ORIGINAL

Nursing Students in an Urban Setting During the COVID-19 Pandemic : Investigating Stress, Stress Response, and Coping Patterns by Descriptive Analysis, Structural Equation Modeling, and Data Sonification

Joannes Paulus Tolentino Hernandez, DComm, MAN, RN, CHSE[1], Ramkumarie Baliram, PhD, MA[2], Sandy Carollo, PhD, RN, FNP-BC[3], and Juliet Baidoo-Kanneh, PhD[4]

[1]Associate Dean of Simulation and Associate Professor of Nursing, Helene Fuld College of Nursing, New York, New York, United States of America, [2]Assistant Dean for Humanities and Professor of Humanities (Full Professor), Helene Fuld College of Nursing, New York, New York, United States of America, [3]Special Advisor to the President and Former Provost and Executive Vice President, Helene Fuld College of Nursing, New York, New York, United States of America, [4]Associate Professor of Science, Helene Fuld College of Nursing, New York, New York, United States of America

Abstract : Background : The COVID-19 pandemic has significantly impacted nursing students in urban settings. Understanding stress and coping in this population is essential for developing effective interventions for future pandemics and post-pandemic nursing education. Aims : This study assesses the interactions between demographic variables and stress responses, demonstrating these relationships through data sonification. Methods : A cross-sectional analytical study was conducted at an urban nursing college, with 195 participants completing modified versions of the Perceived Stress Scale, Physio-Psycho-Social Response Scale, and Coping Behavior Inventory. Structural equation modeling and data sonification were employed for analysis. Results : Nursing students reported moderate stress from academic demands and clinical responsibilities, utilizing coping strategies such as problem-solving and optimism. Structural equation modeling indicated a significant negative relationship between coping skills and physio-psycho-social stress ($\beta = -0.301$, $p < .0001$) and a negative association between age and perceived stress ($\beta = -0.160$, $p = 0.035$). Data sonification revealed synchronization between perceived stress and stress responses, with coping efforts peaking slightly after stress levels. Discussion : While students employ effective coping strategies, targeted interventions are needed to enhance stress management, especially for younger students. Conclusion : Stress and coping among nursing students in urban settings are complex, with data sonification providing deeper insights. J. Med. Invest. 72 : 102-116, February, 2025

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INTRODUCTION

The COVID-19 pandemic has fundamentally transformed healthcare education, particularly for nursing students who face unprecedented challenges in both academic and clinical settings. While the pandemic has affected healthcare education globally, it can be posited that nursing students in urban settings have encountered unique stressors due to higher population density, increased exposure risks, and the concentration of COVID-19 cases in metropolitan areas. This context presents an urgent need to understand how nursing students navigate stress and develop coping mechanisms during such extraordinary circumstances.

Stressors disturb an individual's adaptive state and are well-documented in studies focused on nursing students (1, 2). Research suggests that nursing students' academic and clinical stress negatively impacts their overall wellbeing and performance (3, 4). Existing literature shows that nursing students experience varying degrees of stress during their training due to clinical, academic, and external factors (4, 5, 6). Academic stress among nursing students is linked to long study hours, a rigorous curriculum, heavy workloads, assignments, and examinations (7). While some students report consistent stress levels throughout their studies (8), others attribute their stress to the length of their program (5). Additionally, external factors such as living conditions, financial issues, relationships with peers and family (9), and challenges associated with urban nursing programs—like transportation, safety concerns, congestion, and noise—further exacerbate stress (8). Therefore, nurse educators should assess the causes and levels of stress in each program to develop effective interventions for student coping (10).

The COVID-19 pandemic has introduced additional layers of complexity to these stressors, including rapid transitions to remote learning, modified clinical experiences, and heightened anxiety about personal and family health risks. The urban setting, with its distinct socio-demographic characteristics and healthcare challenges, adds another crucial dimension to this stress-coping phenomenon that remains understudied in the current literature. Stress provokes coping responses (2, 11), which have been defined as thoughts and behaviors that are used in managing the internal and external demands of situations that are appraised as stressful (12). Current research supports that coping, problem-solving, and staying optimistic are common strategies in alleviating stress and helping students cope with the demands of the nursing program (13).

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Address correspondence and reprint requests to Dr. Joannes Paulus Tolentino Hernandez, Helene Fuld College of Nursing, 24 East 120th St., Room 404-17, New York, NY 10035, USA and Fax : +1 (212) 616-7297. E-mail : joannes.tolentinohernandez@helenefuld.edu ; jphernandezrn@gmail.com

Application of Data Sonification

Numerous studies have examined stress and coping among nursing students ; yet, a significant gap remains in understanding these phenomena. Traditional methods often overlook the dynamic interplay between stress, coping mechanisms, and environmental factors, especially during a global pandemic. Data sonification emerges as a novel methodological tool in this context, capable of capturing their temporal and multidimensional nature. An innovative dual-method approach involves combining structural equation modeling with data sonification to quantify the relationships between stress, coping, and academic outcomes while presenting these complex patterns in a more accessible and understandable format.

Data sonification, defined as the transformation of data into sound (14), offers significant advantages in nursing research, where it remains underutilized (14). This method effectively processes multiple variables (15), uncovers hidden patterns (16), and engages stakeholders with complex data (15, 17). By overcoming barriers to scientific literacy (18) and leveraging auditory sensitivity (18), sonification provides a compelling alternative to traditional visual representations, especially for temporal and multidimensional data (19).

Through sonification, we can discover the relationships between perceived stress, stress responses, and coping behaviors by mapping stress levels to pitch, encoding responses through rhythm, and representing coping strategies with distinct sound textures. This approach not only enhances data accessibility but also offers intuitive insights into complex relationships that are often obscured in conventional formats. Particularly relevant during the COVID-19 pandemic, sonification can reveal patterns of interacting stressors over time that may be overlooked in traditional analyses, ultimately contributing to a deeper understanding of the stress-coping phenomenon among nursing students.

Study Aims and Significance

The research aggregates the daily challenges faced by nursing students during the COVID-19 pandemic into "stress response patterns," defined as the interplay of perceived stress, stress responses, and coping behaviors. It addresses existing research gaps by examining the stress-coping relationship among urban nursing students during the COVID-19 pandemic. Specifically, the study aims to 1) assess the interactions between demographic variables and stress responses, and 2) demonstrate these relationships through data sonification.

