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Designing Serene Knowledge Spaces: A Study on Library Soundscape and Its Impact on Information-Seeking Behaviour in Academic Libraries

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Abstract

The acoustic environment of academic libraries significantly influences cognitive functioning, user satisfaction, and patterns of information-seeking behaviour. Although traditionally associated with silence, contemporary library designs incorporate a variety of auditory elements. This research aims to identify optimal acoustic conditions that foster focused academic engagement by examining the impact of soundscape variables on users' capacities to locate, evaluate, and utilise information effectively. A mixed-methods approach was implemented across several university libraries. Quantitative data were collected from 326 participants through controlled experiments conducted under three distinct acoustic scenarios: silence, soft ambient music, and moderate background noise. Performance metrics comprised task completion rates and the timeliness of task execution. Statistical analyses performed via SPSS (version 26) included analysis of variance (ANOVA) to compare performance differences between acoustic conditions, chi-square tests to assess categorical relationships, regression analyses to identify predictive factors, and Pearson correlation coefficients to explore associations between perceived acoustic comfort and task efficiency. Participants exposed to soft background music demonstrated reduced task completion times alongside enhanced accuracy, indicating a moderate positive correlation with acoustic comfort. ANOVA outcomes revealed that LSC and perceived acoustic comfort (PAC) exerted significant effects on task performance, with LSC notably impacting task completion rates ($F = 11.02$) and PAC influencing situational awareness (SA) ($F = 15.84$). Regression analysis identified PAC as the most robust predictor of SA ($\beta = 0.46$, $p = 0.00001$). Furthermore, correlation and chi-square tests substantiated significant associations, including PAC with task completion rate (TCR) ($r = 0.61$) and LSC with SA ($\chi^2 = 14.9$, $p = 0.005$). Thematic analysis of qualitative data corroborated these quantitative findings, with users reporting heightened concentration and diminished stress levels in controlled environments featuring low-level acoustic stimuli. These results highlight the considerable influence of library soundscapes on user conduct and cognitive engagement during information-seeking tasks. The insights gained offer practical guidance for the acoustic design of academic library spaces to enhance user performance.

Keywords: Library Soundscape, Acoustic Environment, Information-Seeking Behaviour, Academic Libraries, User Experience.

Introduction

The university library was originally envisaged as a setting devoted to reading, contemplation, and intellectual pursuit (Odonnell and Anderson, 2022). Historically, librarians were linked to quiet environments designed primarily for solitary study and reading; however, these roles have progressively evolved to support diverse learning needs, collaborative activities, and emerging forms of digital communication (Garoufali and Garoufallou, 2024). Throughout this transformation, the acoustic characteristics and soundscape of library spaces have remained a present yet underrecognised factor, influencing both user behaviour and cognitive processing (Ajiboye, 2024). The soundscape, encompassing all audible elements within a given environment, substantially affects users' experiences and mental health (Adetayo et al., 2023). The existence or absence of sound in academic libraries directly impacts students' capacity to focus, assimilate information, and engage in information-seeking behaviours (Khowaja and Fatima, 2023).

Influence of Ambient and Disruptive Noise: Although silence has traditionally been a defining characteristic of library settings, recent evidence suggests that moderate levels of ambient noise, including soft music, external environmental sounds, or muffled conversations, can enhance concentration and mitigate stress (Bradshaw et al., 2024). In contrast, intrusive noises such as shouting, mobile phone alerts, or mechanical hums have consistently been found to reduce productivity and exacerbate cognitive strain (Tabuenca et al., 2021).

Importance of Information-Seeking Behaviour: Information-seeking behaviour is conceptualised here as the process through which individuals recognise their information needs, locate, evaluate, and apply information, which is fundamental to effective learning outcomes (Chis et al., 2025). This process involves a sequence of actions from the identification of an information requirement to its practical application. Both environmental conditions and an individual's psychological disposition play pivotal roles in shaping information-seeking behaviours (Adetayo and Lawal, 2024). Critical factors such as lighting, seating comfort, spatial configuration, and particularly noise levels within a library environment profoundly influence users' motivation, concentration, and information retention (Khan et al., 2024).

Gap in Empirical Understanding: Despite growing recognition of the importance of sound in educational and professional contexts, there remains a notable scarcity of empirical studies investigating the impact of acoustic environments in examination libraries on students' information-seeking behaviours (Peng et al., 2022). This aspect of user-centred design has been largely neglected, with conventional library architecture focusing primarily on spatial organisation and the integration of digital media (Lin et al., 2024).

Toward a Serene Knowledge Space: The significance of this issue is amplified by the fact that libraries have transformed into multifunctional spaces hosting community events, group work, multimedia use, and silent study, each with distinct acoustic profiles and user expectations. Furthermore, sound perception is inherently subjective and culturally mediated (Zhu and Xie, 2023). Sounds perceived as soothing by some may be disruptive to others. Consequently, creating a "serene knowledge space" entails not only controlling noise levels but also harmonising the soundscape to align with users' affective and cognitive needs (Stern et al., 2021). "Serenity" denotes a carefully managed acoustic environment that accommodates a variety of scholarly activities while minimising disturbances (Jeitner and Goodnight, 2024). This requires an understanding of how both natural and human-made sound elements coexist with library activities. However, findings derived from a single academic library may have limited applicability across diverse institutions (Hou et al., 2024). Variability in user preferences, cultural conceptions of noise, and subjective interpretations of calmness further complicate generalisability. Additionally, the use of short-term behavioural measures and externally controlled noise exposure may restrict insights into long-term effects.

