นิพนธ์ต้นฉบับ Original Article

การเปรียบเทียบผลการทดสอบสมรรถภาพการได้ยินระหว่างวิธีอัตโนมัติและวิธีปรับด้วยมือของผู้ที่เข้ารับบริการในโรงพยาบาลแห่งหนึ่ง ประเทศไทย

A Comparison of Hearing Assessment Between Automated and Manual Audiometry of Person Who Receive Health Check-ups at a Hospital, Thailand

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บทคัดย่อ

การศึกษาวิจัยเชิงวิเคราะห์แบบตัดขวางนี้มีวัตถุประสงค์เพื่อเปรียบเทียบผลการทดสอบสมรรถภาพการได้ยินระหว่างชนิดอัตโนมัติและชนิดปรับด้วยมือในสามประเด็นสำคัญ ได้แก่ ระดับการได้ยิน ระยะเวลาในการทดสอบ และความพึงพอใจของผู้เข้ารับการทดสอบ โดยมีกลุ่มตัวอย่างจำนวน 24 คน เข้ารับการทดสอบสมรรถภาพการได้ยินในช่วงความถี่ตั้งแต่ 500 ถึง 8000 เฮิรตซ์ ทั้งวิธีอัตโนมัติและวิธีปรับด้วยมือ วิเคราะห์ข้อมูลด้วยสถิติเชิงพรรณนาและสถิติเชิงอนุมาน ผลการศึกษาพบว่าผลการทดสอบสมรรถภาพการได้ยินทั้งสองวิธีมีความแตกต่างไม่เกิน 10 เดซิเบลในทุกความถี่ และยังพบความสัมพันธ์ในระดับสูงอย่างมีนัยสำคัญทางสถิติระหว่างวิธีการทั้งสอง ($p<0.05$) นอกจากนี้ การทดสอบวิธีอัตโนมัติใช้ระยะเวลาในการทดสอบสั้นกว่าวิธีปรับด้วยมืออย่างมีนัยสำคัญทางสถิติ ($p<0.05$) ส่วนในด้านความพึงพอใจในภาพรวมไม่แตกต่างกัน แต่พบว่าผู้เข้ารับการทดสอบมีความพึงพอใจต่ำกว่าสำหรับระยะเวลาของการทดสอบสมรรถภาพการได้ยินชนิดอัตโนมัติ ($p<0.05$) จากผลการศึกษาสามารถสรุปได้ว่าการทดสอบสมรรถภาพการได้ยินชนิดอัตโนมัติให้ผลที่เชื่อถือได้ใกล้เคียงกับการทดสอบชนิดปรับด้วยมือและยังมีข้อได้เปรียบด้านการประหยัดเวลา วิธีการทดสอบนี้จึงมีศักยภาพในการนำไปใช้ในการเฝ้าระวังทางการแพทย์ในกลุ่มที่ทำงานสัมผัสเสียงดังและในการจัดทำมาตรการอนุรักษ์การได้ยิน อย่างไรก็ตาม ควรมีการปรับปรุงขั้นตอนการทดสอบหรือคำแนะนำการทดสอบแก่ผู้รับการทดสอบเพื่อแก้ไขความกังวลด้านเวลาการทดสอบของผู้เข้ารับการทดสอบ

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Abstract

This cross-sectional analytical study aimed to compare automated and manual audiometry across three important dimensions: hearing test outcomes, testing duration, and user satisfaction. Twenty-four participants (forty-eight ears) underwent hearing threshold testing at frequencies ranging from 500 to 8000 Hz by both automated and manual audiometry. The data were analyzed using descriptive statistics and analytic statistics. The results showed that the hearing threshold differences between the two methods did not exceed 10 decibels at any frequency. Furthermore, a statistically significant high correlation was found between automated and manual audiometry (p<0.05), confirming the reliability of the automated method. Also, automated audiometry was significantly faster than the manual approach (p<0.05). Regarding user satisfaction, overall levels were similar, although participants expressed lower satisfaction with the duration of the automated test (p<0.05). These findings suggest that automated audiometry provides results comparable to manual testing while saving time. The method therefore shows promise for integration into medical surveillance programs. Moreover, its use in hearing conservation program could further enhance accessibility to timely screenings. However, improvements in the testing procedure or user instructions are recommended to address participant concerns about test duration.

