physicians. More than one-half

Q10. Five audiometry display formats of changes in the threshold of hearing tests from case data of intractable sensorineural hearing loss are shown. However, only the affected ear and air conduction are described. How do you evaluate the comprehensibility of the following aspects in each of the five audiometry display formats? Please check ✔ only one that best describes your evaluation?

1) Numeric table

	Comprehensible	Difficult to comprehend	Ordinary
Passage of time			
Change in thresholds			
Accuracy of threshold			
Notation of other medical practices such as examination finding, checkup, and a prescription			
Other			

2) Piled chart

	Comprehensible	Difficult to comprehend	Ordinary
Passage of time			
Change in thresholds			
Accuracy of threshold			
Notation of other medical practices such as examination finding, checkup, and a prescription			
Other			

3) Overlaid thresholds on a chart

	Comprehensible	Difficult to comprehend	Ordinary
Passage of time			
Change in thresholds			
Accuracy of threshold			
Notation of other medical practices such as examination finding, checkup, and a prescription			
Other			

4) Two-dimensional progress chart

	Comprehensible	Difficult to comprehend	Ordinary
Passage of time			
Change in thresholds			
Accuracy of threshold			
Notation of other medical practices such as examination finding, checkup, and a prescription			
Other			

5) Three-dimensional progress chart

	Comprehensible	Difficult to comprehend	Ordinary
Passage of time			
Change in thresholds			
Accuracy of threshold			
Notation of other medical practices such as examination finding, checkup, and a prescription			
Other			

Fig. 2. The original questionnaire on the comprehensibility of four aspects in five display formats.
The original questionnaire on the comprehensibility of four aspects (passage of time, change in thresholds, accuracy of threshold, and notation of other medical practices) in five display formats (numeric table, piled chart, overlaid thresholds on a chart, two-dimensional progress chart, and three-dimensional progress chart). The survey was conducted in Japanese, and the translation into English is shown in the figure.

of respondents worked in hospitals, and more than 80% of respondents had experience using EMRs in medical practice.

3.2. Opinions regarding the comprehensibility of the five display formats

Table 2 summarizes the opinions of the 112 otolaryngologists. Accurate threshold was most comprehensible when using numeric tables and piled charts. Change in thresholds was most comprehensible when using overlaid thresholds on a chart, two-dimensional progress charts, and three-dimensional progress charts. With regard to overall comprehensibility, overlaid thresholds on a chart were the preferred format. In addition, notation of other medical practice was reported to be ordinary or incomprehensible for all display formats.

As Table 3 shows, the length of experience as a physician did not significantly influence relationships between display format and aspects of comprehensibility. However, as Table 4

Table 1
Demographics of the respondents.

		n	(%)
Years of experience as a physician	<15 y	38	(33.9)
	15–29 y	44	(39.3)
	≥30 y	30	(26.8)
Office type	Clinic	52	(46.4)
	Hospital	60	(53.6)
Experience using EMRs	No	22	(19.6)
	<5 y	25	(22.3)
	≥5 y	65	(58.0)

EMR, electronic medical record.

shows, the type of medical office significantly influenced all four aspects of comprehensibility in the five audiometry display formats, particularly with regard to the passage of time and change in thresholds for each frequency in the numeric table. There was a tendency that otolaryngologists working in clinics found the numeric table to be ordinary or incomprehensible for the passage of time and change in thresholds for each frequency. No other significant influences were revealed through this analysis.

As shown in Table 5, the length of experience in using EMRs significantly influenced the comprehensibility of the passage of time in piled audiograms and in three-dimensional progress charts. With increased use of EMRs in medical practice, the piled audiogram became increasingly ordinary or incomprehensible for the passage of time. However, more than five years' experience or no experience in using EMRs seemed to worsen the comprehensibility of the passage of time on three-dimensional charts. Experience in using EMRs did not influence the comprehensibility of change in the thresholds for each frequency, accurate threshold, or the notation of other medical practices in each display format.