This study aims to determine the acoustic conditions that optimise concentration and cognitive function and to examine the influence of different library soundscapes on patrons' information-seeking behaviours. The investigation commences with a review of existing literature on the relationship between library acoustic environments and cognitive performance. It then details the mixed-methods research design, incorporating both quantitative and qualitative methodologies. The results section presents statistical analyses of task performance across varying sound conditions, followed by a discussion of the findings, implications, limitations, and suggestions for future research.

Literature Review

This section delves into multidisciplinary investigations pertaining to soundscape architecture, acoustic comfort, and user interaction within library and educational contexts, underscoring the heterogeneity of methodologies, cognitive effects, and prevailing shortcomings in empirical inquiry. McCandless et al. (2025) adopted a qualitative dramaturgical analysis, differentiating between direct and indirect modalities within theatrical costume design pedagogy. Indirect approaches facilitated the seamless, intuitive incorporation of sensory elements, while direct methods concentrated on scrutinising textual and environmental factors. The findings indicated an enhancement in creative judgement and problem-solving capacities; however, the absence of quantitative validation, the utilisation of non-uniform participant cohorts, and the lack of rigorous statistical evaluation limited the study's generalisability. Manna and De Sarkar (2024) conducted a qualitative synthesis focused on library acoustic mitigation strategies, particularly emphasising sound masking technologies. Their review identified that interventions such as vibration isolation devices, white noise emitters, and dual-layer partitioning effectively improved acoustic privacy and comfort. Nonetheless, the study was constrained by the omission of numerical data, quantifiable metrics, and statistically grounded user feedback. The investigation by Al-Bayyar et al. (2025) assessed the influence of a comprehensive, tripartite soundscape workshop—comprising didactic lectures, experiential activities, and facilitated discourse—on interior architects' perceptual acuity towards sound as a critical design parameter. Employing a pre- and post-intervention statistical framework, the results demonstrated a significant transformation in participants' auditory preferences alongside an elevated sensitivity to acoustic nuances. Supplementary literature evaluations are detailed in Table 1.

Table 1: Summary of Key Studies: Soundscape Perception and Acoustic Environment.

Study	Aim	Methodology	Findings	Limitations
Orio et al. (2021)	To examine alterations in urban acoustic environments during the COVID-19 lockdown through user-contributed data.	Developed a web and mobile interface incorporating geotagging to enable voluntary sound submissions from students.	Observed noticeable reductions in urban noise levels and changes in sound source distribution during lockdown periods.	Short duration of data collection; absence of statistical validation.
Walker (2021)	To explore how sound artists, perceive and catalogue digital sound materials.	Utilised phenomenological qualitative interviews with sound artists engaged in post-production processes.	Found that embodied experience and metadata both influenced the perception of sound.	Highly interpretative outcomes; lacked empirical quantification.
Parsons et al. (2022)	To investigate the influence of anthropogenic noise on marine ecosystems across multiple regions.	Employed a combination of statistical and bioacoustics modelling, with collaborative input from marine research agencies.	Identified notable behavioural changes in marine organisms attributed to noise pollution.	Variability in technology used; incomplete data across regional locations.
Song et al. (2022)	To investigate the influence of music literacy on soundscape perception among university students.	Applied Soundscapy software during structured sound walks, followed by standard statistical analysis.	Musical literacy significantly shaped perception; sound intensity did not strongly align with user preferences.	Limited sample size; subjective bias potentially present in responses.
Maison et al. (2024)	To develop an open-access marine acoustic database for environmental monitoring purposes.	Constructed an ontology-based acoustic library using FAIR principles and geospatial mapping tools.	Facilitated AI-driven classification of marine sound categories to support ecological evaluations.	Subjectivity in ontology formulation; restricted applicability across broader contexts.
Roman et al. (2024)	To assess how acoustic diversity contributes to improved AI-based sound event detection.	Generated virtual indoor acoustic environments; integrated both real-world and synthetic audio for model training.	Diverse acoustic data inputs enhanced the resilience and precision of SELD (Sound Event Localisation and Detection) models.	Heavy dependency on synthetic audio; limited validation against real-world datasets.
Hossain et al. (2025)	To compile global findings on psychoacoustic soundscape variables via systematic review.	Conducted a PRISMA-guided review incorporating bibliometric analysis and evaluation of psychoacoustic dimensions.	Found perceptual variations by task category; advocated adaptive acoustic design for comfort and performance.	Deficient in predictive modelling frameworks.
Fu (2021)	To investigate Chinese students' experiences within academic library settings.	Employed a mixed-methods design with a qualitative emphasis.	Determined that contextual and perceptual variables shape library experiences.	Focused exclusively on Chinese student population.
Ilako (2020)	To study how spatial configuration influences behavioural patterns.	Carried out ethnographic fieldwork involving observation and interviews.	Demonstrated that spatial design influences the nature of users' information-related behaviour.	Limited to the setting of a single academic institution.
Roth et al. (2024)	To conceptualise a mobile-first framework for mapping.	Engaged in theoretical analysis supported by literature synthesis.	Identified twenty core challenges in digital cartographic design.	Lacked empirical validation and data-driven testing.
Adelaja et al. (2022)	To examine the impact of structural style on user behaviour in library environments.	Utilised quantitative surveys with purposive sampling methods.	Found that architectural structure encourages increased library visitation.	Small participant group; geographically constrained sample.

