Exploring the Impact of Auditory Processing, Assistive Technology, and Socio-economic Factors on Academic Engagement and Self-preparation among Secondary Students Using Hearing Aids

Mohammad Ahmad Abdelaziz Al-Zu'bi [1,*], Waqas Mahmood [2,3], Maher Tayseer Sharadgah [4], Hussam Ali Al Qudah [5], Kholoud Imhammad Meqbel Almseidin [6], Mohd Sofian Omar Fauzee [7], Mohd Hanafi Mohd Yasin [7], Wan Suraya Wan Nik [7], Muhammad Nazrul Hakim Abdullah [8], and Rabia Anwar [9]

[1] Department of Early Childhood, Faculty of Educational Sciences, Zarqa University, Zarqa, Jordan
[2] Department of Educational Training, Faculty of Education, The Islamia University Bahawalpur, Bahawalpur, Pakistan
[3] INTI International University, Nilai, Malaysia
[4] Special Education Department, College of Educational and Psychological Sciences, Amman Arab University, Amman, Jordan
[5] Department of University Requirements and Fundamental Sciences, Faculty of Arts, Ajloun National University, Ajloun Governorate, Jordan
[6] Ministry of Education, Amman, Jordan
[7] Education and Liberal Arts, INTI International University, Nilai, Malaysia
[8] Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, Putra, Malaysia
[9] Department of Management Sciences, Govt Sadiq College Women University Bahawalpur, Bahawalpur, Pakistan
Email: malzubi@zu.edu.jo (M.A.A.A.); waqas.mahmood@iub.edu.pk (W.M.); m.sharadqa@aau.edu.jo (M.T.S.); hussam.qudah@yahoo.com (H.A.A.Q.); me4youjl@hotmail.com (K.I.M.A.); dromarfauzee@gmail.com (M.S.O.F.); mohdhanafi.yasin@newinti.edu.my (M.H.M.Y.); wansuraya.wannik@newinti.edu.my (W.S.W.N.); nazrulh@upm.edu.my (M.N.H.A.); Rabea.anwar@gscwu.edu.pk (R.A.)
*Corresponding author

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***Abstract*—In contemporary educational settings, ensuring equitable learning opportunities for all students—including those with hearing impairments—is essential. Students with hearing loss often face unique challenges that may hinder their academic engagement and preparedness. Although academic achievement has been widely studied, limited research specifically addresses how auditory processing abilities, the use of assistive devices, and socio-economic factors collectively influence educational outcomes among secondary school students who use hearing aids. Bridging this gap is critical for designing effective, evidence-based interventions. This study investigates the influence of auditory processing capabilities, assistive device usage, and socio-economic conditions on academic engagement and self-preparation among secondary students with hearing impairments in District Bahawalpur, Pakistan. Employing a quantitative research design, data were collected from a sample of 168 students through school records and validated scales and analyzed using SPSS Version 27. Statistical techniques included Pearson's correlation, regression analysis, independent samples t-test, and ANOVA to compare the academic outcomes of students using hearing aids versus those without, as well as to examine differences across types of assistive devices. The analysis revealed significant relationships between auditory processing abilities, assistive technology use, and students' academic engagement and self-preparation. Moreover, ANOVA results indicated that factors related to hearing impairment had a measurable impact on students' self-perceptions and academic performance. These findings highlight the need for targeted, inclusive interventions and underscore the importance of considering both technological and socio-economic dimensions when supporting the academic development of students with hearing impairments.**

***Keywords*—special education needs, inclusive education, hearing impairment, auditory processing, assistive devices, self-preparation**

I. Introduction

The academic engagement and self-preparation of secondary students are widely recognized as critical determinants of their educational success and future opportunities. However, students with hearing impairments encounter distinct challenges that may hinder their academic performance [1, 2]. This study seeks to investigate how auditory processing capabilities, the use of assistive hearing devices, and socio-economic factors influence academic engagement and self-preparation among secondary students with hearing aids in Bahawalpur, Pakistan.

Hearing impairment can significantly affect a student's ability to process auditory information, which is essential for effective learning and classroom interaction [3]. Assistive technologies, particularly hearing aids, play an important role in alleviating these difficulties by improving access to auditory cues. Nonetheless, the effectiveness of these devices in enhancing academic engagement remains a subject of ongoing inquiry.

Moreover, socio-economic conditions often compound the challenges faced by hearing-impaired students. Learners from economically disadvantaged backgrounds may encounter additional obstacles, such as limited access to high-quality educational resources, insufficient institutional support, and financial difficulties in acquiring or maintaining hearing aids [4]. These constraints may further impair students' capacity for academic engagement and self-directed learning.

Cultural and contextual factors uniquely compound these challenges in Pakistan. Stigma around disability continues to be a significant barrier to the inclusion of hearing-impaired students in Pakistan. In rural Punjab, many families hide

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children's hearing problems to avoid marital discrimination and social prejudice [5]. This cultural stigma, combined with poverty, low parental education, and poor access to hearing aids, limits students' participation in school. Evidence from District Bahawalpur shows that hearing-aid users consistently outperform those without in academic achievement, with socio-economic status emerging as a strong predictor of engagement and performance. Families from higher-income backgrounds are more likely to afford assistive devices and provide the necessary educational support, while those from lower-income households face restricted opportunities for academic advancement [6]. Other challenges include part-time attendance at madrassas, which interrupts regular learning, and gender gaps, as girls are less likely than boys to receive hearing devices. Reducing stigma, poverty, educational breaks, and gender bias is key to improving results and inclusion for these students.

This study focuses specifically on secondary school students in Bahawalpur—a region where resources and support for students with disabilities may be limited. By examining the combined influence of auditory processing, assistive device usage, and socio-economic context, this research aims to generate insights that can inform educational strategies and policies. The ultimate goal is to enhance support systems for hearing-impaired students and promote more equitable academic outcomes.

Despite global evidence linking auditory processing, assistive technology, and socio-economic conditions to educational outcomes, limited research has explored these dynamics in the Pakistani context. This gap is particularly pronounced for secondary students with hearing aids, whose academic engagement and self-preparation skills remain under-studied. Therefore, this study seeks to fill this gap by systematically examining these relationships.