Its significance includes illuminating the specific challenges faced by urban nursing students during the pandemic ; enhancing the understanding of effective coping strategies in high-stress healthcare education ; showcasing the value of data sonification in nursing education research ; and informing evidence-based interventions to support nursing students in crisis situations. By providing insight into how urban nursing students cope with stress in unprecedented circumstances, this research contributes to the literature and introduces innovative methodologies for studying these phenomena, with important implications for nursing education, student support services, and healthcare education research.

METHODS

Research Design/Setting/Participants

This cross-sectional analytical study was conducted at Helene Fuld College of Nursing (HFCN), an urban campus located in Harlem, New York. All participants were enrolled nursing students, and participation in the study was voluntary. A convenience sampling method was adopted, and the inclusion criteria for participation included : (a) registration in any pre-licensure nursing program at HFCN before the initial COVID-19 pandemic surge ; (b) active registration at the time of data collection ; and (c) willingness to consent to participate. A total of 249 responses were collected ; however, 195 samples had a higher completion rate for data processing.

Definition of Urban Setting

For the purposes of this study, the term "urban setting" refers to a college campus located in the city, characterized by the benefits of cultural diversity and off-campus learning experiences, as well as the challenges of increased distractions, including noise, congestion, and difficulties with commuting and parking.

Definition of Nursing Students

For the purposes of this study, the term "nursing students" refers to individuals who are training to become licensed registered nurses. This includes students with no prior nursing education, as well as those who have initiated the training process by first obtaining a license to practice as a Licensed Practical Nurse (LPN) and then advancing their education to obtain either an Associate in Applied Science (AAS) or a Bachelor of Science in Nursing (BSN) degree.

Target Setting Characteristics

Helene Fuld College of Nursing is a private, non-profit, single-purpose nursing college located in an urban setting in Harlem, New York. The college offers three programs : 1) Associate of Applied Science (AAS) for students who are already licensed as Licensed Practical Nurses (LPNs), 2) Generic Bachelor of Science (GBS) for students with no nursing background, and 3) RN to BSN for students who are licensed as Registered Nurses (RNs) but wish to obtain a Bachelor's degree. It is considered a commuter college, where students travel to school from home rather than live on campus. The college has a diverse student body, with a high number of African American and Hispanic students, and over 90% of students are eligible for federal financial aid. Many students are adult learners who face the additional challenges of balancing school with caring for children and/or aging parents, as well as employment. Academic progress and persistence, as well as successful passage of the licensing examination, were significantly impacted by COVID-19. The primary reason for conducting this research was to better understand how the college can support its students, specifically nursing students attending college in an urban setting, amid the additional stressors associated with COVID-19.

Data-Gathering Procedure

The survey was initiated through the Information Technology Department. Responses were collected via Qualtrics® XM from June 26, 2020, until May 3, 2022. Emails were sent to students containing the survey invitation, study consent, and a link to access the 15-minute self-administered online questionnaire. To ensure anonymity, neither names nor email addresses of respondents were requested. Data was accessible only to researchers. The storage, protection, and communication of all datasets were in compliance with school policy.

Research Instruments

Three questionnaires were revised to include "COVID-19" in some items and to remove specific items.

Modified Perceived Stress Scale (PSS)

The PSS by Sheu, Lin, and Hwang (20) measured stressors

and stress levels on a 5-point Likert-type scale. In this study, the instrument was modified (see Table 2) and consisted of 28 items grouped into 6 subscales, labeled as follows : "Stress from lack of professional knowledge and skills" (3 items) ; "Stress from assignments and workload" (6 items) ; "Stress from taking care of patients" (6 items) ; "Stress from the clinical environment" (5 items) ; "Stress from teachers and nursing staff" (5 items) ; and "Stress from peers and daily life" (3 items). Each item was rated as follows : 1 = Never, 2 = Almost Never, 3 = Sometimes, 4 = Fairly Often, and 5 = Very Often. Typically, both total scores and individual subscale scores were measured, with higher scores indicating a higher level of stress. The scaling for levels of stress by Engelbrecht (21) and Labrague (1) was modified as follows : 3.34 to 5.00 for High Stress ; 1.67 to 3.33 for Moderate Stress ; and 0 to 1.66 for Low Stress.

Modified Physio-Psycho-Social Response Scale (PPSRS)

The PPSRS by Sheu, Lin, and Hwang (20) described nursing students' responses to and emotions caused by stress in clinical practice (1). In this study, it measured the physio-psycho-social health status of students with the assumption of allostasis and allostatic overload (22, 23). It consisted of 22 items instead of 21. Each item was rated on a 5-point Likert-type scale : 1 = Never ; 2 = Almost Never ; 3 = Sometimes ; 4 = Fairly Often ; and 5 = Very Often. The items were divided into three subscales : "Physical symptoms" (8 items) ; "Emotional symptoms" (8 items) ; and "Social-behavioral symptoms" (6 items). A higher score indicated the presence of more serious symptoms and poorer physio-psycho-social health status. The scaling by Labrague (1) was modified as follows : 3.76 – 5.00 for Very High Stress Response ; 2.51 – 3.75 for High Stress Response ; 1.26 – 2.50 for Moderate Stress Response ; 0 – 1.25 for Low Stress Response ; and 0 – 0.62 for Very Low Stress Response.

Modified Coping Behavior Inventory (CBI)

The CBI by Sheu, Lin, and Hwang (20) was reduced to 15 items from 19, with 3 subscales instead of 4 : "Avoidance behaviors" (6 items), which described efforts to avoid stressful situations ; "Problem-solving behaviors" (4 items), which described efforts to deal with stressful situations ; and "Optimistic coping behaviors" (4 items), which described efforts to maintain a positive attitude despite stressful situations. These items were rated on a 5-point Likert-type scale : 1 = Never ; 2 = Almost Never ; 3 = Sometimes ; 4 = Fairly Often ; and 5 = Very Often. Important items were determined by the mean of each item per subscale. Additionally, the items were referenced from Ahmad, Alzayyat, and Al-Gamal (24). Scores were interpreted as follows : 0 – 1.66 for Low ; 1.67 – 3.33 for Moderate ; and 3.34 – 5.00 for High.

Ethical Considerations

This study was approved by the Institutional Review Board at the City University of New York (CUNY UI-IRB 2020-0280).

Data Analysis

Data analysis was conducted in Microsoft Visual Studio Code 1.91.0 using Python 3.11.3 libraries, including Pandas for data manipulation, NumPy for numerical operations, scikit-learn for preprocessing and imputation, Matplotlib and Seaborn for visualization of the correlogram (correlation matrix and heatmap), semopy for structural equation modeling, pydub for audio manipulation, MoviePy for video editing, FFmpeg for saving animations as MP4 files, and SciPy for audio processing.