The major characteristics of otolaryngologists' cognitive processes are summarized in Figs. 3 and 4. In Fig. 3, ratios of comprehensibility of each display format for individuals either experienced or non-experienced with EMRs were depicted separately for passage of time, change in the thresholds of each frequency, accurate threshold and notation of other medical practices, in panels numbered from a to d, respectively. The overlaid thresholds on a chart tended to be superior in comprehensibility for passage of time, change in the thresholds of each frequency and accurate threshold, while none of display formats showed comprehensibility for more than one third of laryngologists. In Fig. 4, the relationship between display format and aspects of comprehensibility is shown for otolaryngologists who were experienced or non-experienced for EMRs. Comprehensibility of more than fifty per cents has been depicted in the figure. The results clearly show that overlaid thresholds on a chart are evaluated as most comprehensible among both, experienced and non-experienced otolaryngologists. It is also remarkable that non-experienced otolaryngologists evaluate piled charts the best for passage of time.

4. Discussion

In the present study, we collected opinions of otolaryngologists regarding the comprehensibility of audiometry display formats. In particular, our data demonstrated that experience in using EMRs influenced the comprehensibility of various aspects of audiometry display formats. Thus far, no preceding research has been conducted worldwide regarding the validation of audiometry display formats. Therefore, to the best of our knowledge, this was the first study to elucidate the diversity and appropriateness of audiometry display format. This information may help to optimize and

Table 2
Opinions regarding the comprehensibility of the five display formats.

Display formats	Comprehensibility aspects	OOI		Comp	
		n	(%)	n	(%)
Numeric table	Passage of time	90	(80.4)	22	(19.6)
	Change in the thresholds of each frequency	85	(75.9)	27	(24.1)
	Accuracy of the threshold	64	(57.1)	48	(42.9)
	Notation of other medical practices	96	(85.7)	16	(14.3)
Piled chart	Passage of time	75	(67.0)	37	(33.0)
	Change in the thresholds of each frequency	78	(69.6)	34	(30.4)
	Accuracy of the threshold	69	(61.6)	43	(38.4)
	Notation of other medical practices	85	(75.9)	27	(24.1)
Overlaid thresholds on a chart	Passage of time	44	(39.3)	68	(60.7)
	Change in the thresholds of each frequency	27	(24.1)	85	(75.9)
	Accuracy of the threshold	51	(45.5)	61	(54.5)
	Notation of other medical practices	81	(72.3)	31	(27.7)
Two-dimensional progress chart	Passage of time	88	(78.6)	24	(21.4)
	Change in the thresholds of each frequency	76	(67.9)	36	(32.1)
	Accuracy of the threshold	99	(88.4)	13	(11.6)
	Notation of other medical practices	103	(92.0)	9	(8.0)
Three-dimensional progress chart	Passage of time	83	(74.1)	29	(25.9)
	Change in the thresholds of each frequency	81	(72.3)	31	(27.7)
	Accuracy of the threshold	101	(90.2)	11	(9.8)
	Notation of other medical practices	105	(93.8)	7	(6.3)

OOI, ordinary or incomprehensible; Comp, comprehensible.

Table 3
Relationship between years of experience as a physician and opinion of comprehensibility.