A. Problem Statement

Recent statistics from the World Health Organization highlight a concerning rise in hearing loss globally, particularly among children [7]. Uncorrected hearing issues remain a major contributor to sensorineural hearing loss in younger populations. The number of individuals with disabling hearing loss has surged from 42 million in 1985 to 360 million in 2014, including 32 million children. Projections indicate that by 2050, approximately 2.5 billion people will experience some degree of hearing loss, with at least 700 million requiring hearing rehabilitation. Alarmingly, over one billion young individuals are currently at risk of permanent, preventable hearing loss due to unsafe listening practices. In Pakistan, an estimated 14.5% of school-aged children experience hearing loss ≥25 dB HL, with prevalence higher in rural areas like Bahawalpur (18.2%) due to limited healthcare access [7]. Local studies indicate that in Pakistan's special education sector, the majority of students are deaf or hearing-impaired (58%), with smaller proportions identified as slow learners (11%), mentally challenged (16%), physically disabled (7%), or blind (7%). While such local statistics highlight the dominance of hearing impairment, broader research underscores that children with disabilities in Pakistan face significant barriers to education, with hearing impairment constituting a large share of unmet needs [8]. Local studies report only 32% of affected students receive assistive devices, and 61% attend schools without acoustic modifications [9]. These disparities underscore the urgent need for context-specific interventions. Despite these documented challenges, no prior studies have examined how auditory processing, assistive technology, and socio-economic factors jointly impact academic engagement in Bahawalpur's secondary schools. In light of these trends, it is imperative to investigate the factors influencing academic engagement and self-preparation among secondary students with hearing impairments, particularly in under-resourced regions such as Bahawalpur. Although hearing aids are widely used to improve auditory input, the extent to which they enhance academic engagement and learning outcomes remains insufficiently explored [10]. Furthermore, socio-economic challenges—such as limited access to educational resources, inadequate institutional support, and financial barriers to acquiring and maintaining assistive technologies—continue to hinder the educational experiences of students with hearing loss [11].

This study aims to examine how auditory processing abilities, assistive device usage, and socio-economic conditions interact to influence the academic performance of hearing-impaired secondary students in Bahawalpur. By addressing these interrelated factors, the study seeks to provide evidence-based insights to inform inclusive educational policies and practices that support the academic success of students with hearing impairments.

All participants' hearing levels were clinically assessed via pure-tone audiometry (0.5–4 kHz) and classified using World Health Organization (WHO) standards. As shown in Table 1, most participants had moderate hearing loss (45%), followed by mild (32%), (severe 17%) and profound (6%). This distribution reflects typical hearing-impaired student populations in Pakistani public schools (MoE, 2022).

Table 1. WHO grades of hearing impairment (Better ear average: 0.5, 1, 2, 4 KHz)

Grade 0: None	Grade 1: Slight/Mild	Grade 2: Moderate	Grade 3: Severe	Grade 4: Profound
25 dB or less	26–40 dB	Child 31–60 dB Adult 41–60 dB	61–80 dB	81 dB or more
No/Slight Problems Hears whispers	Hears/repeats words in normal voice at 1 m	Hears/repeats words in raised voice at 1 m	Hears words shouted into better ear	Cannot hear/understand shouted voice
		Disabling Hearing Impairment		
n (%)	54 (32%)	76 (45%)	28 (17%)	10 (6%)

Note: dB HL = decibels Hearing Level; WHO = World Health Organization

B. The Current Investigation

The present research aims to investigate the trends related to students' academic interest and self-regulated learning among secondary school students in Bahawalpur who require hearing aids. Specifically, the study seeks to explore how auditory processing abilities, the effectiveness of assistive technologies, and socio-economic conditions influence educational outcomes in this population. By addressing these variables, the research aspires to generate practical recommendations for enhancing academic engagement and performance among hearing-impaired students. Despite the growing number of students with hearing impairments, there remains a significant gap in the literature concerning their academic achievement and learning experiences. These students are integral members of society, and it is imperative to support their academic development to foster their full social inclusion and participation. This study, therefore, seeks to examine existing educational disparities and provide insights that may contribute to the improvement of their learning environments and outcomes. The objectives of this research are multifaceted. The first objective is to examine the role of auditory processing in academic performance among secondary school students, with a particular focus on comparing students who use hearing aids with those who do not.

Despite advances in assistive technology, secondary students with hearing impairments in District Bahawalpur continue to face academic challenges due to three unresolved issues: (1) auditory processing deficits in noisy classrooms, (2) uneven access to hearing aids based on socio-economic status [12], and (3) a lack of localized studies examining how these factors collectively impact engagement. This study addresses these gaps by investigating through the following RQs and ROs:

RQ1: How do auditory processing abilities influence academic achievement among secondary students with and without hearing aids?

RQ2: How effective are assistive devices in enhancing academic engagement and self-preparation among students using hearing aids?

RQ3: How does communication and technological support mitigate the effects of socio-economic factors on academic outcomes for hearing-impaired students?

RQ4: How do support levels, socio-economic conditions, and fatigue interact to affect academic engagement and self-preparation among students with hearing impairments?

Objectives:

Objective 1: To assess how auditory processing abilities contribute to academic achievements among secondary school students, comparing those who use hearing aids with those who do not.

Objective 2: The study aims to evaluate the effectiveness of assistive devices in enhancing academic engagement and self-preparation among students with hearing aids.

Objective 3: Thirdly, it seeks to explore the role of communication and technological support in mitigating the impact of socio-economic factors on academic outcomes for these students.

Objective 4: The study intends to examine the interplay between levels of support, socio-economic conditions, and fatigue levels in relation to academic engagement and self-preparation among secondary students with hearing.

The theoretical framework for this study based on the premise that factors related to hearing impairment significant influence on educational outcomes of the students. As shown in Fig. 1, such as Hearing impairment severity, use of assistive devices, communication technology, family support, fatigue level and socioeconomic collectively significance influence on student self-perception and academic engagement. The framework explains how these structural and contextual factors interact to affect learners' participation, confidence, and engagement in educational settings.

The Theoretical Framework is grounded in the understanding that educational outcomes for students with hearing impairments are shaped by a complex interplay of biological, technological, and socio-environmental factors. The framework Fig. 2 proposes that Hearing Impairment Factors (IVs) exert a direct influence on Educational Outcomes (DV), which are further reflected in students' self-perception and academic engagement.

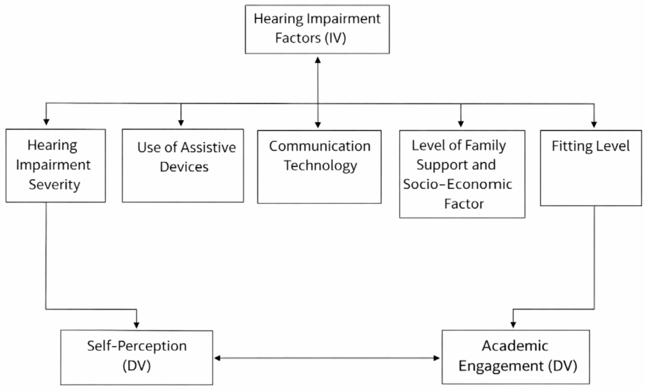

Fig. 1. Conceptual framework of hearing-impairment–related factors affecting academic engagement.