Data Cleaning and Preparation

The process began with data cleaning, which included loading the dataset, selecting relevant columns, handling missing values, removing constant columns, and standardizing the data. Multiple imputation was performed using the "IterativeImputer" from scikit-learn (a machine learning library), followed by sensitivity analysis and factor analysis on the imputed datasets.

With a total of 249 responses, the missing data amounted to 26.97%, which is above the acceptable limit of 0.4% to 10% (25). Procedures for handling missing data were followed according to Khan (25) and Truong (26). Specifically, 54 student responses were excluded. Based on recommended best practices in research, the impact of non-response bias (also known as attrition bias) on data analysis can be reduced through multiple imputation (27). In this study, missing values were replaced using the available information from the survey tool responses of each nursing student through the expectation-maximization technique. The final sample consisted of 195 responses. Twenty-eight demographic variables (Table 1) and items from three survey tools (Tables 2 through 4) were analyzed descriptively and analytically.

On the other hand, the statistical analysis of missing data patterns in the stress study dataset indicates significant relationships between missing values and categorical variables. The PSS 10 variable (part of the Perceived Stress Scale) shows strong associations with Q10 Care Provider and Q7 Marital Status, with low p-values (< .001), suggesting that certain care providers or marital statuses correlate with higher rates of missing responses. Additionally, several COVID-19 status variables (Q25.1 to Q25.5) are significantly related to categorical variables ; for example, Q25.2 COVID-19 Status is linked to Q5 Age Group ($p = .0015$), and Q25.4 COVID-19 Status correlates with Q17 Employment Status ($p = .0162$), indicating that age and employment status may influence missing data. Other associations include links between COVID-19 status and nursing program, ethnicity, gender, and head of household status.

Sensitivity analyses assessed the impact of different missing data handling methods on the relationship between COVID-19 status and PSS 10 scores. Complete case analysis showed a coefficient of 2.0177 for COVID-positive individuals, while simple imputation indicated a slightly stronger effect at 2.1815, both statistically significant ($p < .001$). The confidence intervals overlapped, confirming consistency, and simple imputation yielded a smaller standard error (0.110 vs. 0.157) due to a larger sample size. Mean PSS 10 scores were similar across methods (approximately 2.02 for complete case analysis and 2.18 for imputation).

Factor analysis was performed to reduce the dimensionality of the data, which initially comprised 23 independent variables. Bartlett's Test of Sphericity confirmed that the correlation matrix was not an identity matrix (chi-square ranges from zero to infinity, $p < .05$), validating the use of factor analysis, while the Kaiser-Meyer-Olkin (KMO) test yielded a score of 0.823, indicating an adequate sample size. An initial factor analysis without rotation identified factors with eigenvalues greater than 1, followed by a varimax rotation for better interpretability, which extracted five factors that collectively explained 55.5% of the total variance.

Factor 1, "General Stress and Coping," encompasses a range of stress-related variables and coping mechanisms from the Perceived Stress Scale (PSS) and the Physio-Psycho-Social scale, reflecting feelings of being overwhelmed and strategies such as seeking emotional support. Factor 2 focuses on "Demographic and Socioeconomic Factors," including age, marital status, head of household status, and income, highlighting how these characteristics influence stress levels, particularly for those with greater responsibilities or lower income. Factor 3 addresses "Health and Substance Use," emphasizing the relationship between health behaviors, such as smoking and alcohol consumption, and

Table 1. Characteristics of the nursing student respondents ($n = 195$)

Demographical Factors	*n*	%
Nursing Programs		
Associate Degree	**162**	**83.1**
Generic Bachelor's Degree	32	16.4
RN to Bachelor's Degree	1	0.5
Age (Years)		
18 – 24	7	3.6
25 – 34	**99**	**50.8**
35 – 44	58	29.7
45 – 54	28	14.4
≥ 55	3	1.5
Gender		
Male	9	4.6
Female	**181**	**92.8**
Other	2	1.0
Prefer not to say	3	1.5
Marital Status		
Single (never married)	**97**	**49.7**
Married	67	34.4
Domestic Partnership	9	4.6
Divorced	22	11.3
Head of Household		
Yes	**133**	**68.2**
No	62	31.8
Annual Income		
< $15,000	4	2.1
$15,000 – $40,000	46	23.6
$40,000 – $70,000	**91**	**46.7**
$70,000 – $100,000	40	20.5
> $100,000	14	7.2
Caregiver role		
Yourself	63	32.3
Child/Children	49	25.1
Spouse	1	0.5
Parents	7	3.6
More than one	**75**	**38.5**
Ethnicity		
White	31	15.9
Hispanic or Latino	35	17.9
Black or African American	**106**	**54.4**
American Indian or Alaskan Native	1	0.5
Asian	5	2.6
Native Hawaiian or Pacific Islander	1	0.5
Other	16	8.2
First to go to college		
Yes	62	31.8
No	**133**	**68.2**
Attending night classes		
Yes	86	44.1
No	**109**	**55.9**
Enrolled in nursing courses		
Yes	**166**	**85.1**
No	29	14.9
Hours for study		
< 5	9	4.6
5 – 10	**64**	**32.8**
10 – 15	48	24.6
15 – 20	34	17.4
> 20	40	20.5
Hours for sleep		
< 6	**144**	**73.8**
6 – 8	50	25.6
8 – 10	1	0.5

Demographical Factors	*n*	%
Employment		
Unemployed not looking for work	11	5.6
Unemployed looking for work	11	5.6
Self-Employed	4	2.0
Retired	1	0.5
Employed Part-Time	53	27.2
Employed Full-Time	**115**	**59.0**
Hours of commute		
< 1	35	17.9
1 – 2	**138**	**70.8**
> 2	22	11.3
Type of commute		
Private Transportation	91	46.7
Public Transportation	**104**	**53.3**
Smoking		
Yes	10	5.1
No	**185**	**94.9**
Drinking alcohol		
Never	44	22.6
Socially/Occasionally	**127**	**65.1**
1 to 3 times per week	16	8.2
More than 3 times per week	7	3.6
Daily	1	0.5
Use of recreational drugs		
Never	**188**	**96.4**
Socially/Occasionally	4	2.1
1 to 3 times per week	1	0.5
More than 3 times per week	0	0.0
Daily	2	1.0
Use of Rx medications		
Never	**159**	**81.5**
As needed (PRN)	25	12.8
1 to 3 times per week	1	0.5
More than 3 times per week	1	0.5
Daily	9	4.6
Use of mood-altering substance		
Decreased	30	15.4
Remained the same	76	39.0
Increased	**89**	**45.6**
Tested positive for COVID-19		
Yes	51	26.2
No	**144**	**73.8**
Family member has COVID-19		
Yes	58	29.7
No	**137**	**70.3**
Friend has COVID-19		
Yes	37	19.0
No	**158**	**81.0**
Patient has COVID-19		
Yes	86	44.1
No	**109**	**55.9**
Never affected by COVID-19		
Yes	15	7.7
No	**180**	**92.3**
Have missed work/Off sick		
Never	**78**	**40.0**
Less than 1 week	14	7.2
Between 1 to 2 weeks	39	20.0
Between 2 to 3 weeks	20	10.3
4 weeks or more	44	22.6
Suffered financial loss		
Yes	**133**	**68.2**
No	62	31.8