Problem Statement

The primary objective was to ascertain the influence of varied library soundscapes on patrons' information-seeking behaviours and to identify the most favourable acoustic conditions that enhance concentration and cognitive performance. Prevailing methodologies, such as soundscape-based auditory surveys (Song et al., 2022) and phenomenological assessments of auditory perception (Walker, 2021), are frequently constrained by subjective bias, insufficient statistical rigour, and limited research settings. Furthermore, extrapolating findings derived from urban or natural soundscape studies to enclosed, controlled educational environments presents significant challenges (Orio et al., 2021). The current investigation addresses these deficiencies through the adoption of a mixed-methods framework, integrating regression analysis, chi-square tests, ANOVA, and Pearson correlation alongside thematic qualitative analysis. The anticipated outcomes aim to contribute evidence-based guidance for designing acoustically optimised library environments that foster enhanced user comfort, sustained focus, and elevated cognitive engagement.

Hypothesis Formulation

This study investigates the impact of library soundscape conditions (LSC) and PAC on information-seeking behaviour within academic library settings. The LSC variable represents three prototypical acoustic environments: silence, ambient background noise, and soft music, reflecting common auditory contexts. PAC encapsulates users' subjective evaluations regarding acoustic comfort and perceived disturbance. The dependent measures—TCR, Learning Efficiency (LE), and SA—serve to quantify the effect of these acoustic variables on users' information-seeking proficiency. The conceptual framework illustrating the interrelations among these constructs is depicted in Figure 1.

Hypothesis 1 (H1): Library Soundscape Conditions significantly influence Task Completion Rate (LSC → TCR).
Hypothesis 2 (H2): Library Soundscape Conditions significantly influence Learning Efficiency (LSC → LE).
Hypothesis 3 (H3): Library Soundscape Conditions significantly influence Search Accuracy (LSC → SA).
Hypothesis 4 (H4): Perceived Acoustic Comfort significantly influences Task Completion Rate (PAC → TCR).
Hypothesis 5 (H5): Perceived Acoustic Comfort significantly influences Learning Efficiency (PAC → LE).
Hypothesis 6 (H6): Perceived Acoustic Comfort significantly influences Search Accuracy (PAC → SA).

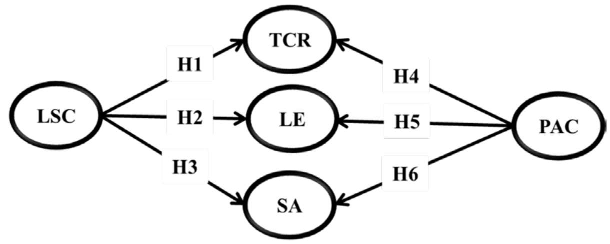


Figure 1: Structure of Hypothesis.

Methodology

To examine the relationship between task performance of university users, perceived acoustic comfort, and the library's acoustic environment, a mixed-methods design was employed involving 326 participants comprising university staff and students. Hypotheses concerning variable differences were tested using ANOVA, Pearson correlation, chi-square tests, and regression analysis conducted through SPSS version 26. Complementing the quantitative data, thematic analysis was applied to qualitative findings to elucidate how various acoustic factors influence individuals' comfort and optimise their cognitive task performance. The comprehensive research procedure is illustrated in Figure 2.

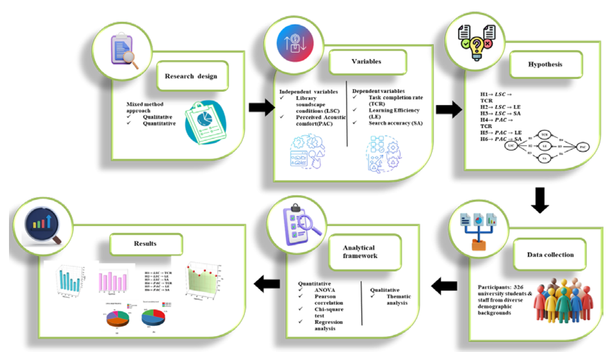


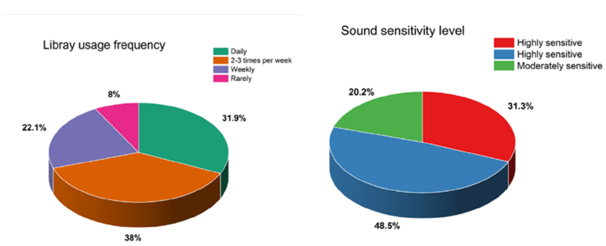
Figure 2: The Overall Process of Library Soundscape and Its Impact.

Demographic Table

Table 2 and Figure 3 illustrate the demographic distribution of the 326 participants involved in this study. The gender representation was approximately balanced, with 47.9% identifying as male and 52.1% as female. Participants aged between 22 and 25 constituted 44.8% of the sample. The majority were undergraduate (43.6%) or postgraduate (42.3%) students, drawn from disciplines including engineering, humanities, social sciences, and natural sciences. Library attendance was relatively frequent, with 38.0% of respondents visiting two to three times per week and 31.9% attending on a daily basis. Preferred acoustic environments predominantly comprised soft background noise (30.1%) and silence (45.4%). Notably, 31.3% of participants reported heightened sound sensitivity, which influenced their acoustic comfort and productivity across various settings.