Comprehensibility aspects	Experience as a physician	Numeric table			Piled charts			Overlaid thresholds on a chart			Two-dimensional progress chart			Three-dimensional progress chart		
		OOI	Comp	P value	OOI	Comp	P value	OOI	Comp	P value	OOI	Comp	P value	OOI	Comp	P value
Passage of time	<15 y	29 (76.3)	9 (23.7)	0.676	28 (73.7)	10 (26.3)	0.326	17 (44.7)	21 (55.3)	0.426	29 (76.3)	9 (23.7)	0.916	26 (68.4)	12 (31.6)	0.615
	15–29y	37 (84.1)	7 (15.9)		30 (68.2)	14 (31.8)		14 (31.8)	30 (68.2)		35 (79.5)	9 (20.5)		34 (77.3)	10 (22.7)	
	≥30 y	24 (80.0)	6 (20.0)		17 (56.7)	13 (43.3)		13 (43.3)	17 (56.7)		24 (80.0)	6 (20.0)		23 (76.7)	7 (23.3)	
Change in the thresholds of each frequency	<15 y	28 (73.7)	10 (26.3)	0.469	29 (76.3)	9 (23.7)	0.544	12 (31.6)	26 (68.4)	0.237	23 (60.5)	15 (39.5)	0.367	25 (65.8)	13 (34.2)	0.606
	15–29y	36 (81.8)	8 (18.2)		29 (65.9)	15 (34.1)		7 (15.9)	37 (84.1)		30 (68.2)	14 (31.8)		35 (79.5)	9 (20.5)	
	≥30y	21 (70.0)	9 (30.0)		20 (66.7)	10 (33.3)		8 (26.7)	22 (73.3)		23 (76.7)	7 (23.3)		21 (70.0)	9 (30.0)	
Accurate threshold	<15y	23 (60.5)	15 (39.5)	0.398	20 (52.6)	18 (47.4)	0.249	18 (47.4)	20 (52.6)	0.946	32 (84.2)	6 (15.8)	0.423	35 (92.1)	3 (7.9)	0.334
	15–29y	27 (61.4)	17 (38.6)		31 (70.5)	13 (29.5)		20 (45.5)	24 (54.5)		41 (93.2)	3 (6.8)		41 (93.2)	3 (6.8)	
	≥30y	14 (46.7)	16 (53.3)		18 (60.0)	12 (40.0)		13 (43.3)	17 (56.7)		26 (86.7)	4 (13.3)		25 (83.3)	5 (16.7)	
Notation of other medical practices	<15y	33 (86.8)	5 (13.2)	0.564	26 (68.4)	12 (31.6)	0.214	26 (68.4)	12 (31.6)	0.536	34 (89.5)	4 (10.5)	0.785	36 (94.7)	2 (5.3)	0.361
	15–29y	39 (88.6)	5 (11.4)		33 (75.0)	11 (25.0)		31 (70.5)	13 (29.5)		41 (93.2)	3 (6.8)		42 (95.5)	2 (04.5)	
	≥30y	24 (80.0)	6 (20.0)		26 (86.7)	4 (13.3)		24 (80.0)	6 (20.0)		28 (93.3)	2 (6.7)		27 (90.0)	3 (10.0)	

Data are presented as number (percentage), unless otherwise indicated.
OOI, ordinary or incomprehensible; Comp, comprehensible.

Table 4
Relationship between the type of office and opinion of comprehensibility.

Comprehensibility aspects	Type of office	Numeric table			Piled charts			Overlaid thresholds on a chart			Two-dimensional progress chart			Three-dimensional progress chart		
		OOI	Comp	P value	OOI	Comp	P value	OOI	Comp	P value	OOI	Comp	P value	OOI	Comp	P value
Passage of time	Clinic	47 (90.4)	5 (9.6)	0.013*	34 (65.4)	18 (34.6)	0.741	16 (30.8)	36 (69.2)	0.086	43 (82.7)	9 (17.3)	0.322	41 (78.8)	11 (21.2)	0.286
	Hospital	43 (71.7)	17 (28.3)		41 (68.3)	19 (31.7)		28 (46.7)	32 (53.3)		45 (75.0)	15 (25.0)		42 (70.0)	18 (30.0)	
Change in thresholds of each frequency	Clinic	44 (84.6)	8 (15.4)	0.045*	38 (73.1)	14 (26.9)	0.462	11 (21.2)	41 (78.8)	0.496	39 (75.0)	13 (25.0)	0.132	40 (76.9)	12 (23.1)	0.311
	Hospital	41 (68.3)	19 (31.7)		40 (66.7)	20 (33.3)		16 (26.7)	44 (73.3)		37 (61.7)	23 (38.3)		41 (68.3)	19 (31.7)	
Accurate threshold	Clinic	31 (59.6)	21 (40.4)	0.623	36 (69.2)	16 (30.8)	0.122	19 (36.5)	33 (63.5)	0.075	46 (88.5)	6 (11.5)	0.983	46 (88.5)	6 (11.5)	0.570
	Hospital	33 (55.0)	27 (45.0)		33 (55.0)	27 (45.0)		32 (53.3)	28 (46.7)		53 (88.3)	7 (11.7)		55 (91.7)	5 (8.3)	
Notation of other medical practices	Clinic	47 (90.4)	5 (9.6)	0.189	41 (78.8)	11 (21.2)	0.496	36 (69.2)	16 (30.8)	0.496	47 (90.4)	5 (9.6)	0.567	47 (90.4)	5 (9.6)	0.171
	Hospital	49 (81.7)	11 (18.3)		44 (73.3)	16 (26.7)		45 (75.0)	15 (25.0)		56 (93.3)	4 (6.7)		58 (96.7)	2 (3.3)	

