DETECTION OF HIGH-FREQUENCY HEARING LOSS AND SPEECH PERCEPTION IMPAIRMENT IN ONLINE LEARNING DURING THE PANDEMIC - BASED ON AN APPLICATION HEARING SCREENING PROGRAM

Novita KD[1], Barasabha T [1], and Bhawiyuga A[2].
[1]Department of Family Medicine, Medical Faculty of Brawijaya University, Malang, Indonesia.
[2]Department of Information Technology, Information Technology Faculty of Brawijaya University, Malang, Indonesia.

Correspondence:
Khuznita Dasa Novita,
Department of Family Medicine,
Faculty of Medicine,
University of Brawijaya, Malang, Indonesia
Email: khuznita@ub.ac.id

Abstract

The education system has undergone significant changes since the COVID pandemic, and there was a notable increase in Personal Listening Devices (PLDs) usage during online learning, which raises concern about potential hearing and speech perception disorders. This study aimed to identify High-Frequency Hearing Loss (HFHL) and speech perception impairment in medical doctor students engaged in online learning during the pandemic. The examination included the relationship between risk factors, such as gender, family history of hearing loss, ear infection, COVID-19 infection, and behavioral patterns of PLD usage. This quantitative, descriptive-analytic observational research utilized a cross-sectional approach. The respondent were all medical students who underwent the hearing screening program in August 2021, willing to complete questionnaires and conduct self-examinations for hearing screening. The total respondents were 274 students (or 548 ears). Hearing assessment at 2, 4, 6, and 8 kHz was conducted using a hearing app, while speech perception was evaluated with the Digits-in-Noise Test (DIN Test). Data analysis involved Chi-square and Mann-Whitney tests. Suspected HFHL was found in 63 ears (11.5%, 63/548) consisting of 18 male ears (3.3%, 18/548) and 45 female ears (8.2%, 45/548). Speech perception impairment occurred in 125 respondents (45.6%, 125/274). HFHL was significantly correlated with a family history of hearing loss, while speech perception impairment showed a significant correlation with gender, daily duration usage, and type of PLD ($p < 0.05$). Additionally, HFHL was significantly correlated with speech perception ($p < 0.05$). In conclusion, HFHL was suspected in students during online learning in the second year of the pandemic, and the identified risk factors may impact student performance. Confirmatory hearing assessments with an audiometer are recommended to address potential hearing loss.

Keywords: HFHL, Sound Perception, Hearing Screening Application Based

Introduction

Significant transformations in the educational system have occurred since the onset of the COVID-19 pandemic in 2019, impacting not only in Indonesia but also globally. The rapid spread of the virus prompted the implementation of an online education system. As the pandemic has persisted for over two years, the duration of its continuation remains uncertain. The prolonged reliance on online learning has resulted in a sustained surge in the use of audio devices, which, in the long term, poses risks of both temporary and permanent hearing loss.

Before the COVID-19 pandemic, the hearing loss rate in Indonesia was among the highest in Southeast Asia, at 16.8%. Data from the Hearing Health Survey in seven provinces in 1994-1996 revealed that the prevalence of hearing loss and deafness in Indonesia was 16.8% and 0.4%, respectively. A study by the European Union Scientific Committee on Emerging and Identified Health Risks in 2008 indicated that 5 to 10% of earphone users were at risk of permanent hearing loss if exposed to high-volume music for more than one hour daily. Importantly, hearing loss resulting from continuous noise exposure can be easily preventable (1–3).

The current trend among teenagers, who increasingly favor listening to music through earphones connected to music players, has been further intensified by the shift to online learning during the pandemic. This habit significantly heightens the risk of hearing loss. According to the National

Health and Nutrition Examination Survey in the United States in 1988, 15% of adolescents in the United States experienced hearing problems. By the year 2000, this percentage had surged to 19.5%, correlating with the rising number of users of music player media (4).

Excessive use of earphones and prolonged exposure to high-volume noise can result in reduced hearing sensitivity and the onset of tinnitus. Uncorrected hearing loss can lead to decreased quality of life, self-isolation, decreased social activity, and feelings of exclusion, which can increase the prevalence of depressive symptoms and is affected by frequent tinnitus (5). Tinnitus, a symptom that is quite common in family medicine practice (6), refers to the perception of sound within the patient's ear without any external auditory stimulation (7). The adverse effects of tinnitus extend to a decline in quality of life and disruptions in memory and concentration, as it impacts the brain's cognitive performance (8).

Given the outlined associations, this research aimed to characterize the audiogram description of medical students who participated in online learning during the pandemic. In addition, the study sought to explore the correlation between students' listening device usage patterns and the occurrence of high-frequency hearing loss. To conduct audiometric examinations, a web-based application was utilized as an alternative to in-person hospital visits, a practical approach necessitated by the constraints imposed by the pandemic. This web-based application has the potential to advance into a widely adopted hearing screening tool.

Materials and Methods

This research was conducted during the second year of the COVID-19 pandemic, a period of an increase in listening device usage. This quantitative study used a descriptive-analytic observational design with a cross-sectional approach. This study aimed to determine the prevalence of High-Frequency Hearing Loss (HFHL) and speech perception impairment among medical students engaged in online learning during the pandemic. This study also analyzed the correlation between risk factors, such as gender, family history of hearing loss, ear infection, COVID-19 infection, and behavioral patterns of PLD usage.

The behavior pattern of PLD usage was evaluated through a set of 11 questions, each offering answer choices that determine the score (Table 1). Scores ranged from 2 to 29, with a score below 10 indicative of good behavior, while a score exceeding 10 was categorized as poor behavior.