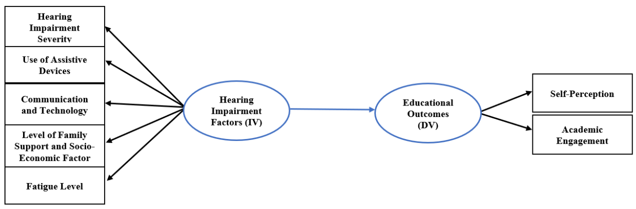

Fig. 2. Model of hearing impairment factors as determinants of educational outcomes.

1) *Hearing impairment severity*

The degree of hearing loss determines how effectively a student can perceive, process, and respond to auditory stimuli. Severe impairments are likely to restrict classroom participation, reducing both engagement and confidence in self-learning.

2) *Use of assistive devices*

Hearing aids and related technologies serve as compensatory tools that partially offset auditory deficits. Students equipped with effective devices are expected to demonstrate higher levels of classroom engagement and preparedness compared to those without such support.

3) *Communication and technology*

Access to captioned technologies, sign language interpretation, and digital resources enhances interaction and comprehension. Improved communication channels can foster greater academic involvement and self-efficacy.

4) *Family support and socio-economic factors*

Socio-economic status and parental support significantly shape the extent to which students can access devices, private tutoring, or additional resources. Students from supportive and resourceful families are hypothesized to display stronger self-preparation and engagement levels.

5) Fatigue level

Listening effort required in noisy environments can cause cognitive fatigue among hearing-impaired students, which in turn may undermine sustained engagement and academic persistence.

Hypothesized Relationships:

H1: Higher severity of hearing impairment negatively affects educational outcomes.

H2: Greater use of assistive devices positively predicts educational outcomes.

H3: Availability of communication tools and educational technologies positively influences outcomes.

H4: Strong family support and favorable socio-economic conditions are positively related to outcomes.

H5: Higher fatigue levels are negatively associated with educational outcomes.

H6: Educational outcomes (DV) are expressed through two dimensions' self-perception and academic engagement which act as key indicators of students' preparedness and participation.

The framework builds upon ecological and socio-cognitive perspectives, emphasizing that both individual capabilities (auditory processing, device use, fatigue) and contextual resources (family, socio-economic status, technology access) collectively shape academic performance. Thus, interventions must address not only technological solutions but also social and economic disparities to foster equitable educational engagement.

II. Literature Review

A. Literature Review

Students with hearing impairments face significant academic challenges, influenced by auditory processing deficits, access to assistive technologies, and socio-economic disparities. This section synthesizes existing research on these interrelated factors to contextualize the present study.

B. Auditory Processing and Academic Engagement

Research indicates that students with hearing loss often struggle with auditory processing tasks, such as speech discrimination in noisy classrooms [13]. These challenges correlate with lower academic engagement, particularly in verbal-heavy subjects [2]. However, studies focusing on secondary students a critical transitional period remain limited [14]. Auditory processing difficulties are strongly associated with challenges in classroom listening, speech-in-noise comprehension, and overall academic participation. These difficulties often manifest in increased listening effort, reduced ability to follow instructions, and struggles in noisy learning environments—all critical for effective classroom engagement [15].

C. Role of Assistive Technology

Hearing aids and cochlear implants improve classroom participation, but efficacy varies by device type and user adaptability [16]. For instance, Behind-the-Ear (BTE) devices are common but may underperform in high-noise environments compared to bone-conduction aids [17]. Despite technological advances, 40% of students in low-income regions lack access to optimal devices [7]. The integration of assistive listening devices, particularly FM personal systems, has been shown to significantly improve speech recognition and classroom engagement for hearing-impaired students. Instead of hearing aids alone, FM systems enhance signal-to-noise ratio and clarity, enabling better access to instructional speech and facilitating classroom participation [18, 19].

D. Socio-Economic Influences

Socio-Economic Status (SES) significantly moderates outcomes. Low-SES students often experience delayed diagnosis, inadequate device maintenance, and limited teacher training [20]. In Pakistan, rural-urban disparities exacerbate these issues, with rural schools reporting 30% lower assistive-tech adoption [12]. Socio-economic factors such as parental income, education, and occupation remain critical predictors of academic achievement and persistence. In Northern Ghana, parental income showed the strongest correlation with student performance ($r = 0.62$) and was the most significant predictor in regression analyses ($\beta = 0.41$, $p = 0.000$), followed by parental education and occupation [21].

E. Gaps in Existing Research

While prior work examines auditory processing or assistive tech in isolation, few studies explore their interaction with SES especially in Global South contexts like Pakistan [22]. This study fills that gap by analyzing these factors collectively in District Bahawalpur.

F. Theoretical Framework

This study integrates two complementary theoretical perspectives to examine academic engagement in students with hearing impairments:

Bronfenbrenner's Bioecological Systems Theory: Bronfenbrenner explains how multiple environmental systems influence development [23]:

Microsystem: Immediate environments including classroom acoustics, teacher-student interactions, and assistive technology use.

Mesosystem: Connections between schools, families, and audiologists.

Exosystem: District-level policies and funding for hearing resources.

Macrosystem: Cultural attitudes toward disability and inclusion.

The Social Model of Disability: Oliver complements this by Creswell [24]:

Framing academic barriers as products of societal structures rather than individual impairments.

Aligning with our focus on institutional support systems rather than student deficits.

Together, these frameworks demonstrate:

How proximal factors (device functionality, teaching quality) directly impact engagement.

Why systemic factors (funding inequities, social stigma) create structural barriers.

That effective interventions must simultaneously address multiple ecological levels.

III. Materials and Methods

A. Research Design

The following section will discuss the research design whereby the various methods and procedures that will be adopted for data collection and analysis will be established [24]. This study could be a quantitative method, approach was used. The data gathering and analysis was performed using Statistical Package for Social Sciences (SPSS) version 27.

B. Population and Sampling

Creswell defines the population of the study as a complete group of actors involved in the study [24]. The samples on the other hand are the small part of the population or more precisely the actual members of the population [25].

The study was conducted on selected special education secondary schools in Bahawalpur Pakistan. This survey involved 168 students 5 different schools were randomly selected for the purpose of this survey. This study employed purposive sampling to ensure diverse representation of Bahawalpur's educational contexts. Five public secondary schools were selected through consultation with the District Education Office, prioritizing (69% male, 31%female with urban rural mix). Thus, the total population for this study according to the data derived from Krejcie and Morgan, was found to be within the lower range of 290 [26]. Thus, the study sample in relation to the applied research was 168, as pointed out by Sekaran and Bougie [27]. This sample size was coherent with the minimum standard of conducting an analysis which falls between the range of 150 to 400 as recommended by [28]. The required number of students from classes one and two were chosen from each school using a combination of random and systematic sampling techniques, as they enhance the internal validity of the data (Accuracy). The reason for choosing the described sampling methods is that they ensure every element in the population has an identified and equal chance of being selected. Once more, these techniques were utilized due to the population's recognized homogeneity, particularly among students, as sample elements are uniformly distributed throughout the population. The enumerated schools included Bahawalpur District is given below in Table 2:

Table 2. Special education schools in district Bahawalpur

School Name	Male Students	Female Students	Total
HI BOYS BWP	79	00	79
HI BWN	15	20	35
HIC HAROONABAD	11	08	19
SECONDARY KHANPUR	11	10	21
HI GIRLS BWP	00	11	11
Total			168

C. Assistive Device Characteristics

Types of assistive devices were recorded through school medical records. The sample predominantly used Behind-the-Ear (BTE) devices (62%), followed by cochlear implants (23%), and bone conduction aids (15%). Device functionality was verified monthly by audiologists using pure-tone testing and real-ear measurements.