Data are presented as number (percentage), unless otherwise indicated.
OOI, ordinary or incomprehensible; Comp, comprehensible.
* Indicates a statistically significant difference between otolaryngologists practicing in a clinic office and a hospital office.

Table 5
Relationship between years of experience using EMRs and opinion of comprehensibility.

Comprehensibility aspects	Years of Experience in using EMRs	Numeric table			Piled charts			Overlaid thresholds on a chart			Two-dimensional progress chart			Three-dimensional progress chart		
		OOI	Comp	P value	OOI	Comp	P value	OOI	Comp	P value	OOI	Comp	P value	OOI	Comp	P value
Passage of time	no	17 (77.3)	5 (22.7)	0.691	7 (31.8)	15 (68.2)	<0.001*	9 (40.9)	13 (59.1)	0.539	20 (90.9)	2 (9.1)	0.074	19 (86.4)	3 (13.6)	0.013*
	<5 y	19 (76.0)	6 (24.0)		18 (72.0)	7 (28.0)		12 (48.0)	13 (52.0)		16 (64.0)	9 (36.0)		13 (52.0)	12 (48.0)	
	≥5 y	54 (83.1)	11 (16.9)		50 (76.9)	15 (23.1)		23 (35.4)	42 (64.6)		52 (80.0)	13 (20.0)		51 (78.5)	14 (21.5)	
Change in the thresholds of each frequency	no	17 (77.3)	5 (22.7)	0.875	13 (59.1)	9 (40.9)	0.280	4 (18.2)	18 (81.8)	0.727	15 (68.2)	7 (31.8)	0.332	15 (68.2)	7 (31.8)	0.419
	<5 y	18 (72.0)	7 (28.0)		16 (64.0)	9 (36.0)		7 (28.0)	18 (72.0)		14 (56.0)	11 (44.0)		16 (64.0)	9 (36.0)	
	≥5 y	50 (76.9)	15 (23.1)		49 (75.4)	16 (24.6)		16 (24.6)	49 (75.4)		47 (72.3)	18 (27.7)		50 (76.9)	15 (23.1)	
Accurate threshold	no	14 (63.6)	8 (36.4)	0.143	13 (59.1)	9 (40.9)	0.726	8 (36.4)	14 (63.6)	0.628	19 (86.4)	3 (13.6)	0.632	18 (81.8)	4 (18.2)	0.091
	<5 y	10 (40.0)	15 (60.0)		14 (56.0)	11 (44.0)		12 (48.0)	13 (52.0)		21 (84.0)	4 (16.0)		21 (84.0)	4 (16.0)	
	≥5 y	40 (61.5)	25 (38.5)		42 (64.6)	23 (35.4)		31 (47.7)	34 (52.3)		59 (90.8)	6 (9.2)		62 (95.4)	3 (04.6)	
Notation of other medical practices	no	19 (86.4)	3 (13.6)	0.962	17 (77.3)	5 (22.7)	0.574	16 (72.7)	6 (27.3)	0.998	20 (90.9)	2 (9.1)	0.978	20 (90.9)	2 (9.1)	0.771
	<5 y	21 (84.0)	4 (16.0)		17 (68.0)	8 (32.0)		18 (72.0)	7 (28.0)		23 (92.0)	2 (8.0)		24 (96.0)	1 (4.0)	
	≥5 y	56 (86.2)	9 (13.8)		51 (78.5)	14 (21.5)		47 (72.3)	18 (27.7)		60 (92.3)	5 (7.7)		61 (93.8)	4 (6.2)	

Data are presented as number (percentage), unless otherwise indicated.
OOI, ordinary or incomprehensible; Comp, comprehensible.
* Indicates a statistically significant difference in the relationship between experience using electronic medical records (EMRs) and opinion of the indicated aspect of the comprehensibility of the indicated display format.