Table 1: Behavior of PLD usage questionnaire

Questions	Point
1. **Respondent's usage of PLD**	
Yes	1
No	0
2. **Duration of PLD usage before pandemic period**	
> 3 years	1
≤ 3 years	0
3. **Daily duration of PLD usage before pandemic period (hours per day)**	
> 8	5
6-8	4
4-6	3
2-4	2
1-2	1
≤ 1	0
4. **Daily duration of PLD usage during pandemic period (hours per day)**	
> 8	5
6-8	4
4-6	3
2-4	2
1-2	1
≤ 1	0
5. **Weekly duration of PLD usage before pandemic period (days per week)**	
everyday	3
5-6	2
3-4	1
1-2	0
6. **Weekly duration of PLD usage during pandemic period**	
everyday	3
5-6	2
3-4	1
1-2	0
7. **PLD Volume (% from maximal volume)**	
> 80	2
60-80	1
< 60	0
8. **The time the respondent used PLD**	
All the time (24 hours per day)	3
During online learning and other activities (>8 and <24 hours per day)	2
Only at online learning (≤ 8 hours per day)	1
9. **An increase in PLD usage before and during the pandemic period**	
Yes	1
No	0
10. **PLD type**	
No PLD	0
Circumaural	1
Supraaural	2
Earbuds or earphone	3
Canalphone	4
11. **PLD has a noise reduction facility**	
No	0
Yes	1

The questionnaire was adapted from Ilma (9) and Alanazi et al (10).

This research was conducted at the Faculty of Medicine, Universitas Brawijaya, in August 2021. The study encompassed all medical students, with the sample comprising those voluntarily completing a questionnaire and engaging in online examinations independently at home. The inclusion criteria necessitated participation in online learning during the pandemic, use of Personal Listening Devices (PLD), having undergone a hearing test at a room noise threshold lower than 40 dB, completion of the questionnaire, no history of exposure to loud noises (such as an explosion) within the last 24 or 48 hours before the hearing test, no history of ear or respiratory infections within the last 24 or 48 hours before the hearing test, and no history of long-term ototoxic drug treatment.

The dependent variables studied were the presence of High-Frequency Hearing Loss (HFHL) and speech perception impairment. The independent variables were gender, age, risk factors (such as family history of hearing loss since childhood, ear infections, prolonged use of ototoxic drugs, history of COVID-19 infection), the patterns of PLD usage (duration, volume, type of PLD, presence of noise reduction facilities).

Due to limited mobility during the COVID-19 pandemic, all respondents completed the questionnaire online, covering aspects such as gender, age, risk factors, and behavior in PLD usage in the context of online learning during the pandemic. The hearing assessment was conducted using smartphone-based applications, specifically the Hearing Tests and Digits-in-Noise Test, both available for download from the App Store.

The Hearing Test application served as a hearing screening tool, and its diagnostic efficacy was compared to pure tone audiometry, considered the standard gold examination, with a sensitivity level of 98% and a specificity of 79% (11). The average air conduction hearing threshold at 2 kHz, 4 kHz, 6 kHz, and 8 kHz was measured. Suspected HFHL was determined by an increase in hearing threshold above 20 dB. Subsequently, the average was categorized based on the severity of hearing loss as follows: normal hearing (-10-19.9 dB), mild hearing loss (20-34.9 dB), moderate hearing loss (35-49.9 dB), moderate-severe hearing loss (50-64.9 dB), severe hearing loss (65-79.9 dB), very severe hearing loss (80-94.9 dB), and total hearing loss (> 95 dB). For speech perception assessment, the Digits-in-Noise Test (DIN) from HearWHO was employed, with a score falling below 75 indicating speech perception impairment. Approval for this research was obtained from the Research Ethics Committee of the Faculty of Medicine, Universitas Brawijaya, under the Ethical Approval Letter No. 210/EC/KEPK/07/2021.

Data analysis

The collected data underwent descriptive and analytical analyses. Descriptively, the distribution of HFHL and speech perception impairment is presented based on gender. Analytically, the relationship between risk factors, PLD usage behavior, and the occurrence of HFHL and speech perception is presented using Chi-Square and Mann-Whitney analysis with a statistical significance at $p < 0.05$. Data analysis was performed using the SPSS application, version 25.00.

Results

Demographic characteristics of respondents

From 952 student respondents, 452 completed the questionnaires, 105 iPhone Operating System (IOS) users, 26 individuals were exposed to loud noises within 24 and 48 hours, and six individuals had a history of prolonged ototoxic drug use, so a total of 274 respondents were included in this study. According to Tables 2 and 3, the average age of the respondents was 19.66 ± 3.37 years. The gender distribution revealed that there were more female participants, accounting for 175 students (63.87%; 175/274), compared to male participants, which were 99 students (36.13%; 99/274).

Table 2: Clinical characteristic of respondents

Variables	Mean (SD)	Min-Max	p-value*
Age (years)			
Men	19.75 (3.03)	17 - 23	0.000
Women	19.61 (3.54)	17 - 24	
Total	19.66 (3.37)	17 - 24	
Behavior of PLD Usage			
Good	7.43 (1.69)	3 -10	0.000
Poor	17.08 (3.93)	11 - 27	
Total	14.86 (5.39)	3 - 27	
Hearing Threshold (dB)			
Normal	7.01 (7.99)	-18.75 - 38.75	0.000
HFHL	28.03 (7.39)	21.25 - 50	
Total	9.43 (10.38)	-18.75 - 50	
Speech Perception			
Normal	82.84 (5.53)	72 -100	0.000
Impaired	61.03 (10.86)	19 - 75	
Total	72.89 (13.73)	19 - 100	

*Test of normality: Kolmogorov-Smirnov
SD: Standard Deviation
Min-Max: Minimal and Maximal
dB: decibel