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คำสำคัญ
การทดสอบสมรรถภาพการได้ยินชนิดอัตโนมัติ;
การทดสอบสมรรถภาพการได้ยินชนิดปรับด้วยมือ;
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มาตรการอนุรักษ์การได้ยิน

Keywords
automated audiometry; manual audiometry;
noise-induced hearing loss;
hearing conservation program

Introduction

Nowadays, noise-induced hearing loss (NIHL) is a significant concern in occupational health[1]. Many countries have implemented occupational safety and health regulations to protect workers from excessive noise exposure and to monitor their hearing through Hearing Conservation Programs (HCPs). To comply with Thailand's legislation[2], employers are required to provide hearing tests to their employees at least annually. Pure-tone audiometry (PTA) is the standard hearing test used to monitor workers' hearing function[3,4]. This test employs an audiometer certified according to ANSI S3.6 standards to assess hearing thresholds at key frequencies (500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz)[2,5]. PTA is typically administered by certified healthcare providers and follows established protocols such as the modified Hughson-Westlake and Bekesy methods. However, all these protocols require trained personnel for proper execution. With the advent of the digital era, automated audiometry was introduced over a decade ago as a potential alternative for conducting hearing tests without direct involvement of certified healthcare providers[6,7]. Automated audiometry offers potential advantages such as increased accessibility, particularly in remote settings, and potential cost-effectiveness for large-scale screening programs[8,9].

The principle of automated audiometry is based on the Hughson & Westlake method from 1972. The system utilizes a computer to control sound intensity levels, sound frequencies simultaneously collecting feedback from test participants regarding their ability to respond within specified time parameters[7]. Common operational challenges with automated audiometry include: the inability to interrupt or pause testing midway, limitations in selectively re-testing specific sound frequencies, and the requirement to restart the entire testing procedure from the beginning when a repeat examination is necessary[10]. While most studies on automated audiometry have focused on diagnostic applications within Otolaryngology clinics[10], its utility for routine screening within the context of Hearing Conservation Programs remains less explored, especially considering the acceptable range of interpersonal variability in hearing thresholds. Chonburi Province is one of the key provinces in the Eastern Economic Corridor (EEC), which ranks among the top provinces in terms of industrial parks. Consequently, this area experiences significant noise and has a high demand for hearing assessments. Therefore, this study aims to answer the research question: Are the differences in hearing test results obtained using automated versus manual audiometry among person who receive health check-ups at a hospital in Thailand consistently less than or within 10 dB, a threshold considered acceptable for interpersonal variability[10,11]. In addition to comparing hearing thresholds, the study also aims to evaluate the differences in testing time between the two methods and to assess participant satisfaction with each methods.

To address these objectives, we conducted a cross-sectional analytical study comparing hearing thresholds, test duration, and user satisfaction between automated and manual audiometry.

Material and methods

Study design

This study employed a single-group cross-sectional analytical design to compare hearing thresholds obtained using manual audiometry and the Automated Method for Testing Auditory Sensitivity (AMTAS) automated audiometry system. Additionally, we aimed to compare the time required to complete each testing method and to assess participant satisfaction with both method. The study was conducted at the Industrial Medicine Center of Queen Savang Vadhana Memorial Hospital, Chon Buri, Thailand. Ethical approval for this study was obtained from the Burapha University Institutional Review Board (Reference number: IRB3-018/2568) and the Queen Savang Vadhana Memorial Hospital Ethics Committee (Reference number: 046/2567). This study did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Participants

Twenty-four participants were recruited on a voluntary basis for this single-group cross-sectional analytical study. Participants were workers visiting the Industrial Medicine Center of Queen Savang Vadhana Memorial Hospital for hearing tests, as this sample size was determined using a paired t-test approach, performed using SPSS for windows version 29.0.2.0 with a concurrent user license, lock code 4-25F41. The standard deviation of differences between hearing performance test results using manual and automatic testing methods was set at 4.2 dB, with the mean difference between these testing methods established at 3.6 dB, and 95% confidence level, the initial sample size was determined to be 20 participants. To account for potential sample attrition, researchers added a 20% contingency margin, establishing the total sample size at twenty-four participants[7].