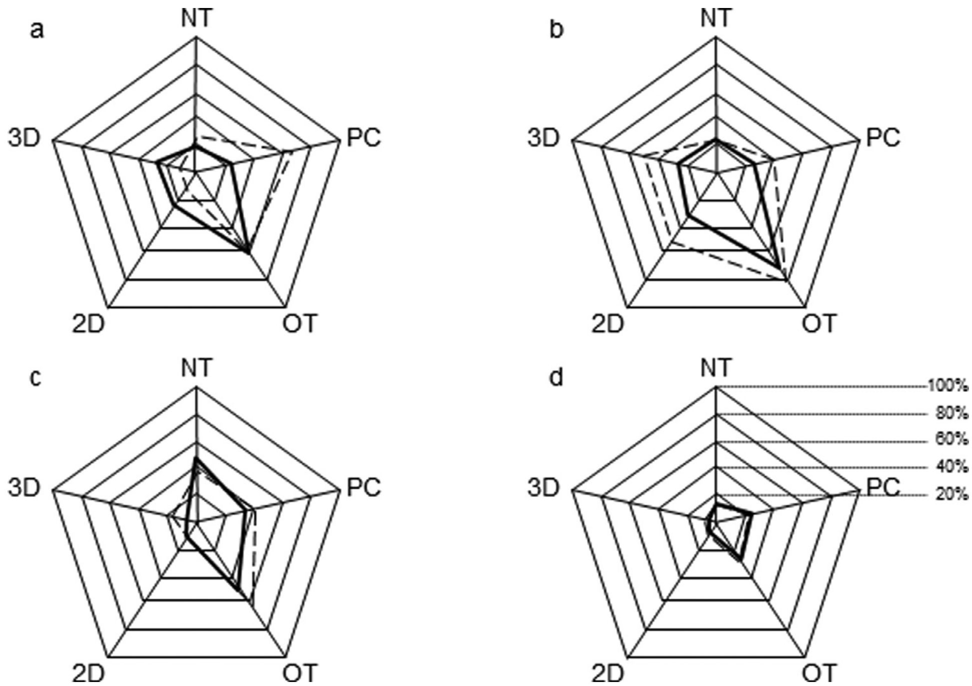

Fig. 3. Relationship between aspects of comprehensibility and display formats among experienced and non-experienced otolaryngologists for EMRs.
Four aspects of comprehensibility in five types of display formats among otolaryngologists who are either experienced or non-experienced in EMRs were depicted in four panels. Panel a, b, c, and d shows the relationship with passage of time, change in the thresholds of each frequency, accurate threshold, and notation of other medical practices, respectively. NT, PC, OT, 2D and 3D depicts numeric table, piled charts, overlaid thresholds on a chart, two-dimensional progress chart and three-dimensional progress chart, respectively.