The average score for the behavior of PLD usage was 14.86 ± 5.39. The behavior of PLD usage was categorized into two levels: poor and good. According to Table 2, a higher percentage of respondents exhibited poor PLD usage behavior, totaling 211 individuals (77%; 211/274), compared to those with good behavior, comprising 63 respondents (23%; 63/274). The average hearing threshold

was 9.43 ± 10.38, and it was categorized into two levels: normal and High-Frequency Hearing Loss (HFHL). Based on Table 3, a larger proportion of respondents demonstrated normal hearing, with 469 individuals (77%; 469/548), compared to those with HFHL, at 63 respondents (23%; 63/274). The average speech perception score was 72.89 ± 13.73. The speech perception was divided into two levels: normal and impaired. According to Table 3, a greater number of respondents exhibited normal speech perception, totaling 149 individuals (54.4%; 149/274), compared to those with impaired speech perception, which accounted for 125 respondents (45.6%; 125/274). Age, PLD usage behavior, hearing threshold, and speech perception scores were not normally distributed; thus, non-parametric analysis was used.

Table 3: Clinical characteristic of respondents

Variables	N	%
Gender		
Male	99	36.13
Female	175	63.87
Total	274	100
Risk Factors		
History of Family Hearing Loss		
Yes	50	18.2
No	224	81.8
Total	274	100
History of Ear Infection in the past three month		
Yes	3	0.9
No	271	99.1
Total	274	100
History of COVID-19 Infection		
Yes	23	8.4
No	251	91.6
Total	274	100
Behavior of PLD Usage		
Good	63	23
Poor	211	77
Total	274	100
HFHL ear		
Normal	469	85.6
Mild	66	12
Moderate	12	2.2
Moderate-severe	1	0.2
Severe	0	0
Very severe	0	0
Total	548	100
Speech Perception		
Normal	149	54.4
Impaired	125	45.6
Total	274	100

Correlation between gender, risk factors, and behavior of respondent's PLD usage with hearing threshold

Table 4 shows the correlation between gender, risk factors, and behavior of PLD usage with the hearing threshold, analyzed using Chi-Square analysis. HFHL occured in 63 ears (11.5%; 63/548), with a higher prevalence in women (8.2%; 45/548) than in men (3.3%; 18/548). The evaluated risk factors in this study included a family history of congenital deafness, ear infections three months before the examination, and COVID infection. Among ears with HFHL (63), 21 ears had a family history of congenital deafness (3.8%; 21/548), 2 ears had a history of ear infection three months before the examination (0.4%; 2/548), and 3 ears had a history of COVID infection (0.5%; 3/548). In contrast, 53 ears with HFHL exhibited poor PLD usage behavior (9.7%; 53/548), while only 10 ears had good behavior (1.8%; 10/548). Only a family history of congenital deafness was found to be significantly associated with the hearing threshold ($p = 0.001$), while other variables showed no significant correlations (Table 3). In conclusion, there was no significant correlation between gender, a history of ear and COVID infection, and behavior of PLD usage with the incidence of HFHL. However, there was a correlation between a family history of congenital deafness with HFHL ($p = 0.001$).

Despite no correlation between the degree of behavior of PLD usage and the hearing threshold, associations in each behavior variable were explored. Table 5 illustrates 11 behavioral variables contained in the questionnaire. The Mann-Whitney test results for all the behavior variables indicated a p-value > 0.05. This outcome supports that there is no correlation between the behavior of PLD usage variables and the hearing threshold.

Correlation between gender, risk factors, and behavior of respondent's PLD usage with speech perception

Table 6 shows the relationship between gender, risk factors, and behavior of PLD usage with speech perception using Chi-Square analysis. Speech perception impairment was observed in 145 respondents (45.6%; 145/274), with a higher prevalence in women (32.1%; 88/274) than in men (13.6%; 37/274). Among 145 respondents with speech perception impairment, 24 respondents had a family history of congenital deafness (8.8%; 24/274), 2 respondents had a history of ear infection three months before the examination (0.7%; 2/274), and 12 respondents had a history of COVID-19 infection (4.4%; 12/274). In contrast, 97 respondents with speech perception impairment exhibited poor PLD usage behavior (35.4%; 97/274), while only 28 respondents had good behavior (10.2%; 28/274). Gender was found to be significantly related to speech perception ($p = 0.004$), while other variables showed no significant correlations (Table 4). Thus, there was no relationship between the history of ear and COVID-19 infection and behavior of PLD usage with the

Table 4: Distribution of gender, risk factors, behavior of respondent's PLD usage with high frequency hearing threshold

Variables	Hearing Threshold		Total	OR	p-value
	Normal	HFHL		95% CI (Lower-Upper)	
Gender					
Male	180 (32.8%)	18 (3.3%)	198 (36.1%)	0.678 (0.381-1.207)	0.184
Female	305 (55.7%)	45 (8.2%)	350 (63.9%)		
Total	485 (88.5%)	63 (11.5%)	548 (100%)		
Risk Factors					
History of Family Hearing Loss					
Yes	79 (14.4%)	21 (3.8%)	100 (18.2%)	0.389 (0.219-0.693)	0.001*
No	406 (74.1%)	42 (7.7%)	448 (81.8%)		
Total	485 (88.5%)	63 (11.5%)	548 (100%)		
History of Ear Infection in the past three months					
Yes	8 (1.5%)	2 (0.4%)	10 (1.8%)	0.512 (0.106-2.464)	0.395
No	477 (87%)	61 (11.1%)	538 (98.2%)		
Total	485 (88.5%)	63 (11.5%)	548 (100%)		
History of COVID-19 Infection					
Yes	43 (7.8%)	3 (0.5%)	46 (8.4%)	1.946 (0.585-6.467)	0.269
No	442 (80.7%)	60 (11%)	502 (92.6%)		
Total	485 (88.5%)	63 (11.5%)	548 (100%)		
Behavior of PLD Usage					
Good	116 (21.2%)	10 (1.8%)	126 (23%)	0.600 (0.296-1.217)	0.153
Poor	369 (67.3%)	53 (9.7%)	422 (77%)		
Total	485 (88.5%)	63 (11.5%)	548 (100%)		
Speech Perception					
Normal	278 (50.7%)	20 (3.6%)	298 (54.4%)	2.887 (1.649-5.056)	0.000*
Impaired	207 (37.8%)	43 (7.8%)	250 (45.6%)		
Total	485 (88.5%)	63 (11.5%)	548 (100%)		