Table 2. Item ratings on the Modified Perceived Stress Scale (n = 195)

Subscale	Mean		*SD*	Interpretation	Cronbach's α
Stress from lack of professional knowledge and skills	**2.30**	**±**	**0.88**	**Moderate Stress**	.889
1. Unfamiliar with medical history and terms.	2.21	±	0.96	Moderate Stress	.892
2. Unfamiliar with professional nursing skills.	2.31	±	0.99	Moderate Stress	.822
3. Unfamiliar with patient's diagnoses and treatments.	2.38	±	0.97	Moderate Stress	.810
Stress from assignments and workload	**3.34**	**±**	**0.88**	**High Stress**	.834
4. Worry about poor grades.	4.08	±	1.02	**High Stress**	.817
5. Pressure from the nature and quality of clinical practice.	3.36	±	1.24	**High Stress**	.819
6. Feelings that performance does not meet teachers' expectations.	3.29	±	1.22	Moderate Stress	.796
7. Feelings that dull and inflexible clinical practice affect family/social life.	3.19	±	1.28	Moderate Stress	.795
8. Feelings that the demands of clinical practice exceed physical and emotional endurance.	3.03	±	1.19	Moderate Stress	.802
9. Pressure from understanding and applying foundational course work (math, science, and humanities).	3.08	±	1.21	Moderate Stress	.813
Stress from taking care of patients	**2.40**	**±**	**0.85**	**Moderate Stress**	.885
10. Lack of experience and ability in providing nursing care and in making judgments.	2.51	±	1.11	Moderate Stress	.858
11. Not knowing how to help patients with physio-psycho-social problems.	2.54	±	1.05	Moderate Stress	.867
12. Unable to reach expectations.	2.65	±	1.14	Moderate Stress	.882
13. Unable to provide appropriate responses to doctors', instructors' and patients' questions.	2.36	±	1.01	Moderate Stress	.854
14. Not knowing how to communicate with patients.	2.02	±	0.97	Moderate Stress	.869
15. Difficulties in changing from the role of a student to that of a nurse.	2.29	±	1.09	Moderate Stress	.861
Stress from the clinical environment	**2.97**	**±**	**0.92**	**Moderate Stress**	.817
16. Feelings of stress in the environment where clinical practice takes place.	2.81	±	1.22	Moderate Stress	.762
17. Unfamiliarity with ward facilities.	3.55	±	1.30	**High Stress**	.817
18. Feelings of stress from rapid changes in patient's conditions.	2.64	±	1.18	Moderate Stress	.770
19. Feelings of stress due to a gap between theory in lectures and real situations in the clinical practice.	2.84	±	1.06	Moderate Stress	.790
20. Feelings of increased stress in the environment where clinical practice takes place during the COVID-19 outbreak.	3.00	±	1.30	Moderate Stress	.766
Stress from teachers and nursing staff	**2.89**	**±**	**0.93**	**Moderate Stress**	.833
21. Not knowing how to discuss a patient's illness with teachers or medical and nursing personnel.	2.30	±	1.00	Moderate Stress	.829
22. Feelings of stress when a teacher's instructions are different from expectations.	3.42	±	1.22	**High Stress**	.768
23. Medical personnel lacking empathy and willingness to help.	3.00	±	1.24	Moderate Stress	.818
24. Feelings that teachers do not evaluate students fairly.	2.79	±	1.21	Moderate Stress	.783
25. Lack of care and guidance from teachers.	2.95	±	1.30	Moderate Stress	.793
Stress from peers and daily life	**2.37**	**±**	**0.91**	**Moderate Stress**	.702
26. Experience of competition from peers in school and clinical practice.	2.57	±	1.17	Moderate Stress	.524
27. Feelings of pressure from teachers who evaluate students' performance by comparison.	2.78	±	1.32	Moderate Stress	.568
28. Inability to get along with group peers.	1.74	±	0.94	Moderate Stress	.702
Overall	**2.77**	**±**	**0.69**	**Moderate Stress**	**.835**

Note. 0 – 1.66, Low Stress ; 1.67 – 3.33, Moderate Stress ; 3.34 – 5.00, High Stress

Table 3. Item ratings on the Modified Physio-Psycho-Social Response Scale (n = 195)

Subscale	Mean	*SD*	Interpretation	Cronbach's α
Emotional symptoms	**2.67**	**0.95**	**High Stress Response**	.924
1. I tend to be worried and nervous.	3.17	1.08	**High Stress Response**	.912
2. I tend to be nervous and anxious.	3.16	1.10	**High Stress Response**	.911
3. I tend to be more nervous and anxious during the COVID-19 outbreak.	3.26	1.20	**High Stress Response**	.931
4. I often feel depressed and miserable.	2.42	1.18	Moderate Stress Response	.912
5. I feel afraid without any reason.	2.02	1.08	Moderate Stress Response	.912
6. I feel I am going to have a nervous breakdown.	2.25	1.27	Moderate Stress Response	.912
7. I feel more anxious lately.	3.03	1.30	**High Stress Response**	.912
8. I cannot calm down.	2.07	1.16	Moderate Stress Response	.909
Social-behavioral symptoms	**2.10**	**0.95**	**Moderate Stress Response**	.869
9. I am not optimistic about my future.	2.00	1.23	Moderate Stress Response	.855
10. My life is not very colorful.	1.95	1.15	Moderate Stress Response	.839
11. I cannot work as usual.	2.18	1.29	Moderate Stress Response	.857
12. I have difficulty in making decisions.	2.10	1.16	Moderate Stress Response	.855
13. I do not feel needed or valued.	2.04	1.25	Moderate Stress Response	.841
14. I cannot think as clearly as before.	2.32	1.24	Moderate Stress Response	.835
Physical symptoms	**1.76**	**0.76**	**Moderate Stress Response**	.895
15. I often feel giddy.	1.90	0.95	Moderate Stress Response	.893
16. I experience nausea and vomiting.	1.72	1.02	Moderate Stress Response	.876
17. I often have vertigo and feel dizzy.	1.76	0.99	Moderate Stress Response	.881
18. I feel pressure in the chest.	1.83	1.07	Moderate Stress Response	.876
19. My fingers and toes feel numb or painful.	1.67	0.93	Moderate Stress Response	.891
20. I have stomach ache and diarrhea.	1.87	1.08	Moderate Stress Response	.879
21. I have difficulties for no reason.	1.69	1.00	Moderate Stress Response	.872
22. I catch cold more often.	1.64	0.94	Moderate Stress Response	.887
Overall	**2.18**	**0.80**	**Moderate Stress Response**	**.898**