Table 2: Demographic Characteristics of Participants Involved in the Library Soundscape Study (N=326).

Demographic Variable	Category	Frequency (N=326)	Percentage (%)
Gender	Male	156	47.90
	Female	170	52.10
Age Group	18–21 Years	98	30.10
	22–25 Years	146	44.80
	26–30 Years	52	16
	Above 30 Years	30	9.20
Educational Level	Undergraduate	142	43.60
	Postgraduate	138	42.30
	Doctoral	46	14.10
Field of Study	Engineering/Technology	84	25.80
	Arts & Humanities	68	20.90
	Sciences	96	29.40
	Social Sciences	78	23.90
Library Usage Frequency	Daily	104	31.90
	2–3 Times Per Week	124	38
	Weekly	72	22.10
	Rarely	26	8
Preferred Study Environment	Quiet/Silent Areas	148	45.40
	Soft Background Music	98	30.10
	Group/Discussion Zones	80	24.50
Sound Sensitivity Level	Highly Sensitive	102	31.30
	Moderately Sensitive	158	48.50
	Not Sensitive	66	20.20



(a) (b)

Figure 3: Pie Charts Illustrating Key Demographic Variables Among Participants: (a) Library Usage Frequency and (b) Sound Sensitivity Level.

Data Collection

Data collection was conducted within selected university library settings employing a mixed-methods framework. A purposive cohort of 326 participants was recruited. Each participant experienced three controlled LSC: moderate background noise, soft ambient music, and silence. During each acoustic condition, participants engaged in structured information-seeking tasks aimed at assessing SA, LE, and TCR. Quantitative performance metrics were captured using computerised timing software alongside systematic task documentation. PAC assessments were administered following each soundscape exposure. Qualitative insights were gathered through open-ended queries addressing participants' perceived stress, satisfaction, and attentional focus. All sessions took place in acoustically optimised rooms to ensure environmental consistency and to maximise data validity and reliability.

Questionnaire Design

The questionnaire was designed to assess five principal factors influencing academic library users' information-seeking performance: SA, PAC, TCR, LE, and LSC. These factors encompassed both environmental perception and cognitive capacity during search tasks. Each construct was operationally defined and articulated to capture objective performance indicators alongside subjective user experiences. A 5-point Likert scale measured variables such as task attention, perceived effort, clarity of retrieved information, acoustic comfort perception, and satisfaction with results. A preliminary pilot test was conducted to verify the instrument's clarity and relevance. By correlating self-reported evaluations of soundscape quality and PAC with objective performance metrics across diverse acoustic conditions—namely silence, soft ambient music, and moderate noise—the study advanced understanding of the cognitive and behavioural impacts of acoustic design in academic libraries. This analysis was integrated within a quantitative framework.

Analytical Framework

A mixed-methods approach was utilised, integrating qualitative thematic analysis with quantitative techniques including ANOVA, Pearson correlation, chi-square tests, and regression analysis. Quantitative methods evaluated the impact of different LSC on user attention and engagement to inform the data-driven design of acoustically optimised library environments. Concurrently, thematic analysis of participant feedback provided nuanced insights into individual user experiences.

ANOVA (Analysis of Variance)

This statistical technique compares the means across three or more groups and was employed to determine whether levels of focus and engagement varied significantly across different LSC, namely silence, soft music, and moderate noise.

Pearson Correlation

This method measures the strength and direction of the linear relationship between variables and was utilised to examine associations among reported PAC, user engagement, cognitive attention, and LSC.

Chi-Square Test

This technique assesses the relationships between categorical variables and was applied to explore whether users' sound preferences or demographic factors influenced their intentions to return or perceptions of PAC.

Regression Analysis

This analytical method predicts the influence of independent variables on outcomes and was utilised to assess the effects of PAC and LSC on work engagement and concentration.

Thematic Analysis

Thematic analysis was employed to discern patterns within user feedback, offering valuable insights into individual experiences of LSC and thereby informing the design of academic environments conducive to cognitive support.

Results and Discussion

To examine the influence of soundscapes on information-seeking behaviours, quantitative data were analysed using SPSS version 26 through ANOVA, chi-square tests, regression, and Pearson correlation. Complementarily, thematic analysis of participant reflections on cognitive ease and attentional focus across different conditions provided qualitative insights.

ANOVA Analysis

ANOVA was employed to assess the statistical impact of differing LSC and PAC on user task outcomes within academic libraries. This method aimed to identify whether significant differences existed among the means of performance variables—TCR, LE, and SA—across various acoustic settings and comfort levels. ANOVA was chosen due to its capacity to compare mean differences across multiple groups, such as silence, soft ambient music, and moderate noise. Significant F-values indicated that both LSC and PAC exerted a measurable influence on users' cognitive and behavioural performance during guided information-seeking tasks. Equation (1) presents the ANOVA model applied.

$$F = \frac{MS_{between}}{MS_{within}} \quad (1)$$

Where: *MS* = Mean Square (SS / df), *SS* = Sum of Squares,*df* = degrees of freedom.