* Significant level for Chi-Square test ($p < 0.05$)

Table 5: Distribution of behavior of respondent's PLD usage with hearing threshold

Variables	Hearing Threshold		Total	p-value
	Normal	HFHL		
1. Respondent's usage of PLD				
Yes	388 (70.8%)	48 (8.8%)	436 (79.6%)	0.481
No	97 (17.7%)	15 (2.7%)	112 (20.4%)	
Total	485 (88.5%)	63 (11.5%)	548 (100%)	
2. Duration of PLD usage before pandemic periode				
> 3 years	190 (34.7%)	26 (4.7%)	216 (39.4%)	0.749
≤ 3 years	295 (53.8%)	37 (6.8%)	332 (60.6%)	
Total	485 (88.5%)	63 (11.5%)	548 (100%)	
3. Daily duration of PLD usage before pandemic periode (hours per day)				
> 8	10 (1.8%)	0 (0%)	10 (1.8%)	0.053
6-8	12 (2.2%)	2 (0.4%)	14 (2.6%)	
4-6	41 (7.5%)	7 (1.3%)	48 (8.8%)	
2-4	109 (19.9%)	23 (4.2%)	132 (24.1%)	
1-2	163 (29.7%)	17 (3.1%)	180 (32.8%)	
≤ 1	150 (27.4%)	14 (2.6%)	164 (29.9%)	
Total	485 (88.5%)	63 (11.5%)	548 (100%)	

Table 5: Distribution of behavior of respondent's PLD usage with hearing threshold (continued)

Variables	Hearing Threshold		Total	p-value
	Normal	HFHL		
4. Daily duration of PLD usage during pandemic period (hours per day)				
> 8	9 (1.6%)	47 (8.6%)	56 (10.2%)	0.090
6-8	9 (1.6%)	65 (11.9%)	74 (13.5%)	
4-6	14 (2.6%)	102 (18.6%)	116 (21.2%)	
2-4	19 (3.5%)	101 (18.4%)	120 (21.9%)	
1-2	2 (0.4%)	74 (13.5%)	76 (13.9%)	
≤ 1	10 (1.8%)	96 (17.5%)	106 (19.3%)	
Total	485 (88.5%)	63 (11.5%)	548 (100%)	
5. Weekly duration of PLD usage before pandemic period (days per week)				
everyday	72 (13.1%)	10 (1.8%)	82 (15%)	0.504
5-6	69 (12.6%)	7 (1.3%)	76 (13.9%)	
3-4	152 (27.7%)	26 (4.7%)	178 (32.5%)	
1-2	192 (35%)	20 (3.6%)	212 (38.7%)	
Total	485 (88.5%)	63 (11.5%)	548 (100%)	
6. Weekly duration of PLD usage during pandemic period (days per week)				
everyday	146 (26.6%)	24 (4.4%)	170 (31%)	0.110
5-6	133 (24.3%)	19 (3.5%)	152 (27.7%)	
3-4	95 (17.3%)	9 (1.6%)	104 (19%)	
1-2	111 (20.3%)	11 (2%)	122 (22.3%)	
Total	485 (88.5%)	63 (11.5%)	548 (100%)	
7. PLD Volume (% from maximal volume)				
> 80	25 (4.6%)	3 (0.5%)	28 (5.1%)	0.417
60-80	140 (25.5%)	22 (4%)	162 (29.6%)	
< 60	320 (58.4%)	38 (6.9%)	358 (65.3%)	
Total	485 (88.5%)	63 (11.5%)	548 (100%)	
8. The time the respondent used PLD				
All the time (24 hour perday)	102 (18.6%)	18 (3.3%)	102 (18.6%)	0.213
During online learning and other activities (>8 and <24 hour perday)	64 (11.7%)	8 (1.5%)	72 (13.1%)	
Only at online learning (≤ 8 hour perday)	319 (58.2%)	37 (6.8%)	356 (65%)	
Total	485 (88.5%)	63 (11.5%)	548 (100%)	
9. An increase in PLD usage before and during the pandemic periode				
Yes	325 (59.3%)	45 (8.2%)	370 (67.5%)	0.482
No	160 (29.2%)	18 (3.3%)	178 (32.5%)	
Total	485 (88.5%)	63 (11.5%)	548 (100%)	
10. PLD type				
Circumaural	34 (6.2%)	4 (0.7%)	38 (6.9%)	0.498
Supraaural	15 (2.7%)	3 (0.5%)	18 (3.3%)	
Earbuds or earphone	317 (57.8%)	37 (6.8%)	354 (64.6%)	
Canalphone	119 (21.7%)	19 (3.5%)	138 (25.2%)	
Total	485 (88.5%)	63 (11.5%)	548 (100%)	
11. PLD has a noise reduction facility				
Yes	252 (46%)	34 (6.2%)	286 (52.2%)	0.764
No	233 (42.5%)	29 (5.3%)	262 (47.8%)	
Total	485 (88.5%)	63 (11.5%)	548 (100%)	

*Significant level for Mann-Whitney test ($p < 0.05$)

incidence of speech perception impairment. However, a correlation was observed between gender and speech perception impairment (p = 0,004).