Note. 3.76 – 5.00, Very High Stress Response ; 2.51 – 3.75, High Stress Response ; 1.26 – 2.50, Moderate Stress Response ; 0.63 – 1.25, Low Stress Response ; 0 – 0.62, Very Low Stress Response

Table 4. Item ratings on the Modified Coping Behavior Inventory (n = 195)

Subscale	Mean	*SD*	Interpretation	Cronbach's α
Avoidance behaviors	**1.67**	**0.64**	**Low**	.771
1. To avoid duties during clinical practice.	1.56	0.86	Low	.739
2. To avoid teachers.	1.66	0.98	Low	.731
3. To quarrel with others and lose temper.	1.51	0.82	Low	.714
4. To expect miracles so one does not have to face difficulties.	1.61	0.93	Low	.711
5. To expect others to solve the problem.	1.48	0.76	Low	.733
6. To attribute to fate.	2.20	1.21	Moderate	.797
Problem-solving behaviors	**3.71**	**0.84**	**High**	.876
7. To adopt different strategies to solve problems.	3.66	0.95	**High**	.857
8. To set up objectives to solve problems.	3.62	0.96	**High**	.806
9. To make plans, list priorities, and solve stressful events.	3.89	0.97	**High**	.834
10. To have confidence in performing as well as senior schoolmates.	3.68	1.05	**High**	.864
Optimistic coping behaviors	**3.35**	**0.63**	**High**	.522
11. To keep a positive attitude in dealing with life events.	3.93	0.97	**High**	.397
12. To see things objectively.	3.80	0.93	**High**	.422
13. To have confidence in overcoming difficulties.	3.90	0.97	**High**	.375
14. To cry, feel moody, sad and helpless.	2.48	1.19	Moderate	.580
15. To cry, feel moody, sad and helpless during the COVID-19 outbreak.	2.64	1.29	Moderate	.543
Overall	**2.78**	**0.49**	**Moderate**	**.756**

Note. 0 – 1.66, Low ; 1.67 – 3.33, Moderate ; 3.34 – 5.00, High

stress, suggesting that these may serve as coping mechanisms. Factor 4 captures the "COVID-19 Impact," including variables like pandemic status and financial strain, underscoring the significant influence of the pandemic on stress levels. Finally, Factor 5 relates to "Academic and Employment Stress," incorporating factors such as nursing course load, study hours, and employment status, which illustrate the stress from balancing academic and work commitments.

Descriptive Statistics

Descriptive statistics include frequency, mean, and standard deviation (*SD*).

Inferential Statistics

The Shapiro-Wilk test (*W*) was selected to assess the normality of the sample distribution, specifically when the *p*-value is greater than .05. The multivariate assessment of normality and outliers was conducted in accordance with Purwaningsih *et al*. (28). The Mahalanobis *d*-squared values of the data ranged from 28.519 to 96.526 ; since this range is below the chi-square value of 643.781, it indicates that no outliers exist. Conversely, if the critical ratio (CR) of skewness lies outside the range of -3.29 to +3.29 (29), the data is considered skewed. A *p*-value of ≤ .001 in the context of structural equation modeling (SEM) was deemed statistically significant. Cronbach's alpha (α) was employed to measure the internal consistency of the modified research instruments.

SEM was defined and fitted, with results saved as CSV (comma-separated values) and TXT (text) files. Correlation analysis produced a correlation matrix, which was visualized using heatmaps and pair plots. Strong associations were defined as factor loadings with absolute values greater than 0.4, and communalities above 0.5 indicated good representation by the factors. Variables with high loadings and communalities were selected for structural equation modeling (SEM), confirming the suitability of factor analysis and identifying key variables for further analysis. Factor 1 is strongly associated with physiological and psychosocial aspects, featuring high loadings from variables such as Physio-Psycho-Social 8 (0.7754) and Physio-Psycho-Social 4 (0.7507), indicating their significance in the dataset. Factor 2 emphasizes coping strategies, with strong negative associations from items like Coping 11 (-0.7454) and Coping 12 (-0.7326), highlighting their role in stress management. Factor 3 relates to perceived stress, evidenced by variables such as PSS 4 (-0.5455) and PSS 3 (-0.5266), while Factor 4 also addresses perceived stress with different items like PSS 25 (0.3975) and PSS 29 (0.3888), underscoring the complexity of stress perception. Factor 5 combines perceived stress with other variables, including PSS 29 (-0.3905) and Q10 Care Provider (0.3817), suggesting additional influences on stress. Factor 1 accounts for 59.85% of the variance, while Factors 2 and 3 explain approximately 14% and 12%, respectively, with Factors 4 and 5 contributing 7.35% and 6.73%.

The power analysis for the stress study among nursing students assessed the adequacy of the sample size for SEM, using gender as a grouping variable and the first item of the PSS 1 as the outcome measure. This analysis yielded an effect size of 0.5453, indicating a moderate group difference according to Cohen's guidelines. With a desired statistical power of 0.8 and a significance level of 0.05, a sample size of 54 participants per group (totaling 108) was recommended ; however, the current dataset of 249 participants significantly exceeds this requirement, enhancing statistical power and the likelihood of detecting true effects. This confirms that the sample size is sufficient for SEM.

The default model was tested for different fit indices. However, maximum likelihood (ML) bootstrapping was considered as a method to help the model fit the non-normal data (30). Structural equation modeling was conducted with 4,880 bootstraps. In other words, estimates were generated 4,880 times—each time with a slightly different sample drawn randomly (resampling) with replacement (31). The measurement accuracy and reliability of sample estimates (32) in the structural equation model can be asserted. Reference values from Ertaş *et al*. (33), Dash and Paul (34), and Cho *et al*. (35) were used for the model fit indices.