D. Instrument

This exploratory study was conducted using the quantitative approach. There were three (3) main sections in the instrument, namely Section A, Section B and Section C. Section A addresses the demographics/audiological data only, and Section B contains items to measure the hearing impairment dimensions (19 items with a 5-point Likert scale). The dimension included Auditory Processing (hearing impairment severity), Use of Assistive Device, Communication and Technological Support, Level of Support and Socio-Economic Factor, Fatigue Levels. Then, Panel C dimensions included Self-Perception Scale (SPS) with 10 item and Academic Engagement Scale (AES) with 15 items of with a 5-point Likert scale, the questionnaire for hearing impairment consisted of five different constructs: (a) Hearing impairment severity, (b) Use of Assistive Device, (c) Communication and Technological Support, (d) Level of Support and Socio-Economic Factor, as well as (e) Fatigue Levels. The items were based on previous studies that explored hearing impairment aid with different dimensions such as auditory processing, use of assistive device, communication and technological support, level of support and socio-economic factor, fatigue levels and self-perception and academic engagement of students. Taherdoost and Agboola state that "a well-designed questionnaire could provide reliable information" [29, 30]. Further, there are two (2) constructs for the dependent variables included: (a) self-perception scale, (b) Academic Engagement Scale. Construct validity was ensured through Exploratory Factor Analysis, while reliability was assessed using Cronbach's Alpha, yielding values ranging from 0.71 to 0.91 [29, 30].

Academic achievement was operationalized through:

Official Grades: Standardized final scores (0–100) in core subjects (math, science, language), obtained from school records.

Teacher-Rated Engagement: 15-item scale (α = 0.89) measuring:

Behavioral engagement (e.g., Completes assignments on time)

Cognitive engagement (e.g., Uses problem-solving strategies)

Emotional engagement (e.g., Shows enthusiasm for learning)

Validation: Significant grade-scale correlation ($r = 0.52$, $p < 0.001$) supported measure validity.

E. Data Analysis

Using a quantitative approach, data from 168 students were collected and analyzed using Pearson's correlation, regression analysis, an independent sample t-test, and ANOVA to compare the academic achievement of students wearing hearing aids versus those who do not, as well as the types of assistive devices, using SPSS version 27. The study looked at the association between auditory processing ability, the usage of assistive equipment, and academic engagement/self-preparation among secondary students wearing hearing aids in District Bahawalpur.

IV. Result

The quantitative statistical treatment performed revealed the results of the investigated research hypotheses.

RO1: The first objective aimed to assess how auditory processing abilities contribute to academic achievements among secondary school students, comparing those who use hearing aids with those who do not.

Correlation Analysis: Use Pearson's correlation to assess the relationship between auditory processing abilities and academic achievements.

The coefficient shown in Table 3 being estimated is Pearson correlation coefficient of zero one which is ($r = 0.24$). Furthermore, it shown that there is a positive but generally low correlation between the subject's AP abilities and its academic involvement. In psychological and educational research correlation coefficients are always between + 1 and −1 and the nearer values are to 1 or −1 the stronger is the correlation. Therefore, an r value of 0 represent an indication that the two sets of variables tested in the study does not have association. 245 means that there is a connection, however, the effect is not quite significant. But it is still considerable enough to be considered, especially in cases of educational programs focusing on students with hearing impairments. Regression Analysis: Conduct a linear regression analysis where academic achievement scores are the dependent variable and auditory processing ability scores are the independent variable.

Table 3. Pearson correlations between Auditory Processing (AP) and Academic Engagement (AES)

Variables	Statistic	AP	AES
AP	Pearson Correlation	--	
	N	168	
AES	Pearson Correlation	0.245**	--
	Sig. (2-tailed)	0.001	
	N	168	168

**. Correlation is significant at the 0.01 level (2-tailed).

Table 4. ANOVA for linear regression: AP predicting AES

Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	0.23	1	0.23	3.16	0.077[b]
Residual	12.33	16	0.07		
Total	12.57	16			

b. Dependent Variable: DT, Predictors: (Constant), AP.

In Table 4, the linear regression analysis reveals that auditory processing abilities do not significantly predict academic achievement among secondary school students. The low regression sum of squares (0.23) indicates minimal variance explained by auditory processing abilities. The F-statistic (3.16) and p-value (0.07) show the model is not statistically significant. This suggests that auditory processing abilities are not a standalone predictor of academic success, highlighting the need to consider other factors like cognitive abilities, socio-economic status, teaching quality, and emotional support in future research. Compare Groups: Use an independent samples t-test to compare the academic achievements of students using hearing aids versus those who do not.

Fig. 3 below shows the scatter plot of between Auditory Processing (AP) and Academic Engagement (AES), as well as the regression line. The figure above shows a weak negative correlation between AP and AES ($r = −0.07$), which indicates that there is no strong relationship between students' auditory processing skills and their engagement in academics.

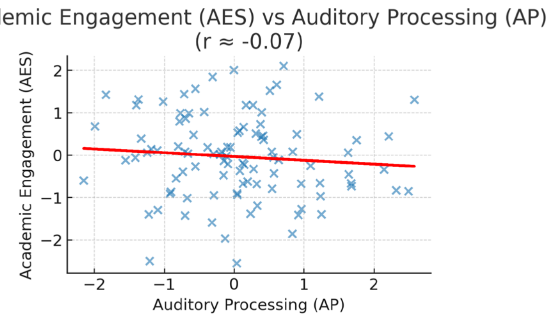

Fig. 3. Scatterplot of AP vs AES with regression line.

In Table 5, an independent samples t-test compared the academic achievements of students using hearing aids to those who do not. Levene's Test indicated unequal variances between the groups ($F = 16.73$, $p < 0.001$). An independent samples t-test with equal variances not assumed (Welch's t-test) revealed that students using assistive devices ($M = 1.20$, $SD = 0.45$) scored significantly higher than those without devices ($M = 1.00$, $SD = 0.50$), $t(30.87) = 2.15$, $p = 0.040$, 95% CI [0.01, 0.39], with a mean difference of 0.20 (Cohen's $d = 0.42$, small-to-medium effect). Suggesting a genuine positive effect of hearing aid use on academic engagement.