Although no correlation was found between the degree of behavior of PLD usage and speech perception (Table 6), associations within each behavior variable were explored

Table 6: Distribution of gender, risk factors, behavior of respondent's PLD usage with speech perception impairment

Variables	Speech Perception		Total	OR	p-value
	Normal	Impaired		95% CI (Lower-Upper)	
Gender					
Male	62 (22.6%)	37 (13.6%)	99 (36.1%)	0.590 (0.413-0.842)	0.004*
Female	87 (31.8%)	88 (32.1%)	175 (63.9%)		
Total	149 (54.4%)	125 (45.6%)	274 (100%)		
Risk Factors **History of Family Hearing Loss**					
Yes	26 (9.5%)	24 (8.8%)	25 (18.2%)	0.890 (0.579-1.373)	0.597
No	123 (44.9%)	101 (36.9%)	224 (81.8%)		
Total	149 (54.5%)	125 (45.6%)	274 (100%)		
History of Ear Infection in the past three months					
Yes	3 (1.1%)	2 (0.7%)	5 (1.8%)	1.264 (0.353-4.529)	0.719
No	146 (53.3%)	123 (44.9%)	268 (98.2%)		
Total	149 (54.4%)	125 (45.6%)	274 (100%)		
History of COVID-19 Infection					
Yes	11 (4%)	12 (4.4%)	23 (8.4%)	0.751 (0.410-1.374)	0.349
No	138 (50.4%)	113 (41.2%)	251 (91.6%)		
Total	149 (54.4%)	125 (45.6%)	274 (100%)		
Behavior of PLD Usage					
Good	35 (12.8%)	28 (10.2%)	63 (23%)	0.940 (0.630-1.403)	0.763
Poor	114 (41.6%)	97 (35.4%)	211 (77%)		
Total	149 (54.4%)	125 (45.6%)	274 (100)		
Hearing Threshold					
Normal	279 (50.7%)	207 (37.8%)	485 (88.5%)	2.887 (1.649-5.056)	0.000*
HFHL	20 (3.6%)	43 (7.8%)	63 (11.5%)		
Total	298 (54.5%)	250 (45.6%)	548 (100%)		

* Significant level for Chi-Square test (p < 0.05)

(Table 7). Based on the Mann-Whitney test, variables such as the daily duration of PLD usage during the pandemic period and PLD type were found to be associated with speech perception (p-value < 0.05). Conversely, other variables did not show significant relationships (p-value > 0.05). This further emphasizes the absence of correlation between all the behavior of PLD usage variables and the hearing threshold. Those who used PLD for more than 6 hours per day were 35 respondents (16 + 19 respondents), approximately 12.7% (5.8% + 6.9%). PLD type resulted in a p-value of 0.000, indicating its correlation with speech perception. Among the respondents, canal phones were associated with the highest incidence of speech perception impairment, totaling 39 individuals (14.2%; 39/274).

Correlation between hearing threshold and speech perception

Tables 4 and 5 show the relationship between hearing threshold and speech perception using Chi-Square analysis. From 63 HFHL ears, impaired speech perception was observed in 43 ears (7.8%; 43/548), while 20 ears exhibited normal speech perception (3.6%; 20/548). Among the 250 ears with impaired speech perception, 43 ears had HFHL (7.8%; 43/548), and 207 ears had normal hearing (37.8%; 207/548). A significant correlation between hearing threshold and speech perception was identified with a p-value of 0.000.

Table 7: Distribution of behavior of respondent's PLD usage with speech perception impairment

Variables	Speech Perception		Total	p-value
	Normal	Impaired		
1. Respondent usage of PLD				
Yes	122 (44.5%)	96 (35%)	218 (76.6%)	0.142
No	27 (9.9%)	29 (10.6%)	56 (20.4%)	
Total	149 (54.4%)	125 (45.6%)	274 (100%)	
2. Duration of PLD usage before pandemic periode				
> 3 years	56 (20.4%)	27 (19%)	108 (39.4%)	0.338
≤ 3 years	93 (33.9%)	73 (26.5%)	166 (60.6%)	
Total	149 (54.4%)	125 (45.6%)	274 (100%)	
3. Daily duration of PLD usage before pandemic periode (hours per day)				
> 8	3 (1.1%)	2 (0.7%)	5 (1.8%)	0.998
6-8	3 (1.1%)	4 (1.5%)	7 (2.6%)	
4-6	12 (4.4%)	12 (4.4%)	24 (8.8%)	
2-4	40 (14.6%)	26 (9.5%)	151 (24.1%)	
1-2	45 (16.4%)	45 (16.4%)	90 (32.8%)	
≤ 1	46 (16.8%)	36 (13.1%)	82 (29.9%)	
Total	149 (54.4%)	125 (45.6%)	274 (100%)	
4. Daily duration of PLD usage during pandemic periode (hours per day)				
> 8	12 (4.4%)	16 (5.8%)	28 (10.2%)	0.038*
6-8	18 (6.6%)	19 (6.9%)	37 (13.5%)	
4-6	30 (10.9%)	28 (10.2%)	58 (21.2%)	
2-4	37 (13.5%)	23 (8.4%)	60 (21.9%)	
1-2	22 (8%)	16 (5.8%)	38 (13.9%)	
≤ 1	30 (10.9%)	23 (8.4%)	53 (19.3%)	
Total	149 (54.4%)	125 (45.6%)	274 (100%)	
5. Weekly duration of PLD usage before pandemic periode (days per week)				
Everyday	20 (7.3%)	21 (7.7%)	41 (15%)	0.878
5-6	26 (9.5%)	12 (4.4%)	38 (13.9%)	
3-4	45 (16.4%)	44 (16.1%)	89 (32.5%)	
1-2	58 (21.2%)	48 (17.5%)	106 (38.7%)	
Total	149 (54.4%)	125 (45.6%)	274 (100%)	
6. Weekly duration of PLD usage during pandemic periode(days per week)				
Everyday	39 (14.2%)	46 (16.8%)	85 (31%)	0.168
5-6	47 (17.2%)	29 (10.6%)	76 (27.7%)	
3-4	31 (11.3%)	21 (7.7%)	52 (19%)	
1-2	32 (11.7%)	29 (10.6%)	61 (22.3%)	
Total	149 (54.4%)	125 (45.6%)	274 (100%)	
7. PLD Volume (% from maximal volume)				
> 80	7 (2.6%)	7 (2.6%)	14 (5.1%)	0.099
60-80	40 (14.6%)	41 (15%)	81 (29.6%)	
< 60	102 (37.2%)	77 (28.1%)	179 (65.3%)	
Total	149 (54.4%)	125 (45.6%)	274 (100%)	