Data Sonification

The digital audio compression codec used is Advanced Audio Coding (AAC). The chosen frequency range of 200-2000 Hz is particularly effective for several reasons. Firstly, human hearing sensitivity is highest between 2000-5000 Hz, and the selected range falls within the optimal speech perception range, making it audible for data sonification. Additionally, human frequency discrimination, measured as the Just Noticeable Difference (JND), is approximately $\Delta f/f \approx 0.003$ (0.3%), which allows for a clear distinction between different intensity levels within this range. Furthermore, the human auditory temporal resolution is around 2-3 milliseconds, and the segment duration within this frequency range allows for distinct perception of sequential tones, enhancing overall auditory clarity.

Audacity 3.4.2 was used to acquire sound intensities in decibels (dB). The nonparametric Welch method was applied to reduce variance in estimating the power spectral density (36), and cube root autocorrelation was selected to reveal correlated 'key frequencies' (sound peaks) (37). Through parameter mapping in data sonification, data dimensions are systematically mapped to sound parameters, as defined by Scaletti in 2018 (14), to achieve timbre changes (as recommended in the literature, rather than pitch) due to the sensitivity of the auditory system (18). However, later in the process, the data were normalized to frequency ranges on which the animations and audio files were based. These were combined with video, and stress phases were defined and visualized through sound analysis.

RESULTS

Participants

One hundred ninety-five participant samples were selected for this study. Each participant elected to complete all three surveys. Demographic characteristics are presented in Table 1. The majority of participants were enrolled in the Associate program (83.1%), aged 25-34 (50.8%), female (92.8%), single (49.7%), and African American (54.4%). Additional noteworthy characteristics include being recognized as head of household (68.2%), enrolled in clinical nursing courses (85.1%), getting less than 6 hours of sleep (73.8%), employed full-time (59%), commuting for 1 to 2 hours (70.8%) using public transportation (53.3%), using mood-altering substances (45.6%), and experiencing financial loss (68.2%).

Instrument Reliability

The interpretation of Cronbach's α was referenced from Arof, Ismail, and Saleh (38) as follows : > 0.90, Excellent ; 0.80 to 0.89, Good ; 0.70 to 0.79, Acceptable ; 0.60 to 0.69, Questionable ; 0.50 to 0.59, Poor ; and < 0.50, Unacceptable. The pilot test ($n = 97$) demonstrated strong internal consistency for all three modified scales—PSS, PPSR, and CBI—with overall Cronbach's α values of 0.962, 0.953, and 0.777, respectively, and individual item values for PSS and PPSR ranging from 0.960 to 0.963 and 0.949 to 0.953, respectively, suggesting that these scales are well-constructed and reliable. However, the actual survey responses ($n = 195$) revealed a more varied picture for the PSS scale, with

an overall Cronbach's α of 0.835 and individual item values ranging from 0.524 to 0.892, indicating that items Q26 (0.524) and Q27 (0.568) may need to be removed due to lower reliability. The PPSR scale maintained strong reliability with an overall Cronbach's α of 0.898, and individual item values between 0.835 and 0.931, all above 0.8. In contrast, the CBI scale presented issues, with item values ranging from 0.375 to 0.864 ; items Q11 (0.397), Q12 (0.422), and Q13 (0.375) were notably less reliable and should be considered for removal. The internal consistency reliability of the PSS, PPSR, and CBI was not far from those reported by Sheu, Lin, and Hwang (20), Labrague (1), Engelbrecht (21), and Ahmad, Alzayyat, and Al-Gamal (24), respectively.

Findings from the online surveys among nursing student respondents

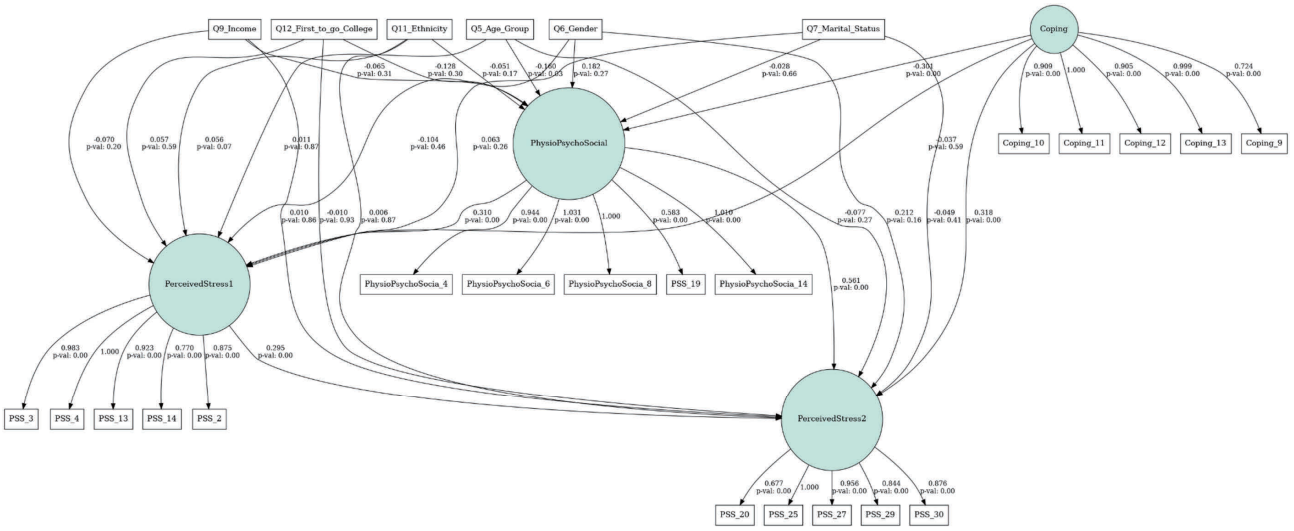
From the modified PSS, it was revealed that the primary source of stress for participants was "stress from assignments and workload," with moderate overall stress levels. Specific high-stress factors included "worry about grades," "pressure from the nature and quality of clinical practice," "unfamiliarity with ward facilities," and "feelings of stress when a teacher's instructions differ from expectations" (see Table 2). The modified PPSR indicated a moderate stress response, with emotional symptoms being the most prominent, particularly during the COVID-19 outbreak, as participants reported increased worry and anxiety, such as "I tend to be worried and nervous," "I tend to be nervous and anxious," "I tend to be more nervous and anxious during the COVID-19 outbreak," and "I feel more anxious lately" (see Table 3). Lastly, the modified CBI showed that participants generally employed moderate coping behaviors, with low reliance on avoidance strategies, except "to attribute to fate". High scores in problem-solving behaviors ("to adopt different strategies to solve problems," "to set objectives to solve problems," "to make plans, list priorities, and address stressful events," and "to have confidence in performing as well as senior schoolmates") and optimistic coping behaviors ("to keep a positive attitude in dealing with life events," "to see things objectively," and "to have confidence in overcoming difficulties") were noted (see Table 4).