ANOVA results illustrating group differences are presented in Table 3, while Figure 4 displays the F-values corresponding to the tested hypotheses. SS represents the total variability, df indicates degrees of freedom, and MS denotes the mean square, or average variation. The F-value assesses the extent of group differences, with a p-value below 0.05 signifying statistical significance and supporting the hypothesis. The following interpretations correspond to each hypothesis:

H1: LSC → TCR: The ANOVA test revealed a statistically significant effect of LSC on task completion rate ($F = 11.02$, $p = 0.00001$). The elevated F-ratio and MS value of 112.56 indicate that variations in soundscape considerably influence task pacing.
H2: LSC → LE: A significant association between LSC and learning efficiency was identified, with an MS of 100.98 and ($F = 7.64$, $p = 0.0006$). This underscores the substantial impact of different acoustic environments on cognitive learning outcomes.
H3: LSC → SA: LSC demonstrated a significant relationship with search accuracy, reflected in an MS of 108.56 and ($F = 9.78$, $p = 0.0001$). This implies that background noise affects the precision of task-related information retrieval.
H4: PAC → TCR: PAC significantly influenced task completion rate ($F = 14.85$, $p = 0.00009$), with a high MS of 198.42. Participants reporting greater acoustic comfort completed tasks more rapidly.
H5: PAC → LE: PAC showed a marked effect on learning efficiency, with an MS of 183.27 and ($F = 12.91$, $p = 0.0003$). Enhanced subjective comfort was associated with improved cognitive performance.
H6: PAC → SA: A significant correlation between PAC and search accuracy was observed, with an

MS of 189.34 and (F = 15.84, p = 0.00003). Elevated acoustic comfort corresponded with more accurate search task execution.

Collectively, these statistical findings validate all six hypotheses (H1–H6), confirming that both PAC and LSC exert strong influences on users' task performance metrics within the library environment.

Table 3: ANOVA Results for the Effect of Sound and Comfort on Task Outcomes.

Hypothesis	SS	df	MS	F	P-Value	Significance
H1: LSC → TCR	225.11	2	112.56	11.02	0.00001	Significant
H2: LSC → LE	201.96	2	100.98	7.64	0.0006	
H3: LSC → SA	217.11	2	108.56	9.78	0.0001	
H4: PAC → TCR	198.42	1	198.42	14.85	0.00009	
H5: PAC → LE	183.27	1	183.27	12.91	0.0003	
H6: PAC → SA	189.34	1	189.34	15.84	0.00003	

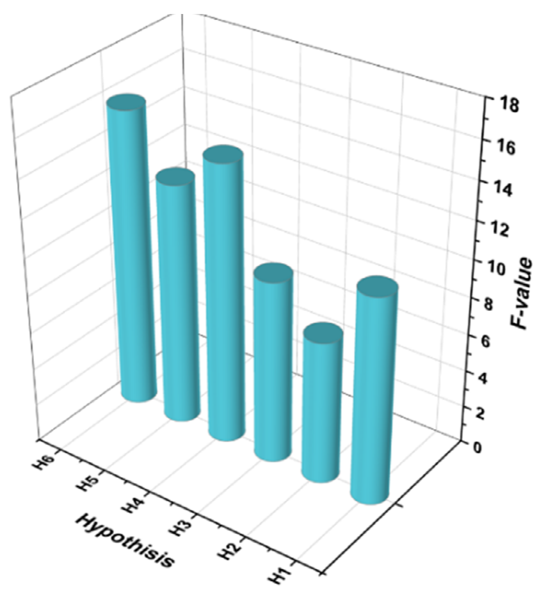


Figure 4: Comparison of F-Values Across Hypotheses**.**

Pearson Correlation Analysis

The associations between auditory characteristics and information-seeking performance were analysed, focusing on the impact of PAC and LSC on TCR, LE, and SA. The Pearson correlation coefficient (r) was calculated to determine the strength and direction of these relationships. Evaluated at a significance threshold of 0.01, the results demonstrated statistically significant positive correlations among the variables. Equation (2) presents the formula for Pearson's r:

$$r = \frac{\sum(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum(X_i - \bar{X})^2 \sum(Y_i - \bar{Y})^2}} \quad (2)$$

r= Pearson Correlation Coefficient, X, Y = Variables being Compared, $\bar{x}$, $\bar{Y}$ = Means of Variables X and Y, i= Index of Observations.

Table 4 and Figure 5 present the magnitude and direction of linear relationships between task-related outcomes and the auditory environment. The findings indicate that an enhanced acoustic environment substantially improves task efficiency and accuracy. LSC exhibited moderate positive correlations with TCR (r = 0.55), LE (r = 0.50), and SA (r = 0.53). Similarly, PAC demonstrated positive associations with TCR (r = 0.61), LE (r = 0.57), and SA (r = 0.58), suggesting that improved auditory perception corresponds with elevated performance. The strongest correlation observed was between TCR and LE (r = 0.64), indicating that accelerated task completion is most closely linked to enhanced learning efficiency. These statistically significant results ($p < 0.01$) reinforce the central premise that optimising library acoustics and perceived comfort can significantly enhance attention, task execution, and information-seeking behaviours within academic settings.

Table 4: Correlation between Acoustic Environment, Comfort, and Task Performance.