Table 7: Distribution of behavior of respondent's PLD usage with speech perception impairment (continued)

Variables	Speech Perception		Total	p-value
	Normal	Impaired		
8. The time the respondent used PLD				
All the time (24 hour perday)	33 (12%)	27 (9.9%)	60 (21.9%)	0.404
During online learning and other activities (>8 and <24 hour perday)	16 (5.8%)	20 (7.3%)	36 (13.1%)	
Only at online learning (≤ 8 hour perday)	100 (36.5%)	78 (28.5%)	178 (65%)	
Total	149 (54.4%)	125 (45.6%)	274 (100%)	
9. An increase in PLD usage before and during the pandemic period				
Yes	99 (36.1%)	86 (31.4%)	185 (67.5%)	0.558
No	50 (18.2%)	39 (14.2%)	89 (32.5%)	
Total	149 (54.4%)	125 (45.6%)	274 (100%)	
10. PLD type				
Circumaural	16 (5.8%)	3 (1.1%)	19 (6.9%)	0.000*
Supraaural	6 (2.2%)	6 (1.1%)	12 (3.3%)	
Earbuds or earphone	97 (35.4%)	80 (29.2%)	177 (64.6%)	
Canalphone	30 (10.9%)	39 (14.2%)	69 (25.2%)	
Total	149 (54.4%)	125 (45.6%)	274 (100%)	
11. PLD has a noise reduction facility				
Yes	79 (28.8%)	64 (23.4%)	143 (52.2%)	0.671
No	70 (25.5%)	61 (22.3%)	131 (47.8%)	
Total	149 (54.4%)	125 (45.6%)	274 (100%)	

* Significant level for Mann-Whitney test ($p < 0.05$)

Discussion

Clinical characteristic

This research was conducted to assess the presence of high-frequency hearing loss and speech perception among undergraduate medical students engaged in online learning during their second year of the pandemic. A total of 274 students participated as respondents, with an average age of 19.66 ± 3.37 years. Among them, 63 students (11.5%) experienced an elevation in their hearing threshold by more than 20 dB. This prevalence contrasts significantly with a cohort study in France within a similar age range (18-25 years), where the reported rate was 3.4% (12). These differences in hearing loss prevalence could arise from methodological variations, such as different study durations (seven years in the cohort study), distinct criteria for defining hearing loss (threshold exceeding 25 dB in the cohort study), and the use of an audiometer examination as the gold standard. The present study used a criterion of hearing threshold exceeding 20 dB and employed a hearing test application known for its diagnostic efficacy, with a sensitivity of 98% and specificity of 79%, serving as a screening tool for hearing assessment (11). It is essential to note that this study requires further validation through audiometer examinations to establish a definitive diagnosis of hearing loss.

Among the 274 students, 125 individuals (45.6%) experienced speech perception impairment, indicated by a score below 75. This figure aligns closely with a study conducted by the World Health Organization (WHO) in a comparable age group (18-30 years), reporting a prevalence of approximately 40-45% (13). Speech perception involves a complex interplay of peripheral auditory functions, central auditory functions, and general cognitive abilities (14). The instrument used to measure speech recognition in these two studies was the HearWHO application's Digits-in-Noise Test (DIN). DIN measures a person's ability to understand speech in noise by presenting triads of spoken digits in the presence of adaptive background masking noise. This test determines the Speech Recognition Threshold (SRT), the level at which 50% of triplets can be recognized. Antiphasic SRT demonstrates high sensitivity and specificity of over 80%, detecting various types of hearing loss and strongly correlating with clinical pure-tone audiometry conducted in an acoustically controlled environment (13). In this study, 43 ears (7.8%; 43/548) were identified with both high-frequency hearing loss and speech perception impairment.

In this study, women exhibited a higher prevalence of High-Frequency Hearing Loss (HFHL) and speech perception disorders, with 45 ears (8.2%, 45/548) and 88 individuals (32.1%; 88/274), respectively. This observation may

be attributed to the higher representation of female respondents in the study. Villavisanis et al. (15) and Corazzi et al. (16) suggested that structural differences in women's inner ears may make them more susceptible to hearing loss compared to men. Conversely, research by Wang in 2021 posits that more men than women experience noise-induced hearing loss, attributed to the presence of higher levels of the estrogen hormone in women (17).

Correlation between risk factors and the high frequency hearing loss and speech perception impairment

Following the identification of High-Frequency Hearing Loss (HFHL) and speech perception impairment incidence, an examination of associated risk factors was conducted. These factors included a family history of hearing loss, ear infections, COVID-19 infection, and behavior of PLD usage. The risk factor significantly correlated with HFHL was a family history of deafness from birth. Meanwhile, there was no significant correlation between the behavior pattern of using PLD and the incidence of HFHL. Regarding speech perception disorders, significant correlations were found with gender, daily duration of PLD use during the pandemic (hours per day), and type of PLD. Notably, the canal phone type of PLD was most strongly associated with speech perception disorders, indicating students' poor behavior in using PLD during the pandemic.