Findings from the Structural Equation Modeling

In Figure 1, there is a statistically significant negative association between coping mechanisms and physio-psycho-social stress (β = -0.301, $p < .001$), suggesting that better coping skills lead to lower stress levels. Age also shows a significant negative relationship with stress (β = -0.160, $p = .035$), indicating that older participants report less stress. Although the model suggests a positive relationship between gender and stress (β = 0.182), it is not statistically significant ($p = .268$). Other demographic factors, such as marital status and income, did not show significant relationships with stress. The model's fit suggests room for improvement, with a Chi-square value of 1015.32 ($p < .001$) indicating a significant difference between the observed and model-implied covariance matrices. The Comparative Fit Index (CFI) of 0.804 and the Root Mean Square Error of Approximation (RMSEA) of 0.101 indicate a mediocre fit, suggesting that the relationships among the variables have not been fully captured. This limitation reflects the need for further investigation.

Findings from the Correlation Analysis

The data reveals a general trend of positive correlations among all variables, indicating that as perceived stress increases, physio-psycho-social responses and coping mechanisms also intensify (Figures 2.1 and 2.2). Interestingly, the strongest correlation is between perceived stress and physio-psycho-social responses ($r = 0.98$), indicating a close link between stress levels and physiological, psychological, and social impacts (Figure 2.2). Similarly, the strong correlation between perceived stress and coping ($r = 0.94$) suggests that higher stress prompts more frequent use of coping strategies, while the physio-psycho-social responses and coping relationship ($r = 0.89$) demonstrates the



Note : The diagram is a structural equation model with demographic variables (income, college status, ethnicity, age, gender, marital status) influencing latent variables ("PhysioPsychoSocial," "PerceivedStress1," "Coping," "PerceivedStress2"). Observed variables serve as indicators for these latent constructs. Relationships are shown with arrows indicating strength and direction, along with *p*-values for significance. Demographics affect "PhysioPsychoSocial" and "PerceivedStress1," while both influence their indicators and "PerceivedStress2," which also connects to its own indicators.

Fig 1. A structural equation model from the survey response tools used in the study

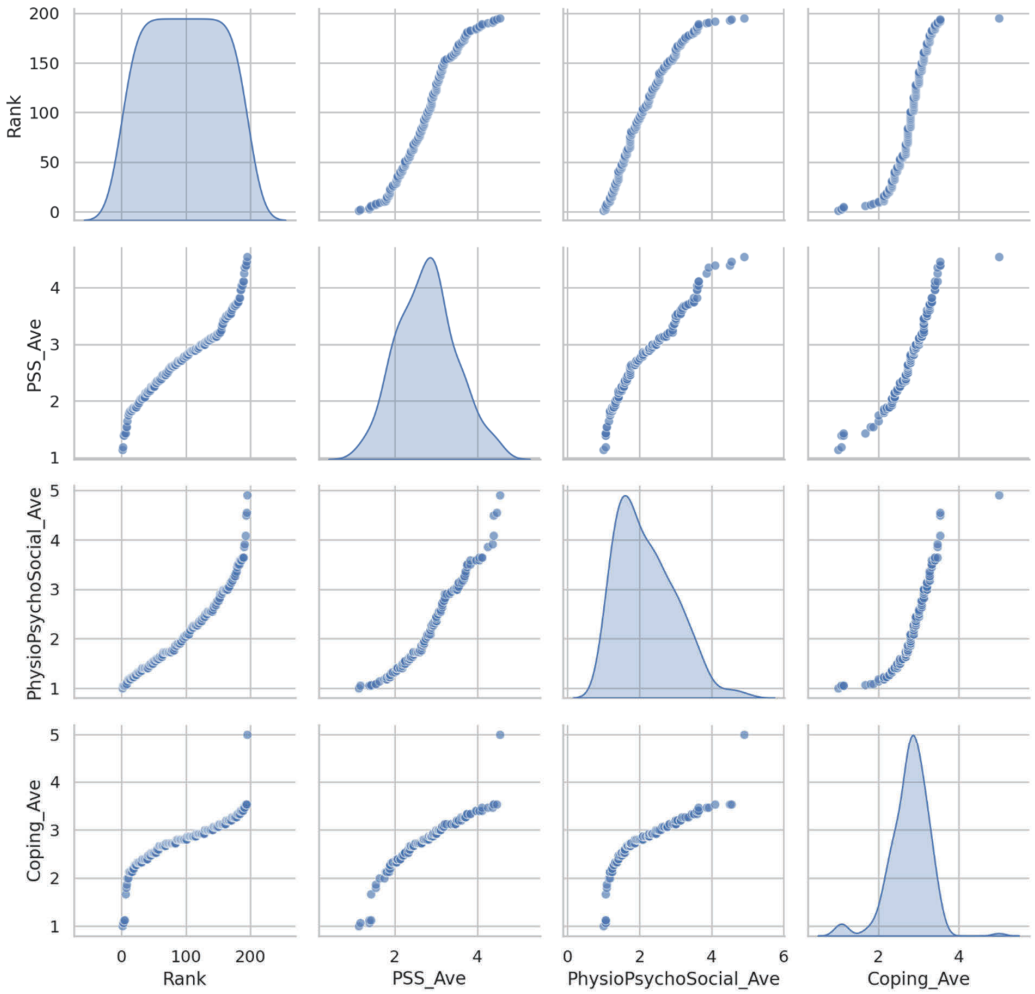


Fig 2.1. Cumulative distribution and scatterplot matrix of variables used in data sonification