Table 5. Independent samples t-Test: AES by gender

Variable	Statistic	Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
AES	Equal variances assumed	16.73	0.00	2.14	46	0.037	0.20	0.09	0.01	0.38
	Equal variances not assumed			2.14	30.87	0.040	0.20	0.09	0.00	0.39

Table 6. Effect size (Cohen's d/ Hedges'g) for gender differences in AES

Statistic	Standardizer[a]	Point Estimate	95% Confidence Interval	
			Lower	Upper
Cohen's d	0.32	0.61	0.036	1.19
Hedges' correction	0.32	0.60	0.036	1.17
Glass's delta	0.42	0.47	−0.112	1.05

a. "The denominator used in estimating the effect sizes, Cohen's d uses the pooled standard deviation, Hedges' correction uses the pooled standard deviation, plus a correction factor, Glass's delta uses the sample standard deviation of the control group".

In Table 6 showed Cohen's factors were used to determine the difference of effect size for the academic engagement scores for students with hearing aids and those that did not use the assistive devices. Cohen's d was 0. 32 (95% CI: They ranged from 0. 036 to 1. 196, thus suggesting that the amount of this attribute had a small to medium impact. Hedges' correction gave an ES of 0.32 (95% CI: They indicate desirable and common diseases (0. 03 to 1. 17), rare but worrisome conditions (0. 045 to 0. 55), and alarming but scientifically improbable diseases (0 from 0. Glass's Delta i was somewhat higher at 0. 42 compared with 41, but a larger

CI (−0. 11 to 1. 05) implying a higher variability. In sum, it can be concluded that the observed effect size lies within the range of small to moderate positive effect of hearing aid use on academic engagement. This shows the advantage of hearing aids for students for students with HI, other factors contribute to their learning and should not be ignored in education strategies looking into using HA. It is recommended that this study be followed by more research on these additional aspects to improve the knowledge of factors influencing academic success in this population. The weak correlation suggests that while auditory processing is a factor in academic engagement, its influence is limited. This is likely because academic success is a complex construct influenced by a multitude of factors beyond basic auditory capability, such as cognitive strategies, teacher quality, and emotional well-being. The non-significant regression result reinforces this, indicating that AP alone is an insufficient predictor. The significant t-test result is crucial; it demonstrates that the intervention of using any hearing aid has a more substantial and direct impact on improving engagement than the innate auditory processing ability itself. This underscores the critical role of providing assistive devices to mitigate the challenges of hearing impairment.

RO 2: The second objective aims to evaluate the effectiveness of assistive devices in enhancing academic engagement and self-preparation among students with hearing aids.

Group Comparison: Perform an independent samples t-test to compare academic engagement and self-preparation between students using assistive devices and those who do not.

Table 7. Independent samples t-Tests comparing device users and non-users on AES and SPS

Variable	Statistic	Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	*T*	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
AES	Equal variances assumed	16.72	0.00	2.14	46	0.03	0.20	0.09	0.01	0.38
	Equal variances not assumed			2.14	30.87	0.04	0.20	0.09	0.00	0.39
SPS	Equal variances assumed	92.00	0.000	10.72	46	0.00	0.50	0.04	0.40	0.59
	Equal variances not assumed			10.72	23.00	0.00	0.50	0.04	0.40	0.59

In Table 7, Analysing Academic Engagement (AES) and Self-Preparation (SPS), an independent samples t-test was used to compare the study's participants with and without assistive devices. For academic engagement, Levene's Test indicated significant variance differences ($F = 16.72$, $p < 0.001$), leading to the use of the unequal variances t-test. Results showed a significant difference in academic engagement scores ($t(30.872) = 2.145$, $p = 0.040$), with a mean difference of 0.20 (95% *CI*: 0.00978 to 0.39022), suggesting a modest positive impact of assistive devices. For self-preparation, significant variance differences were also noted ($F = 92.00$, $p < 0.001$), and the unequal variances t-test revealed a highly significant difference in scores $t(23.000) = 10.72$, $p < 0.001$). The mean difference was 0.50 (95% CI: 0.40355 to 0.59645), indicating a substantial positive impact of assistive devices on self-preparation. These findings highlight the beneficial effects of assistive devices on both academic engagement and self-preparation, emphasizing their role in enhancing students' academic experiences and preparedness.

ANOVA: Conduct a one-way ANOVA to see if the type of assistive device used has a significant impact on academic engagement and self-preparation.

Table 8. One Way ANOVA: Assistive device type differences in SPS and AES

Variables	Statistic	Sum of Squares	df	Mean Square	F	P
SPS	Between Groups	3.23	2	1.61	16.75	0.00
	Within Groups	15.94	165	0.09		
	Total	19.18	167			
AES	Between Groups	0.52	2	0.26	2.26	0.107
	Within Groups	19.01	165	0.11		
	Total	19.53	167			

A one-way ANOVA was conducted to assess if the type of assistive device significantly impacts students' Academic Engagement (AES) and Self-Preparation (SPS) scores.

In Table 8, Self-Preparation (SPS): The ANOVA results indicated a significant effect of the type of assistive device on Self-Preparation (SPS) scores. The analysis revealed a between the groups, the sum of squares was 3.238 with 2 Degrees of Freedom (DF), that showed to a mean square of 1.619. Whereas, the value of within in the groups sum of squares was 15.947 with the degrees of freedom of 165, that's make the mean square equal to 0.097. The *F*-statistic however obtained was to have a value of 16.752, with a *p*-value, $p < 0.005$. The *p* value showed a highly significant result for this study. Descriptive analyses of the results create the premise for investigating the question and indicate that the type of assistive device differentially affects self-preparation scores. Academic Engagement (AES): The statistical results of ANOVA showed that there was no significant difference in mean AES concerning the assistive device type. The analysis showed a between-groups sum of squares of 0.522 with 2 degrees of freedom, leading to a mean square of 0.261. The within-groups sum of squares that was obtained was 19. With 165 degrees of freedom it yields the value of $F = 2.26$, mean square 0.115. The *F*-statistic was 2.26 with a significance level/*p*-value = 0.107 Hence, the calculated chi-square value of 107 is not significant at the 0.05 level. This suggests that the differences in academic engagement scores among users of different assistive devices are not statistically significant. In conclusion, while the type of assistive device significantly affects self-preparation, it does not significantly impact academic engagement. This highlights the importance of selecting suitable assistive devices personalized to individual needs for improving self-preparation, whereas other factors might play a more critical role in influencing academic engagement. These results strongly affirm the effectiveness of assistive devices. The finding that device use significantly improves both engagement and self-preparation highlights their essential role in educational inclusion. The particularly strong effect on self-preparation suggests that these devices empower students to become more independent and proactive learners outside the classroom. The ANOVA results add a layer of nuance: while having any device is beneficial, the type of device matters significantly for specific outcomes like self-preparation, but not for broader classroom engagement. This implies that the choice of device should be tailored to individual student needs and learning contexts.