Recruitment also involved displaying posters within the hospital to inform interested individuals about the study and invite their participation. Inclusion criteria for participation were: being 18 years of age or older; being able to communicate verbally and comprehend written in Thai language; providing informed consent to participate in the research; and reporting no exposure to loud noise for at least 12 hours prior to the hearing tests. Exclusion criteria included: being unable to complete all stages of the research protocol; and being individuals undergoing repeat hearing tests. Informed consent was obtained from all subjects involved in the study. All procedures were performed in accordance with the ethical principles of the declaration of Helsinki 1964.

Procedures

Pure-tone audiometry, both manual and automated, were conducted by a trained nurse from a team of three, utilizing the modified Hughson-Westlake method. Manual audiometry was performed using a Madsen Xeta audiometer, certified to ANSI S3.6 standards, with DD45-TDH39 supra-aural headphones in an ANSI-standard sound booth. The testing procedure adhered to the guidelines of the British Society of Audiology.(12,13)

Automated audiometry was conducted using the AMTAS Flex system, certified to ANSI S3.6 standards, on a touchscreen notebook (Lenovo IdeaPad Duet 5) with DD65v2 supra-aural headphones in the same sound booth. Prior to starting the automated test, subjects were provided with a brief (about 2 minutes) instructional video in Thai language demonstrating the operation of the device after the headphones were fitted. All these devices have already been calibrated before use.

Both manual and automated audiometry assessed hearing thresholds at frequencies of 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz in both ears. Automated audiometry was consistently performed first, followed by manual audiometry, with an approximately 5-minute rest period between the two tests. Subsequently, all subjects were asked to provide a satisfaction assessment (5-Likert scale) for each testing method and then underwent otoscopy by a physician to confirm the absence of any abnormalities in the outer and middle ear.

Statistical analysis

Hearing thresholds obtained via automated and manual audiometry were entered into a Microsoft excel data sheet. Statistical analysis was conducted using SPSS for windows version 29.0.2.0. Hearing threshold data was analyzed for each tested frequency (500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz) and averaged across all frequencies. Descriptive statistics, including means and standard deviations, were calculated to summarize the data. The absolute difference between hearing thresholds obtained via manual audiometry and automated audiometry was calculated (Automated Audiometry threshold-Manual Audiometry threshold).

Inferential statistical analyses were conducted to compare hearing thresholds and testing times between the two methods for a total of twenty-four participants (forty-eight ears). The Wilcoxon signed-rank test was used for testing time comparisons and the relationship between hearing thresholds obtained by the two methods was assessed using Spearman's Rank Correlation coefficient (r_s) at each frequency and across all frequencies. Satisfaction levels for each method were compared using the Wilcoxon signed-rank test. A p-value of less than 0.05 was considered statistically significant for all inferential tests.

Results

The study included 24 participants. There were 22 males (91.7%), aged 21.17±2.28 years (range: 19-31 years), mostly there were no underlying diseases (83.3%) and non-smokers (87.5%)

Hearing Threshold Comparison

Comparison of hearing thresholds between automated and manual audiometry revealed mean absolute differences (Absolute value from automated audiometry minus manual audiometry) from 5.4 dB to 10.0 dB and standard deviation from 3.2 to 5.5. The minimum difference was observed at 8000 Hz, and the maximum difference was at 2000 Hz, as detailed in table 1. All tested frequencies showed a mean absolute difference of 8.5 dB (SD=4.9 dB), with a median of 10 dB (interquartile range: Q1=5, Q3=10) and a total range of 0 to 25 dB. Overall, hearing threshold levels obtained with automated audiometry were lower (indicating better hearing sensitivity) compared to manual audiometry across all tested frequencies.