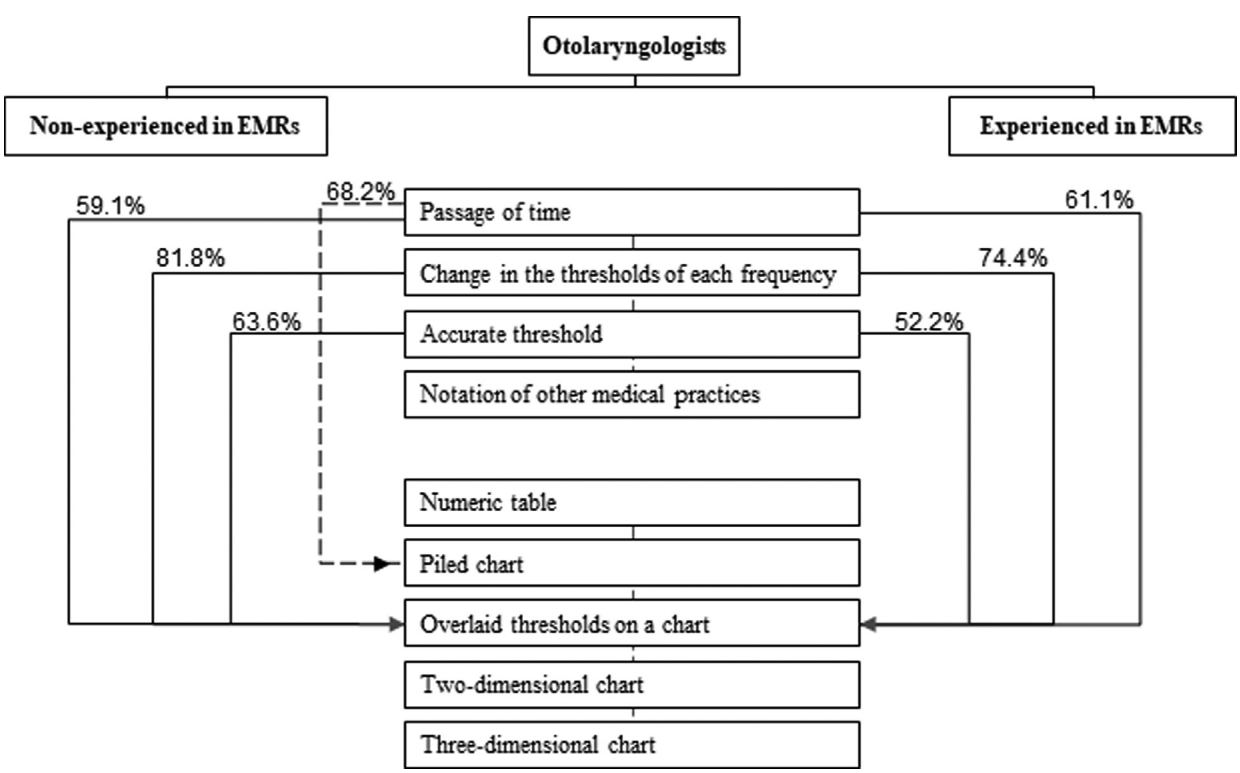

Fig. 4. Major cognitive process in four aspects of comprehensibility for EMRs among experienced and non-experienced otolaryngologists.
To summarize the cognitive process for audiometry among otolaryngologists, cognitive flow for each display format was lined from cognitive aspect to comprehensibility. Percentage data depicts the ratio of otolaryngologists who evaluated comprehensibility for the indicated display format. While non-experienced otolaryngologists evaluated piled charts as most comprehensible for passage of time, the experienced did not. More than 50% of both, experienced and non-experienced otolaryngologists evaluated overlaid thresholds on a chart most superior for three aspects other than notation of other medical practices.

standardize audiometry presentation methodology in the era of information technology. Our data suggest that each display format has its own advantages and disadvantages for comprehension of audiometry results. Our data further suggest that sophisticated combinations of these formats may be achieved with the aid of computerized information technology. In the future, combining formats may improve the quality of audiometry in clinical practice.

Several display formats have been utilized in the scientific literature regarding otology. These formats include numeric tables [19-21], overlaid thresholds on a chart [22-24], and two-dimensional progress charts [13-15]. We could not specifically identify the other three display formats in the scientific literature; notably, it seems unlikely that the piled audiogram has been discussed in prior publications. An array of diagrams may serve as an alternative for the piled audiogram [25]. For overlaid thresholds on an audiogram, truncated datasets have been presented in prior reports [22-24], which suggests that greater complexity may be problematic for use in clinical practice. Piled audiograms can be regarded as a series of audiograms attached serially on a sheet. Therefore, it may be meaningless to search for examples in the literature because their usage in medical practice has not been described thus far. We could not identify any studies involving the use of a three-dimensional progress chart, within the literature. This may be due to the complexity of this display format with respect to readers of scientific articles.

We found that overlaid thresholds on a chart were the preferred display format for all aspects of comprehensibility, and that the notation of other medical practices was generally regarded as ordinary or incomprehensible. However, the four aspects of comprehensibility differed among display formats. These results suggest that audiograms may have different advantages and disadvantages for comprehending data from pure tone audiometric tests.