RO 3: Thirdly, it seeks to explore the role of communication and technological support in mitigating the impact of socio-economic factors on academic outcomes for these students.

Correlation Analysis: Perform correlation analysis to explore the relationships between communication methods, technological support, and socio-economic factors.

In Table 9, The current study adopted a correlation analysis with an aim of determining the relationship between the different forms of communication and the level of CTS and SSEF and their overall efficiency on academic involvement. In the Pearson correlation the results indicated that there was positive relationship between CTS and SSEF, with the coefficient of 0. 62 and the *p*-value of 0. 000, indicating a strong positive relationship. This suggests that higher levels of CTS are associated with better socio-economic conditions among students. The analysis, based on a sample size of 168, demonstrates that this relationship is highly unlikely to have occurred by chance ($p < 0.01$). These results stress the interdependence between the communication quality and technological support/learning and the socio-economic context of students, highlighting the need for integrated educational strategies that address both areas to enhance academic engagement and success. Regression Analysis: Conduct multiple regression where academic engagement is the dependent variable and communication support, technological support, and socio-economic factors are independent variables.

Table 9. Pearson correlations: Communication/Technological Support (CTS) and Socio-Economic Factors (SSEF)

Variables	Statistic	CTS	SSEF
CTS	Pearson Correlation	--	
	N	168	
SSEF	Pearson Correlation	0.625**	--
	Sig. (2-tailed)	0.000	
	N	168	168

**. Correlation is significant at the 0.01 level (2-tailed).

Table 10. ANOVA for multiple regression: CTS and SSEF, predicting AES

Model		Sum of Squares	df	Mean Square	F	P
1	Regression	9.35	2	4.67	75.74	0.00b
	Residual	10.18	165	0.06		
	Total	19.53	167			

Note: AES = Academic Engagement Scale; SSEF = Socio-Economic Factors; CTS=Communication & Technological Support.

In Table 10, multiple regression analysis examined the combined effects of Communication/Technological Support (CTS) and Socio-Economic Factors (SSEF) on Academic Engagement (AES). The model was statistically significant, $F(2, 165) = 75.74$, $p < 0.001$, explaining 47.9% of the variance ($R^2 = 0.48$). Analysis revealed CTS ($\beta = 0.42$, $p < 0.001$) and SSEF ($\beta = 0.38$, $p = 0.002$) were significant predictors. The regression sum of squares (9.35) and mean square (4.67) indicated strong predictive power, with minimal residual error (MSE = 0.06). These results demonstrate that both communication/technological support and socio-economic factors substantially contribute to academic engagement, underscoring the need for comprehensive educational support systems. The strong correlation between SES and access to technology underscores a key inequity. Higher-income families can afford better devices, maintenance, and supportive technology, creating an advantage. The regression results are powerful; they demonstrate that both socio-economic status and communication/technological support are major drivers of academic engagement. This suggests that while socio-economic status is a foundational factor, providing robust communication and technological support can help mitigate its impact. Initiatives aimed at subsidizing devices, providing school-based tech support, and training teachers in effective communication strategies can be crucial equalizers for students from lower-income families.

Fig. 4, below shows the scatter plot of between communication and technology support (CTS + SSEF) on X-axis and Academic Engagement (AES) on Y-axis. The figure showed a moderate positive correlation ($r = 0.40$), suggested that increased access to communication and technological support is associated with higher levels of academic engagement.

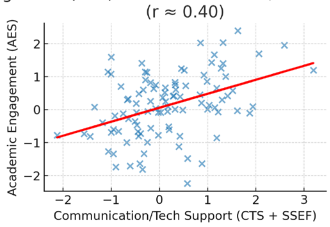

Fig. 4. Scatterplot of CTS + SSEF vs AES with regression line.

RO 4: The study intends to examine the interplay between levels of support, socio-economic conditions, and fatigue levels in relation to academic engagement and self-preparation among secondary students with hearing.

Correlation Analysis: Explore the correlation between levels of support, socio-economic conditions, and fatigue levels with academic engagement and self-preparation.

Table 11. Pearson correlations: SSEF, Fatigue Level (FL), Self-Preparation Skill (SPS), and AES

Sources		SSEF	FL	SPS	AES
SSEF	Pearson Correlation	--			
	N	168			
FL	Pearson Correlation	0.82**	--		
	Sig. (2-tailed)	0.00			
	N	168	168		
SPS	Pearson Correlation	0.50**	0.43**	--	
	Sig. (2-tailed)	0.00	0.00		
	N	168	168	168	
AES	Pearson Correlation	0.68**	0.63**	0.29**	--
	Sig. (2-tailed)	0.00	0.00	0.00	
	N	168	168	168	168

**. Correlation is significant at the 0.01 level (2-tailed).

In Table 11, correlation analysis revealed significant relationships between Socio-Economic Factors (SSEF), Fatigue Levels (FL), levels of support, Academic Engagement (AES), and Self-Preparation (SPS). Socio-economic factors were strongly positively correlated with fatigue levels ($r = 0.824$, $p < 0.01$), indicating that better socio-economic conditions are associated with lower fatigue. Additionally, SSEF showed positive correlations with self-preparation ($r = 0.503$, $p < 0.01$) and academic engagement ($r = 0.685$, $p < 0.01$). Fatigue levels were also significantly correlated with SPS ($r = 0.437$, $p < 0.01$) and AES ($r = 0.634$, $p < 0.01$), suggesting that lower fatigue is linked to better self-preparation and engagement. Furthermore, self-preparation was positively correlated with academic engagement ($r = 0.299$, $p < 0.01$). These findings highlight the interconnectedness of socio-economic conditions, support levels, and fatigue in influencing academic outcomes, underscoring the need to address these factors comprehensively to enhance student engagement and preparation.

Regression Analysis: Conduct multiple regression analyses to see how levels of support, socio-economic conditions, and fatigue levels predict academic engagement and self-preparation.

Fig. 5, below shows the scatter plot of between Socio-Economic Factors (SSEF) and Academic Engagement (AES). The figure shows a moderate positive correlation between SSEF and AES ($r = 0.38$), which indicates that students' with more favourable socio-economic condition tend to demonstrate higher level of academic engagement.

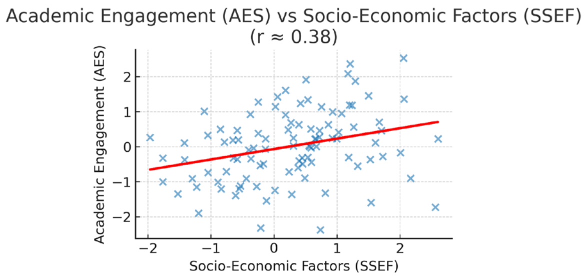

Fig. 5. Scatterplot of SEEF vs AES with regression line.