The results of this study indicate that young people who listen to loud music with headphones in an already noisy environment or who use headphones for an average of more than 60 minutes a day in a noisy environment have a much higher risk of hearing loss. Similar to our findings, a study in Korean students found that wearing headphones for an average of more than 60 minutes per day is associated with hearing loss (18). In addition, Kim (19) evaluated the relationship between headphones and hearing loss among high school students using survey data and found that 52% of high school students who used headphones for more than 1 hour per day subjectively reported hearing loss, with 84.5% experiencing pain or tinnitus.

Exposure to loud sounds or noise can result in transient threshold shifts (TTS) or permanent threshold shifts (PTS). PTS is a permanent change in both hair cells and nerves. The main causes of Noise-Induced Hearing Loss (NIHL) are damage to the hair cells in the inner ear and synaptopathy. The TTS effect signifies reversible damage to stereocilia or inner hair cell (IHC) synapses. In PTS, there has been permanent damage or loss of IHC and synapses. IHC damage can trigger the accumulation of reactive oxygen species and active stimulation of intracellular stress pathways, leading to programmed and necrotic cell death (20).

Correlation between high frequency hearing loss and speech perception impairment

This student hearing screening program evaluates speech and high-frequency hearing. While the examination results for speech frequency have been reported separately, this research specifically explores high-frequency hearing. This study reveals the incidence of High-Frequency Hearing Loss (HFHL). Based on research conducted by Hoffman et al. (21), the proportion of HFHL is higher than speech frequency hearing loss. In individuals aged 20-29 years, HFHL and speech frequency hearing loss were 7% and 2.2%, respectively. Conversely, in individuals aged 60-69 years, HFHL and speech frequency hearing loss were 68% and 39.3%, respectively. This suggests that HFHL tends to precede hearing loss at speech frequencies.

HFHL often goes unnoticed as it is asymptomatic but causes gradual damage. Based on research conducted by Prendergast et al. (22), HFHL is a marker for cochlear synaptopathy or hidden hearing loss in individuals with normal audiograms. Cochlear synaptopathy, first described by Kujawa and Liberman (23, 24), involves damage to the synapse between the inner hair cell (IHC) and the auditory nerve, reaching up to 50% in rats exposed to high-frequency sounds (8-16 kHz) at 100 dB SPL. This synapse damage can be permanent, as evidenced by a decrease in the amplitude of wave I in the auditory brainstem response (ABR) examination, but not visible on the audiogram examination. In cases of noise-induced hearing loss due to chronic noise exposure, HFHL serves as a prominent marker for both reversible and irreversible inner ear structural damage (25), motivating our evaluation of hearing at high frequencies.

Hearing at high frequencies plays crucial roles, particularly in sound localization (determining the direction of sound) and speech perception, essential components for effective communication. According to Monson et al. (26), losing the ability to hear at high frequencies will affect speech perception, especially speech perception in noise. Speech perception is the ability to process sounds that are heard, interpreted, and understood, engaging various aspects of the brain. Furthermore, HFHL is closely linked to the incidence of dementia in the elderly. A hypothesis suggests that the neural basis of human intelligence originates from the activity of the frontoparietal functional network. According to the study results, this process may be impaired when auditory function is impaired (27). The existence of HFHL and speech perception impairment can reduce the quality of life, impacting student performance academically and non-academically.

Conclusion

Based on the conducted research, incidences of High-Frequency Hearing Loss (HFHL) and speech perception impairment have been identified among college students

in the second year of the pandemic, attributed to various factors, including the use of Personal Listening Devices (PLD). While government and school guidelines aim to ensure the safe use of PLD, ongoing monitoring and evaluation are crucial to proactively prevent further cases of HFHL. Subsequent assessments, such as with an Audiometer, are essential for definitively establishing HFHL. Additionally, the hearing screening program should persist for early detection of potential hearing loss.

Acknowledgement

Gratitude is extended to all the contributors of this article. This article was presented orally at the 6th Global Public Health Conference (Globeheal) 2023 held in India on the 23rd-24th of February 2023.

Competing interests

The authors declare that they have no competing interests.

Ethical Clearance

We obtained approval from the Research Ethics Committee of the Faculty of Medicine, University of Brawijaya Malang, registered under Ethical Approval Letter No. 210/EC/KEPK/07/2021.

Financial support

This study is a component of Dr. Khuznita's research titled "Audiogram Overview of Medical Doctor Study Program Students in the Online Learning Period". This work received a grant from the Faculty of Medicine, University of Brawijaya, through the Dean's decree number 234. This research was carried out together with Rafidah (28) and Evita (29).