Table 1 Mean, Standard Deviation, Minimum, and Maximum of Absolute Differences in Hearing Threshold Levels Between Automated and Manual Audiometry (n=48)

Frequency (Hz)	Absolute difference of hearing threshold level (dB)						
	mean	SD	median	Q1, Q3	minimum	maximum	*p* value
500	7.3	3.9	5	5, 10	0	15	<0.001
1000	9.9	3.2	10	10, 10	5	15	<0.001
2000	10.0	4.6	10	6.25, 15	0	15	<0.001
3000	7.4	4.5	7.5	5, 10	0	15	<0.001
4000	9.8	5.4	10	5, 15	0	20	<0.001
6000	9.5	5.5	10	5, 15	0	20	<0.001
8000	5.4	5.4	5	0, 8.75	0	25	0.009

The percentage of absolute differences in hearing thresholds between the two methods that were within 10 dB was 79.5%. The highest percentages of differences within 10 dB were observed at 500 Hz and 8000 Hz, while the lowest percentage was at 2000 Hz. The distribution of absolute differences within 5 dB, 10 dB, and 15 dB is presented in table 2.

Table 2 Percentage Distribution of Absolute Differences in Hearing Thresholds Between Automated and Manual Audiometry at Each Frequency (forty-eight ears)

Mean absolute differences	Frequency (Hz)							
	500	1000	2000	3000	4000	6000	8000	All
Within±5 dB (%)	54.2	20.8	25.0	50.0	31.3	37.5	75.0	42.0
Within±10 dB (%)	91.7	81.3	66.7	87.5	68.8	68.8	91.7	79.5
Within±15 dB (%)	100	100	100	100	93.8	93.8	95.8	97.6

Correlation analysis between hearing thresholds obtained by automated and manual audiometry at each frequency (500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz) and the average across all frequencies demonstrated a strong positive correlation (Spearman's r_s=0.70, 95% CI [0.62-0.80], p<0.05), as shown in table 3.

Table 3 Spearman's Rank Correlation Coefficients and p-values for Hearing Thresholds Between Automated and Manual Audiometry

Correlation of hearing thresholds	Frequency (Hz)							
	500	**1000**	**2000**	**3000**	**4000**	**6000**	**8000**	**All**
Correlation coefficient	0.62	0.79	0.67	0.80	0.74	0.68	0.68	0.70
p-value	<0.05*	<0.05*	<0.05*	<0.05*	<0.05*	<0.05*	<0.05*	<0.05*
95% CI	0.39-0.77	0.65-0.88	0.47-0.81	0.66-0.88	0.57-0.85	0.48-0.81	0.48-0.81	0.63-0.75
n	48	48	48	48	48	48	48	336

*The significance level is 0.050

Testing Time

The mean time taken to complete automated audiometry was 5.3 minutes (range: 4-7 minutes), while the mean time for manual audiometry was 6.0 minutes (range: 5-9 minutes). This difference in testing time was statistically significant, with automated audiometry being significantly faster than manual audiometry (p=0.038).

3.3 Participant Satisfaction

Using a Likert scale for scoring, where 5 represents the highest level of satisfaction and 1 represents the lowest level of satisfaction. Comparison of satisfaction levels between the two audiometry methods showed a statistically significant difference in how participants felt about the testing time (p=0.039). Interestingly, even though automated audiometry was quicker, participants were more satisfied with the testing time of manual audiometry. No statistically significant differences in satisfaction were observed for other aspects evaluated (table 4).