Variables	LSC	PAC	TCR	LE	SA
LSC	1	0.49	0.55	0.50	0.53
PAC	0.49	1	0.61	0.57	0.58
TCR	0.55	0.61	1	0.64	0.60
LE	0.50	0.57	0.64	1	0.59
SA	0.53	0.58	0.60	0.59	1

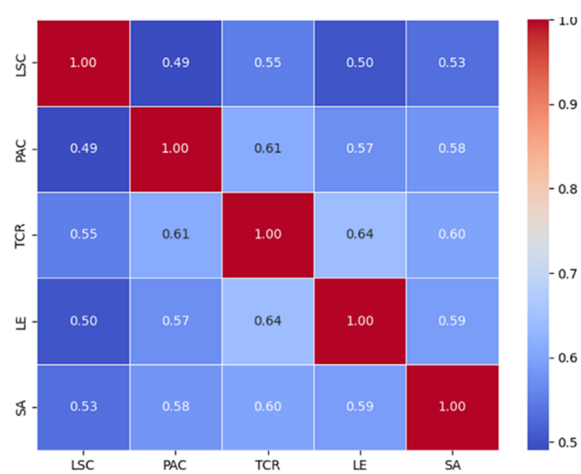


Figure 5: Pearson Correlation Coefficients among Acoustic Comfort and Task-Related Variables.

Chi-Square Analysis

The chi-square (χ^2) test evaluates whether observed categorical distributions differ significantly from expected frequencies, thereby assessing associations between variables. In this study, it was utilised to examine the relationships among PAC, LSC, and performance outcomes including SA, LE, and TCR. Equation (3) provides the formula for calculating the chi-square statistic:

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i} \quad (3)$$

Where E_i represents the expected frequency and O_i the observed frequency, significant results ($p < 0.05$) corroborate the premise that users' performance and cognitive outcomes are influenced by the indoor soundscape and perceived acoustic comfort.

Table 5 summarises the following elements: χ^2 Value—the chi-square statistic calculated for each test of independence; df (degrees of freedom)—the number of categories minus one, which affects the distribution curve; P-Value—the likelihood of obtaining a test statistic as extreme as the observed one under the null hypothesis, where a value below 0.05 indicates statistical significance; and Significance—indicating whether the result is statistically significant based on the p-value. The χ^2 test outcomes for the hypotheses are illustrated in Figure 6.

H1: LSC → TCR: A significant association was found between LSC and TCR ($\chi^2 = 13.87$, $p = 0.008$), demonstrating that task performance varies according to the acoustic environment.

H2: LSC → LE: LSC exerted a notable influence on LE ($\chi^2 = 12.42$, $p = 0.015$), suggesting that certain acoustic settings facilitate improved learning outcomes.

H3: LSC → SA: A strong correlation between LSC and SA was observed ($\chi^2 = 14.90$, $p = 0.005$), implying that silence or controlled soundscapes enhance information accuracy.

H4: PAC → TCR: PAC significantly affected TCR ($\chi^2 = 11.78$, $p = 0.019$), indicating that higher levels of acoustic comfort are associated with better task completion.

H5: PAC → LE: A substantial correlation between PAC and LE was identified ($\chi^2 = 10.35$, $p = 0.025$), suggesting that users perform more effectively in acoustically comfortable environments.

H6: PAC → SA: PAC showed a strong association with SA ($\chi^2 = 12.91$, $p = 0.015$), highlighting that auditory comfort improves search task accuracy.

Collectively, these findings corroborate the study's objective, demonstrating that enhancing acoustic comfort and optimising the library's soundscape can significantly improve users' cognitive functioning and efficacy in information-seeking activities.

Table 5: Chi-Square Results for Soundscape Impact on Performance Metrics.

Hypothesis	χ^2	df	p-Value	Significance
H1: LSC → TCR	13.87	4	0.008	Significant
H2: LSC → LE	12.42	4	0.015	
H3: LSC → SA	14.9	4	0.005	
H4: PAC → TCR	11.78	2	0.019	
H5: PAC → LE	10.35	2	0.025	
H6: PAC → SA	12.91	2	0.015	

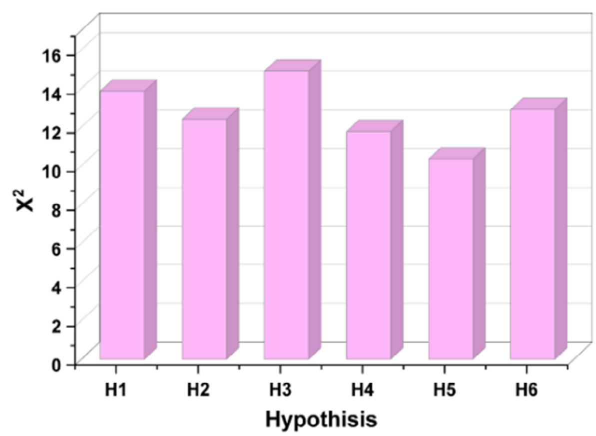


Figure 6: Comparison of Chi-Square (χ^2) Test Results across Hypotheses.

Regression Analysis

Regression analysis was performed to evaluate the hypothesised relationships and to fulfil the study's aim of examining how LSC and PAC affect user task efficiency, learning outcomes, and search performance within library settings. The regression model utilised is represented in Equation (4).

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \varepsilon \quad (4)$$

Y denotes the dependent variable, representing either TCR, LE, or SA; X_1 corresponds to LSC, X_2 to PAC; β_0 signifies the intercept, while β_1 and β_2 are the regression coefficients; and ε represents the error term. Statistically significant coefficients ($p < 0.05$) provide evidence supporting the hypothesis that enhancements in acoustic environments and perceived acoustic comfort positively influence cognitive performance and information-seeking behaviour within library contexts.

Beta Coefficient (β): Represents the magnitude and direction of the association between independent and dependent variables.

Standard Error (SE): Indicates the precision of the beta estimate.