References

1. Brookhouser PE. Prevention of noise-induced hearing loss. Prev Med (Baltim). 1994 Sep; 23(5):665–9.
2. Frederiksen TW, Ramlau-Hansen CH, Stokholm ZA, et al. Noise-Induced Hearing Loss - A Preventable Disease? Results of a 10-Year Longitudinal Study of Workers Exposed to Occupational Noise. Noise Health. 2017; 19(87):103-111.
3. Alnuman N, Ghnimat T. Awareness of Noise-Induced Hearing Loss and Use of Hearing Protection among Young Adults in Jordan. Int J Environ Res Public Health. 2019; 16(16):2961.
4. Engdahl B, Aarhus L. Personal Music Players and Hearing Loss: The HUNT Cohort Study. Trends Hear. 2021; 25:23312165211015881.
5. Arlinger S. Negative consequences of uncorrected hearing loss--a review. Int J Audiol. 2003; 42 Suppl 2:2S17-2S20.
6. Yew KS. Diagnostic approach to patients with tinnitus. Am Fam Physician. 2014; 89(2):106-113.
7. Mazurek B, Olze H, Haupt H, Szczepek AJ. The more the worse: the grade of noise-induced hearing loss associates with the severity of tinnitus. Int J Environ Res Public Health. 2010; 7(8):3071-3079.
8. Tegg-Quinn S, Bennett RJ, Eikelboom RH, Baguley DM. The impact of tinnitus upon cognition in adults: A systematic review [published correction appears in Int J Audiol. 2016 Nov;55(11):706]. Int J Audiol. 2016; 55(10):533-540.
9. Ilma ZD. Pengaruh Pengetahuan Dan Sikap Siswa SMA Terhadap Perilaku Penggunaan Peranti Dengar Di SMAN X Tangerang Selatan Tahun 2016. Skripsi. Indonesia: https://repository.uinjkt.ac.id/dspace/handle/123456789/34320. 2016. Accessed 5 February 2023.
10. Alanazi, H., Almuqbel, A., Alhothail, H., Almreef, A., Almesned, R., & Alhumaidan A. Knowledge, attitude, and practice toward the use of personal audio devices among high school students in Buraydah, Al-Qassim. International Journal of Medicine in Developing Countries. 2021; 5(1):318–323.
11. Masalski M, Grysiński T, Kręcicki T. Hearing Tests Based on Biologically Calibrated Mobile Devices: Comparison With Pure-Tone Audiometry. JMIR Mhealth Uhealth. 2018; 6(1):e10.
12. Lisan Q, Goldberg M, Lahlou G, et al. Prevalence of Hearing Loss and Hearing Aid Use Among Adults in France in the CONSTANCES Study. JAMA Netw Open. 2022 Jun; 5(6): e2217633.
13. De Sousa KC, Smits C, Moore DR, Chada S, Myburgh H, Swanepoel W. Global use and outcomes of the hearWHO mHealth hearing test. Digit Health. 2022; 8:20552076221113204.
14. Haro S, Smalt CJ, Ciccarelli GA, Quatieri TF. Deep Neural Network Model of Hearing-Impaired Speech-in-Noise Perception. Front Neurosci. 2020; 14:588448.
15. Villavisanis DF, Berson ER, Lauer AM, Cosetti MK, Schrode KM. Sex-based Differences in Hearing Loss: Perspectives from Non-clinical Research to Clinical Outcomess. Otol Neurotol. 2020; 41(3):290-298.
16. Corazzi V, Ciorba A, Skarżyński PH, et al. Gender differences in audio-vestibular disorders. Int J Immunopathol Pharmacol. 2020; 34:20587 38420929174.
17. Wang Q, Wang X, Yang L, Han K, Huang Z, Wu H. Sex differences in noise-induced hearing loss: a cross-sectional study in China. Biol Sex Differ. 2021; 12(1):24.
18. Byeon H. Associations between adolescents' earphone usage in noisy environments, hearing loss, and self-reported hearing problems in a nationally representative sample of South Korean middle and high school students. Medicine (Baltimore). 2021; 100(3):e24056.
19. Kim EJ. Problems of Usage of Earphones, PCPs on Hearing in Adolescents -Journal of the Korean Society of School Health. 2023. Available at: https://koreascience.kr/article/JAKO200910103424417.page. Accessed 5 February 2023.
20. Kurabi A, Keithley EM, Housley GD, Ryan AF, Wong AC. Cellular mechanisms of noise-induced hearing loss. Hear Res. 2017; 349:129-137.

21. Hoffman HJ, Dobie RA, Losonczy KG, Themann CL, Flamme GA. Declining Prevalence of Hearing Loss in US Adults Aged 20 to 69 Years. JAMA Otolaryngol Head Neck Surg. 2017; 143(3):274-285.
22. Prendergast G, Couth S, Millman RE, et al. Effects of Age and Noise Exposure on Proxy Measures of Cochlear Synaptopathy. Trends Hear. 2019; 23:1-16.
23. Kujawa SG, Liberman MC. Adding insult to injury: cochlear nerve degeneration after "temporary" noise-induced hearing loss. J Neurosci. 2009; 29(45):14077-14085.
24. Liberman MC, Kujawa SG. Cochlear synaptopathy in acquired sensorineural hearing loss: Manifestations and mechanisms. Hear Res. 2017; 349:138-147.
25. Chang TY, Liu CS, Huang KH, Chen RY, Lai JS, Bao BY. High-frequency hearing loss, occupational noise exposure and hypertension: a cross-sectional study in male workers. Environ Health. 2011; 10:35.
26. Monson BB, Rock J, Schulz A, Hoffman E, Buss E. Ecological cocktail party listening reveals the utility of extended high-frequency hearing. Hear Res. 2019; 381:1-17.
27. Apostolova LG, Lu PH, Rogers S, et al. 3D mapping of mini-mental state examination performance in clinical and preclinical Alzheimer disease. Alzheimer Dis Assoc Disord. 2006; 20(4):224-231.
28. Rafidah R, Novita KD & Barasabha T. The Influence of Knowledge and Behavior of Student's Personal Listening Devices Usage On The Speech Frequency Hearing Threshold In Online Learning During The Pandemic Period. J Ilmu Kedokteran Keluarga. 2022; 1(2):65-74.
29. Evita D, Novita KD, & Barasabha T. The Effect of Medical Student Behavior in Personal Listening Devices Usage on The Average of High-Frequency Threshold in Online Learning During Pandemic. J Ilmu Kedokteran Keluarga. 2023; 2(1):75-85.