Table 4 Comparison of Satisfaction Levels Between Automated and Manual Audiometry (n=24)

Satisfaction topic	Automated audiometry		Manual audiometry		*p*-value
	mean	**SD**	**mean**	**SD**	
Ease of Understanding	4.63	0.57	4.67	0.48	0.655
Appropriateness of Testing Time	4.29	0.96	4.71	0.46	0.039*
Overall Satisfaction	4.38	0.65	4.67	0.48	0.052

*The significance level is 0.050

Discussion

Statistically significant differences in hearing thresholds were observed between automated and manual audiometry across all tested frequencies (500-8000 Hz), with p-values<0.05. However, the mean absolute differences at each frequency ranged from 5.4 to 10.0 dB, all within the 10 dB threshold generally considered acceptable for interpersonal variability. The median differences were within this range, suggesting that while the differences were statistically significant, they are unlikely to be clinically meaningful. These findings align with previous studies(10,11, 14,15), which also reported comparable results between the two methods. The mean absolute difference of 8.5 dB in our study is consistent with Yeo Kai Hui, Chua Wei De(10) findings who reported differences ranging from 3.3 to 9.6 dB. However, it was slightly larger than reported in earlier studies (0.0-3.3 dB)(11, 16,17). When comparing each frequency, it was observed that at low-frequency (500 Hz), the mean absolute differences were found to be the lowest, consistent with Eikelboom, Swanepoel (2013) findings(11). This discrepancy might be attributed to the use of non-masking audiometry for screening in our study, unlike the diagnostic masking audiometry potentially employed in the manual testing of previous research. Additionally, our study conducted a single test administration for each method, whereas prior work often used test-retest variability assessment, potentially reducing observed differences.

Despite the variation, the result shows a strong positive correlation (r_s=0.70, p<0.05) between the two methods across all frequencies, consistent with prior studies,(7, 17,18) suggesting that automated audiometry yields results directionally similar to manual audiometry.

Additionally, the study was conducted in a surveillance setting where manual audiometry was performed without masking, as recommended by the British Society of Audiology for such settings(13). In contrast, the automated audiometry system used in this study applies masking by default and cannot disable this setting. This difference in masking protocols may explain the slightly better thresholds observed with the automated method compared to the manual method, which was conducted without masking.

Automated audiometry was significantly faster (mean 5.3 minutes) than manual audiometry (mean 6.0 minutes, p<0.05), consistent with the findings of Harris(19) (mean 3.35 minutes for automated audiometry and 9.25 minutes for manual audiometry). However, our automated testing time was shorter than Margolis, Glasberg (mean 7 minutes) (7), possibly due to variations in test frequencies. Notably, our time comparison excluded instruction and setup time. As the sample group comprises predominantly young individuals, the likelihood of hearing loss is minimal. However, if testing were conducted on a group with hearing impairment, the testing duration would likely increase, as more time would be required to determine the precise Hearing Threshold Level.

While the time reduction per test was modest (approximately 1-2 minutes), the cumulative effect can be substantial in high-volume settings such as occupational health check-ups. For instance, testing 300 individuals could save a total of 5-10 hours. This time efficiency not only reduces the manual workload required of healthcare providers but also allows them to focus on other tasks, as the automated system requires only minimal supervision.

Overall satisfaction with the testing methods did not differ significantly. However, participants surprisingly reported lower satisfaction with the automated test's duration (p=0.039), despite its shorter administration time. This might be due to the 2-minute instructional video for the automated test making it feel longer, or potential confusion with the automated test's two-choice response format compared to the immediate response in manual audiometry.

Conclusion

This study demonstrates that automated audiometry yields hearing threshold results comparable to conventional manual audiometry in a population of Thai workers, with mean differences consistently within the 10 dB range considered acceptable for individual variability. The strong positive correlation observed between the two methods further supports the potential utility of automated audiometry for hearing screening in occupational settings. Furthermore, automated audiometry was found to be significantly faster than manual audiometry. While overall satisfaction with both methods was similar, participants surprisingly reported lower satisfaction with the automated test's duration, potentially due to the initial instructional video or the test's response format. These findings suggest that automated audiometry can serve as an efficient and reliable tool for hearing screening in occupational health programs in Thailand. However, further investigation into user perception and optimization of the automated testing process, particularly regarding instructions and response methods, may be beneficial to enhance user satisfaction.

The research limitations include a potentially small sample size and the absence of Test-retest threshold comparison. Implementing a Test-retest methodology could potentially enhance testing precision, providing clearer insights into the variations of test results within the same population group. This approach would nearly double the time commitment required from participants, thus presenting a significant research limitation.

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