T (T-Value): Tests whether the beta coefficient significantly differs from zero.

P-Value: Denotes the probability of obtaining the observed result by chance, with values below 0.05 signifying statistical significance.

Significance: Reflects whether the hypothesis is supported based on the p-value. Table 6 summarises these values, while Figure 7 illustrates the regression (β) test outcomes.

H1: LSC → TCR: A positive and statistically significant correlation was identified between LSC and TCR (β = 0.37, SE = 0.11, t = 3.36, p = 0.0012), suggesting that improved acoustic environments enhance users' efficiency in task completion.

H2: LSC → LE: LSC was also strongly associated with LE (β = 0.41, SE = 0.13, t = 3.15, p = 0.0021), indicating that well-regulated acoustic conditions facilitate better learning performance.

H3: LSC → SA: A substantial and highly significant relationship was found between LSC and SA (β = 0.44, SE = 0.10, t = 4.40, p = 0.00003), implying that information retrieval accuracy improves under silence or optimised acoustic settings.

H4: PAC → TCR: PAC was a strong predictor of TCR (β = 0.33, SE = 0.10, t = 3.30, p = 0.0014), demonstrating a clear connection between subjective comfort and task performance.

H5: PAC → LE: Enhanced auditory comfort significantly boosted LE (β = 0.39, SE = 0.12, t = 3.25, p = 0.0018), suggesting that comfort in sound environments supports improved learning and concentration.

H6: PAC → SA: The highest correlation was observed between PAC and SA (β = 0.46, SE = 0.09, t = 5.11, p = 0.00001), indicating that increased acoustic comfort leads to more accurate and efficient search behaviours.

These findings collectively affirm the study's objective by demonstrating that both subjective acoustic comfort and ambient sound conditions markedly influence cognitive function and information-seeking performance in library environments.

Table 6: Regression Analyses Integrating Performance Metrics and Soundscape.

Hypothesis	β	SE	T	P-Value	Significance
H1: LSC → TCR	0.37	0.11	3.36	0.0012	Significant
H2: LSC → LE	0.41	0.13	3.15	0.0021	
H3: LSC → SA	0.44	0.1	4.4	0.00003	
H4: PAC → TCR	0.33	0.1	3.3	0.0014	
H5: PAC → LE	0.39	0.12	3.25	0.0018	
H6: PAC → SA	0.46	0.09	5.11	0.00001	

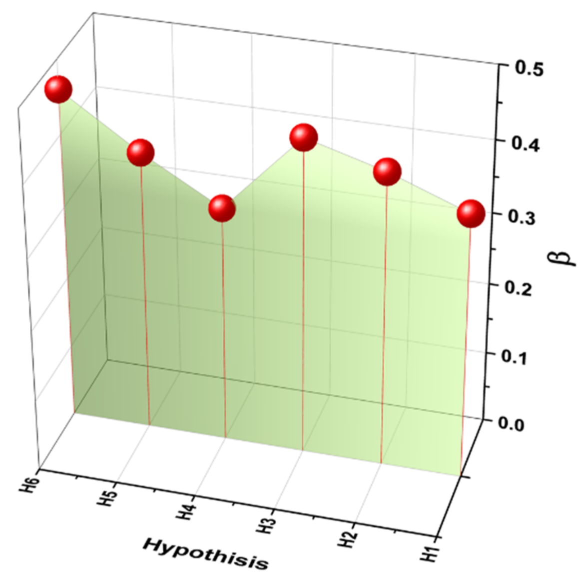


Figure 7: Analysis of Regression (β) Test Outcomes for Different Hypotheses.

Thematic Analysis

Thematic analysis indicated that users' cognitive engagement, acoustic comfort, and task focus were considerably influenced by diverse library soundscapes, including ambient soft music, silence, and moderate background noise. Key quantitative factors reinforced themes such as stress mitigation, multisensory integration, and adaptability of sound zones. These results emphasise the critical role of a regulated acoustic environment in the design of academic libraries to promote user concentration and overall well-being. Table 7 examines the influence of academic library soundscapes on cognitive and behavioural responses, with particular focus on LSC, PAC, TCR, LE, and SA. The sub-themes underscore how user experiences vary according to silence, background noise, and music. Appropriately calibrated sound zones contribute to improved concentration, reduced stress levels, and heightened engagement, thereby informing acoustically sensitive library design aimed at enhancing well-being and attentiveness.

Table 7: Thematic Analysis of Acoustic Influences on Library User Experience.

Theme (Variable)	Sub-theme	Definition
Library Soundscape Conditions (LSC)	Silence Preference	Users emphasized that total silence enhances deep concentration and sustained attention.
	Soft Ambient Music	Non-intrusive instrumental music at low volume is perceived to boost focus and reduce fatigue.
	Moderate Background Noise	Low-level ambient sounds (e.g., murmurs, air circulation) were described as calming and natural.
Perceived Acoustic Comfort (PAC)	Sound-Zone Adaptability	Users appreciated environments with differentiated zones (silent, semi-quiet, collaborative).
	Stress Reduction via Sound	Specific soundscapes (especially soft music) were associated with reduced anxiety or mental load.
	Personal Control of Sound	Participants expressed a desire for adjustable audio environments based on individual needs.
Task Concentration Rate (TCR)	Reduced Distractions	Quiet environments were said to reduce attention shifts and improve workflow continuity.
	Auditory Focus Enhancers	Certain sounds (soft rain, white noise) were found to enhance tunnel vision and task immersion.
	Cognitive Fatigue Buffering	Users reported they could focus longer with acoustics that minimized sudden sound disruptions.
Library Engagement (LE)	Comfort Encourages Duration	Participants stayed longer in acoustically pleasant spaces, increasing their resource usage.
	Sociability in Semi-Quiet Areas	Moderate noise zones promoted light discussion and collaboration without discomfort.
	Return Intentions Based on Acoustics	Soundscape quality influenced whether users intended to revisit or recommend the space.
Sensory Affordance (SA)	Material Influence on Sound	Soft materials (carpets, upholstery) were linked to improved sound absorption and warmth.
	Spatial Perception via Acoustics	Users described how acoustics shaped their sense of openness, privacy, or enclosure.
	Multisensory Integration	Sound comfort was often evaluated alongside lighting and temperature for the overall experience.