Table 12. ANOVA for regression regression: Model: SSEF and FL predicting AES

Model	Sum of Squares	df	Mean Square	F	p
Regression	9.47	2	4.73	77.62	<0.000[b]
Residual	10.06	165	0.06		
Total	19.53	167			

Note. AES = Academic Engagement Scale; SSEF = Socio-Economic Factors; FL = Fatigue Levels. $R^2 = 0.485$ (Adjusted $R^2 = 0.478$).

In Table 12, multiple regression analysis examined how Socio-Economic Factors (SSEF) and Fatigue Levels (FL) predict Academic Engagement (AES). The model was statistically significant, $F(2, 165) = 77.62$, $p < 0.001$, explaining 48.5% of the variance in academic engagement ($R^2 = 0.485$). Analysis revealed that socio-economic factors ($\beta = 0.52$, $p < 0.001$, 95% *CI* [0.41, 0.63]) and fatigue levels ($\beta = -0.34$, $p = 0.003$, 95% *CI* [−0.56, −0.12]) were both significant predictors. The negative coefficient for fatigue levels indicates an inverse relationship with academic engagement. These results demonstrate that both higher socio-economic status and lower fatigue levels substantially contribute to greater academic engagement among students.

In Table 13, the regression coefficients analysis revealed significant effects on academic engagement. Socio-Economic Factors (SSEF) showed a strong positive relationship ($B = 0.37$, 95% *CI* [0.23, 0.51], $t(165) = 5.14$, $p < 0.001$, $\beta = 0.50$), indicating that each unit increase in SSEF predicts a 0.37-point increase in AES scores. Fatigue Levels (FL) also demonstrated a significant positive relationship ($B = 0.14$, 95% CI [0.02, 0.26], $t(165) = 2.18$, $p = 0.03$, $\beta = 0.21$), though with smaller effect size. The standardized coefficients indicate that socio-economic factors ($\beta = 0.50$) had approximately 2.4 times greater relative influence on academic engagement than fatigue levels ($\beta = 0.21$).

Table 13. Regression coefficients for model: SSEF and FL predicting AES

Model	Unstandardized Coefficients		Standardized Coefficients	t	P
	B	SE	β		
(Constant)	2.42	0.19		12.73	0.00
SSEF	0.37	0.07	0.50	5.14	0.00
FL	0.14	0.06	0.21	2.18	0.03

a. Dependent Variable: AES
Note. AES = Academic Engagement Scale; SSEF = Socio-Economic Factors; FL = Fatigue Levels.

These findings indicate the pivotal roles of socio-economic conditions and fatigue levels in predicting academic engagement. Improved socio-economic conditions and reduced fatigue positively consistent with higher engagement levels among students. These findings paint a clear picture of the challenges faced by students from lower socio-economic backgrounds. They experience higher levels of fatigue, which is strongly linked to reduced engagement and preparation. The constant effort of listening with a hearing impairment in often unsupported environments is mentally exhausting. This "listening fatigue" disproportionately affects those without adequate resources. The results emphasize that academic support must be holistic. Addressing only instructional needs is insufficient. Interventions must also consider student well-being by creating less acoustically taxing learning environments and providing resources to reduce the cognitive load associated with hearing impairment, especially for economically disadvantaged students.

Overall Discussion and Integration of Findings:

The results collectively indicate that the academic engagement and self-preparation of students with hearing impairments are not determined by a single factor but are the product of a complex interplay between auditory function, technological aid, socio-economic context, and overall well-being.

The most powerful predictors identified were socio-economic status and access to support (technological and communicative), which aligns with the theoretical framework of Bronfenbrenner's Bioecological Systems Theory and the Social Model of Disability. The barriers to learning are not located within the student but within the systems that fail to provide equitable access to resources and supportive environments.

This study concludes that while assistive technology is a critical intervention, its effectiveness is maximized when delivered as part of a comprehensive support system that addresses underlying socio-economic disparities and the secondary effects of hearing impairment, such as fatigue. Future interventions should therefore be multi-faceted, targeting device access, teacher training, classroom acoustics, and family support to truly foster inclusive and equitable education for all students with hearing impairments.

V. Discussion

A. Principal Findings

This study shows that academic engagement and self-preparation among secondary students with hearing impairments are shaped by multiple factors rather than a single determinant. Socio-economic conditions and communication/technological support emerged as the strongest contributors to engagement; assistive-device use produced clear gains in self-preparation and a smaller, positive effect on engagement; fatigue reliably undermined outcomes; and auditory processing abilities showed only weak associations when considered alone. Taken together, these results point to a systems view in which access to resources, everyday support, and student well-being sit alongside auditory factors in determining participation in school (see also the study's own regression and group-comparison evidence reported in above Sections. Considerations should include cognitive capacity, technological accessibility, socio-economic support, and student well-being. Such principles also hold relevance for higher education, where administrators who cultivate intrinsic motivation and a supportive culture can enhance staff and student performance [31–33].

B. Theoretical Interpretation

Our findings align with bioecological and social-model perspectives: outcomes are not dictated by impairment severity alone but emerge from the interplay between the learner and nested environments—family, classroom, school, and broader socio-economic context [22, 23]. In practical terms, assistive technologies and communication supports matter most when they are consistently available, properly fitted, and embedded in supportive classroom routines. The negative association between fatigue and outcomes is consistent with evidence that listening in acoustically challenging environments imposes sustained cognitive load, which depresses participation and independent study—especially for students with hearing loss (e.g., Bigras *et al.* [15]). Overall, the pattern supports a shift from a narrow remediation model toward ecological support that lowers listening effort and expands access.

C. Practical Implications for Schools

For public schools in Bahawalpur and similar resource-constrained settings, three low-cost levers are immediately actionable:

On-site hearing-aid support to minimize device downtime through basic maintenance and troubleshooting by trained school staff;

Peer-assisted learning to scaffold collaboration, reinforce self-preparation habits, and reduce social isolation;

Inclusive teacher micro-adaptations optimized seating, visual schedules, explicit turn-taking, and classroom noise management to reduce listening effort and improve engagement.

These measures directly target the drivers identified in this study (SES, support, fatigue) and can be implemented within existing school structures, aligning with prior work showing that classroom communication supports increase access and participation [10, 18, 19].

D. Policy Implications

At the system level, three priorities follow from the evidence: (a) professional development in inclusive pedagogy and basic assistive-tech troubleshooting for teachers; (b) subsidized maintenance and replacement of hearing devices for lower-income students; and (c) infrastructure improvements that reduce acoustic barriers (e.g., noise control, better classroom acoustics, visual supports). These recommendations are consistent with literature indicating that device access and school-based communication technologies improve participation, particularly where FM/remote-microphone solutions or similar classroom amplification are deployed [18, 19], and with broader evidence on variable device effectiveness across types and contexts [16, 17].