Furthermore, we found that opinions regarding the comprehensibility of audiometry display formats among otolaryngologists were associated with otolaryngologists' characteristics. First, we found that the type of medical office influenced otolaryngologists' opinions regarding the four aspects of comprehensibility for each of the five audiometry display formats. This influence was most striking for the passage of time and change in the thresholds for each frequency (i.e., the elapsed time information). Conversely, we found no relationship between the type of medical office and the piled charts audiogram, which does not provide any axis for the presentation of elapsed time. Otolaryngologists appeared to indicate that audiograms with time-dependent factors are not comprehensible. Specifically, otolaryngologists working in clinics indicated that time-dependent information was not comprehensible, whereas otolaryngologists working in hospitals did not. In Japan, otolaryngologists working in clinics care for a greater number of patients than do otolaryngologists working in hospitals. This factor may have affected the opinions of otolaryngologists in this regard. Further studies are necessary to elucidate the influence of the medical office type with respect to comprehensibility of audiometry display formats.

Another factor that influenced otolaryngologists' opinions was the length of experience in using EMRs. The results demonstrated that otolaryngologists who were well-experienced in using EMRs did not prefer the piled charts audiogram because of its ability for comprehending the passage of time. This finding indicated that experience in using EMRs caused otolaryngologists to indicate that the passage of time in the piled charts audiogram was not comprehensible. The present findings therefore imply that the entry of information technology into the field of otology will accelerate the development of an optimized audiometry display format for comprehending the passage of time.

Regarding three-dimensional progress charts, we observed an interesting result regarding the relationship with experience in using EMRs. Otolaryngologists who were beginners, as well as those who were well-experienced, both indicated that the passage of time in three-dimensional progress charts was not comprehensible. For beginners, three-dimensional charts may be somewhat complicated for grasping data. However, the poor opinion regarding three-dimensional charts among well-experienced otolaryngologists suggested that this format is not optimal for comprehension of the passage of time.

There were several limitations in the present study. First, the number of respondents with valid replies was not large as we expected. This is likely because the participants were limited to otolaryngologists who were interested in the results of the present research project. Moreover, a lack of time in their clinical schedules may have hindered replies from potential respondents. Additionally, the lack of an incentive for responding to the questionnaire may have contributed to the low response rate. Second, our present research was unique in that there has been no similar report thus far. Therefore, we could not compare the results of the survey among regions, countries, or institutions. We also could not compare opinions regarding audiogram comprehensibility among medical and co-medical staff workers, other than otolaryngologists. Further studies will enable broader interpretation and analysis. Third, we could not add real computer displays to the questionnaire for representing each display format owing to difficulties in defining software specifications for each representative display format. While numeric table and piled charts are easily demonstrable on computer software, the evaluation of the other three formats may be influenced by various factors such as screen response speed, arrangement of screen operation tools and implementation of programmers' original function for each format. Therefore, we had to refrain from applying the computerized display format for the present study. Nevertheless, our results clearly showed the considerable superiority of overlaid thresholds on a chart; this may have supported the adequacy of presentation of display formats for the present study.

We have summarized the results of our study in Figs. 3 and 4. In the very early phase of the present study, we hypothesized that otolaryngologists experienced in EMRs would evaluate multi-dimensional charts as superior, as they would skilled in manipulating the computer screen. Our results elucidate one of the most important issues regarding constructing the software for audiometry. The information that the conventional threshold chart is regarded to be the most superior for otolaryngologists should be shared with all the system integrators and software programmers for audiometry and EMRs.

In the present study, we could not evaluate the future increase in value of multi-dimensional charts. Further precise analyses on otolaryngologists' cognitive processes will be required in the stage of full-scale software development to elucidate their value for audiometry.

5. Conclusions

Audiometry display formats may exhibit different advantages and disadvantages for comprehending data from pure tone audiometric tests. Comprehensibility of audiometry display formats among otolaryngologists were associated with otolaryngologists' characteristics. Appropriate combinations of display formats consistent with otolaryngologists' cognitive processes are needed in the era of information technology and should be developed to improve the quality of clinical practice.

Declaration of Interest Statement

The authors report no conflicts of interest.

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