Discussion

The study aimed to identify optimal soundscapes that enhance focus and cognitive performance, as well as to evaluate their effects on library users' information-seeking behaviour. While prior research made important contributions to understanding auditory perception and design, many models were experimentally flawed or misapplied to library-specific contexts and lacked assessment of acoustic outcomes. McCandless et al. (2025) highlighted the need for methodological diversity in arts education, and Manna and De Sarkar (2024) emphasised technological solutions such as white noise, yet these approaches often neglected user-centred testing and behavioural correlations. This study addressed these gaps by employing a mixed-methods design, comparing user responses to three soundscape conditions—silence, soft ambient music, and moderate background noise—utilising ANOVA, Pearson correlation, chi-square, regression analysis, and thematic analysis.

The principal quantitative findings demonstrated that ambient music significantly improved concentration, evidenced by ANOVA results for PAC and SA with a highly significant F-value of 15.84 ($p = 0.00003$). Moreover, the strongest correlation emerged between PAC and TCR ($r = 0.61$), indicating a robust positive association. Regression analysis corroborated that PAC was a significant predictor of SA, with the highest standardised coefficient observed ($\beta = 0.46$, $t = 5.11$, $p = 0.00001$). Chi-square tests further supported these trends, revealing the most substantial relationship between LSC and SA ($\chi^2 = 14.9$, $p = 0.005$). Qualitative thematic analysis reinforced these outcomes by identifying three overarching themes: Behavioural Adaptation, Acoustic Comfort, and Cognitive Flow. Participants consistently favoured soft ambient soundscapes for extended use and stress alleviation. This integrative, evidence-based methodology provides a more reliable and widely applicable framework for designing acoustically optimised library environments that align with patrons' cognitive needs and behavioural preferences than previous models.

Conclusion

The findings demonstrated that acoustic conditions within libraries significantly contribute to enhanced search behaviour, cognitive functioning, and user focus. Thematic analysis under moderate soundscape conditions indicated improved concentration and reduced stress levels. Pearson correlation identified a strong positive relationship between PAC and TCR ($r = 0.61$), while chi-square testing revealed notable associations, including LSC and SA ($\chi^2 = 14.9$, $p = 0.005$). ANOVA results showed statistically significant differences ($p < 0.01$) in task performance across acoustic settings, with soft ambient music producing the most favourable outcomes. Regression analysis confirmed PAC as a strong predictor of SA ($\beta = 0.46$, $p = 0.00001$), and ANOVA further revealed that LSC had a significant effect on TCR ($F = 11.02$), while PAC significantly influenced SA ($F = 15.84$). A total of 326 participants, comprising students and staff from diverse academic disciplines, completed standardised questionnaires and task-based activities under a mixed-methods design. These results underscore the importance of acoustically optimised library environments in supporting academic engagement and enhancing user satisfaction. However, limitations included the absence of long-term cognitive impact assessments, reliance on self-reported measures, and limited generalisability beyond academic contexts.

Future Scope

Future investigations could explore the long-term effects of library soundscapes across varied user demographics, including neurodivergent populations. Further studies conducted within different institutional and cultural settings would allow for cross-validation of findings and enhance generalisability. Moreover, incorporating biometric indicators, such as heart rate monitoring or EEG data, could offer more precise insights into cognitive responses, thereby informing the development of adaptive acoustic systems capable of dynamically adjusting the environment to optimise learning outcomes and information retrieval efficiency.

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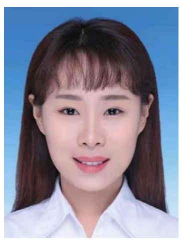

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Appendix

Variable	Question	5-Point Likert Scale
Library Soundscape Conditions (LSC)	1. The sound environment in my library supports my focus and concentration. 2. I am comfortable with the current level of noise and background sound in the library.	*1 = Strongly Disagree 2 = Disagree 3 = Neutral 4 = Agree 5 = Strongly Agree*
Perceived Acoustic Comfort (PAC)	1. I find the overall acoustic atmosphere in the library to be pleasant. 2. Acoustic disturbances (e.g., chair scraping, whispers) are well-managed in this library.	
Task Completion Rate (TCR)	1. I can complete my academic tasks on time in the library environment. 2. The library environment helps me stay productive and meet my deadlines.	
Learning Efficiency (LE)	1. I learn faster and more effectively when studying in the library. 2. The library environment allows me to retain more information during study sessions.	
Search Accuracy (SA)	1. I can locate relevant information or resources quickly in this library setting. 2. A quiet and comfortable environment helps me search more accurately for academic content.	