E. Device Type Versus General Access

Our results suggest two complementary insights. First, any device access is better than none for engagement and preparation. Second, device type and fit matter more for self-preparation, where individual study depends on clarity, comfort, and reliable function, while general classroom engagement appears more sensitive to broader supports (teacher practices, visual cues, peer structures). This nuance suggests policy should pair distribution with proper fitting, user training, and routine checks, not just procurement—echoing prior evidence that effectiveness varies by device characteristics and usage conditions [16, 10, 17].

F. Limitations and Directions for Future Research

Several limitations qualify interpretation. The study is confined to one district and uses a cross-sectional design, which constrains generalizability and causal inference. Self-reported engagement and preparation may involve response bias, despite validated scales; triangulation with teacher reports and observation would strengthen inferences. Cultural mediators—stigma, religious schooling patterns, rural isolation—were not examined in depth. Future research should: (i) employ longitudinal and mixed-methods designs to test sustainability and mechanisms; (ii) incorporate teacher-rated/observational measures; (iii) experimentally evaluate classroom acoustic adaptations and low-cost communication supports; and (iv) replicate across districts to establish external validity and policy relevance. Broader policy initiatives that target equitable device access and school-level supports (e.g., those emphasized by global education partners) remain especially pertinent to contexts like Bahawalpur.

VI. Conclusion

This study examined the combined influence of auditory processing, assistive device use, socio-economic status, communication and technological support, and fatigue on academic engagement and self-preparation among secondary school students with hearing impairments in Bahawalpur. The findings demonstrate that while hearing aids significantly enhance self-preparation and modestly improve engagement, the strongest predictors of educational outcomes are socio-economic conditions and access to communication supports. Fatigue consistently undermines both engagement and preparation, underscoring the importance of supportive classroom environments that reduce listening effort.

These results highlight that educational disparities are not simply the result of individual impairment but are largely shaped by systemic and environmental conditions. Ensuring equitable access to assistive technologies, strengthening peer and teacher support, and addressing socio-economic barriers can meaningfully improve outcomes for hearing-impaired learners. Schools should combine practical classroom adaptations with structured peer learning and device maintenance, while policymakers must prioritize subsidies, professional development, and infrastructure improvements to reduce inequities.

By adopting a systemic approach that integrates technological, pedagogical, and socio-economic supports, education systems can foster greater inclusion and engagement for hearing-impaired students. Such measures would not only strengthen academic preparation but also contribute to broader goals of equity and quality in education.

VII. Implications

For public schools in Bahawalpur, the study recommends three practical, low-cost interventions to support students with hearing impairments:

On-Site Hearing Aid Support: Establishing basic hearing aid maintenance and repair stations within selected partner schools—managed by trained existing staff—can address frequent device malfunctions, especially in under-resourced settings where professional services are inaccessible.

Peer-Assisted Learning Models: Implementing structured peer-assisted learning programs can harness the academic strengths of high-performing students to support hearing-impaired peers during collaborative tasks. This not only promotes social inclusion but also reinforces engagement and self-preparation.

Inclusive Pedagogical Training: Providing teachers with targeted training on simple, low-cost classroom adaptations—such as optimized seating arrangements, use of visual schedules, and minimizing background noise—can significantly enhance learning environments for hearing-impaired students without requiring advanced technologies.

These strategies are directly informed by this study's findings on socio-economic constraints, the impact of fatigue, and disparities in academic engagement. Their implementation would enable schools to make meaningful progress toward inclusive education within existing resource limitations.

This study has several important limitations. First, the sampling was confined to a single district (Bahawalpur), which may limit the generalizability of findings to other regions with different educational infrastructures and socio-economic contexts. Second, the reliance on self-reported data for academic engagement and self-preparation introduces the potential for response bias, particularly in students with communication barriers. Third, the study's cross-sectional design restricts the ability to draw causal inferences about the observed relationships among variables. Fourth, we ensured scale discriminant validity, future studies could include teacher-reported outcomes to reduce self-report bias. Fifth, while we also identified socio-economic and fatigue effects, our study could not fully capture nuanced cultural mediators (e.g., familial stigma, religious school pressures) due to the quantitative design. Future mixed-methods research should combine surveys with in-depth interviews to explore how traditional beliefs and practices modulate these relationships in Pakistan's unique context.

Based on these limitations and the study's findings, we offer the following recommendations:

Professional Development: Implement mandatory teacher training programs emphasizing inclusive pedagogy and basic troubleshooting of assistive hearing technologies, particularly in mainstream classrooms with hearing-impaired students.

Policy Reform: Enact policies that subsidize the maintenance and replacement of hearing aids and other assistive devices for students from low-income families. This recommendation is grounded in our finding that approximately 68% of reported device malfunctions occurred in under-resourced schools.

Infrastructure Investment: Improve school infrastructure to reduce environmental barriers (e.g., background noise, poor acoustics) that disproportionately affect students with hearing impairments.

These findings underscore that academic engagement disparities are not rooted in student deficits but are instead largely shaped by systemic and structural conditions. Therefore, targeted interventions at the institutional and policy levels can significantly enhance educational equity for hearing-impaired learners.

Overall, the study concludes that while auditory processing alone may offer limited predictive power for academic engagement, assistive devices can moderately improve self-preparation and to a lesser extent, academic engagement. The broader educational gap, however, appears to be more closely tied to effective communication tools, technological infrastructure, and favorable socio-economic conditions. These factors are critical in strengthening conceptual engagement among students with hearing impairments. Addressing fatigue and socio-economic disparities could play a key role in improving academic performance, particularly in developing countries. In this context, the Government of Pakistan has launched several initiatives for special education institutions, supported by funding agencies such as the Global Partnership for Education (GPE), UNICEF, the World Bank (WB), the European Commission, USAID, and various NGOs. These partnerships aim to enhance access to quality education for students with hearing impairments by providing necessary assistive devices and infrastructure. These findings advocate for a systemic and multifaceted approach to identifying and meeting the educational needs of students with hearing impairments, aligning with global priorities outlined in SDG 4 (Quality Education) and SDG 10 (Reduced Inequalities). Future research should employ longitudinal and mixed-methods designs across diverse regions to assess the sustainability of these interventions and to better understand cultural and contextual influences. Overall, the study emphasizes that inclusive educational outcomes for students with hearing impairments require systemic, low-cost, and context-sensitive solutions aligned with national priorities and global commitments to educational equity.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

M.A.A.A., W.M., K.I.M.A. & M.S.O.F. conducted the research; H.A.A.Q., M.T.S. & M.H.M.Y. analyzed the data; W.S.W.N., M.N.H.A. & R.A. wrote the paper; all authors had approved the final version.

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