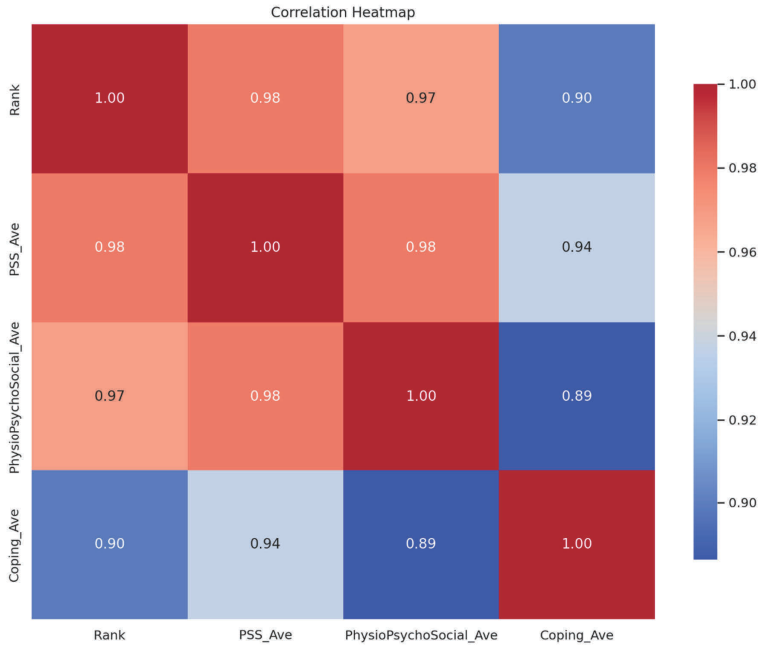


Fig 2.2. Correlogram of the variables used in data sonification

interplay between stress responses and coping efforts (Figure 2.2). The positive correlation with "Rank" suggests that as students advance academically during the COVID-19 pandemic, they experience increased stress but also develop stronger coping mechanisms. However, the skewed distributions of physio-psycho-social responses and coping averages (Figure 2.1) indicate that while most students report moderate levels, a subset experiences significantly higher stress responses and coping efforts, reflecting variability in individual experiences.

Findings from the Data Sonification

Figure 3 displays the normalized frequency values (in Hertz, Hz) for three variables : PSS average (blue line, 200 to 2000 Hz), PPS average (orange line, 100 to 1000 Hz), and coping average (green line, 300 to 3000 Hz). Fluctuations in these lines indicate variations in stress levels, physio-psycho-social responses, and coping mechanisms among nursing students. The higher frequency values of the coping average line suggest more active engagement with coping strategies. The PSS average and PPS average lines often move in tandem, indicating a correlation between perceived stress and wellbeing. Peaks and troughs may represent periods of heightened stress or effective coping. As perceived stress increases, physio-psycho-social wellbeing declines while coping abilities improve, reflecting an adaptive response to stress and highlighting the dynamic interplay between stress, wellbeing, and coping among nursing students.

The sonification of the dataset translates each data point into distinct tones : PSS average is represented by a sine wave (200-2000 Hz), PPS average by a square wave (100-1000 Hz), and coping average by a triangle wave (300-3000 Hz), with higher frequencies indicating higher values. The entire audio duration reflects the full dataset, with each data point lasting 150 milliseconds. When the sine (PSS average), square (PPS average), and triangle (coping average) waves overlap harmoniously, they suggest a potential correlation among the variables, revealing synchronized periods of stress and effective coping strategies. In contrast, divergence or dissonance in the sounds indicates misalignment, such as instances where elevated stress levels occur without corresponding coping mechanisms being engaged (listen to the sonification of Figure 3 available at https://github.com/jphernandezrn/Dataset-Sonification). Variations in amplitude provide information about the intensity of each variable ; for example, an increase in the amplitude of the sine wave signifies heightened perceived stress, while a rise in the triangle wave suggests proactive coping efforts. Further, higher frequencies across the waves correlate with greater levels of stress or pronounced physiological responses. The temporal patterns within the soundscape indicate how these variables change over time, with consistent patterns reflecting stability and abrupt shifts signaling changes in stress levels or coping strategies. This auditory approach enriches the understanding of the data, revealing intricate relationships and patterns that may remain obscured in traditional visual analyses, ultimately offering a deeper perspective on the patterns of stress, physiological responses, and coping mechanisms.

The observed pattern in the data, as illustrated in Figure 4, begins with initial frequencies at low values of approximately 200-300 Hz, reflecting lower intensity levels. As the data progresses, frequencies gradually increase and plateau, indicating a steady rise in intensity, culminating in a sharp increase that reaches 2000 Hz, corresponding to the highest intensity values. This pattern represents nursing students' stress levels, with baseline fluctuations between 200-400 Hz capturing daily variations. The gradual increase in frequency, peaking at 2000 Hz, signifies rising stress due to factors such as "assignments and workload," "worries about grades," and "pressure from clinical practice," potentially marking an extreme stress event heightened during COVID-19 (listen to the sonification of Figure 4 at https://github.com/jphernandezrn/Dataset-Sonification). Despite these stressors, participants displayed low avoidance behaviors and moderate recognition of external stressors, while high levels of problem-solving and optimistic coping behaviors indicate effective stress management, as evidenced by the stable baseline amidst fluctuations.

DISCUSSION

Here, we investigated the dynamics of stress and the accompanying coping responses among nursing students during the COVID pandemic by using response survey tools such as the modified Perceived Stress Scale (PSS), the modified Physio-Psycho-Social (PPS) response scale, and the modified Coping Behavior Inventory (CBI) scales.

Demographic profiles are shown in Table 1. The respondents, primarily single, female, employed, and aged 25-34, provide context for their stress, anxiety, and coping behaviors. This group experienced minimal direct effects from COVID-19 compared to older adults, which aligns with research indicating that the virus predominantly impacted the oldest-old population (39, 40). Despite facing lower COVID-19 effects, moderate anxiety levels were common among participants, with emotional symptoms such as worry and nervousness being particularly prominent during the pandemic. Notably, 45.6% of participants reported using mood-altering substances, indicating a reliance on emotional coping strategies. However, the data collected do not specify the types of mood-altering substances being used, the frequency or patterns of use, the relationship between substance use and anxiety levels, or whether the substance use preceded or followed increased anxiety levels. This lack of detail limits this study to draw comprehensive conclusions about the relationship between substance use and anxiety in the studied population. These gaps may inform future research on the connections between demographic factors, developmental stage, and coping mechanisms, as well as targeted interventions to address anxiety and promote healthier coping strategies in younger, working-age populations (39, 40).

The results show that some students were not stressed by the COVID-19 pandemic, likely due to their developmental stage as young adults, while most reported moderate stress from clinical responsibilities. This moderate stress can positively influence student performance, consistent with Yerkes-Dodson's theory (41), which posits that moderate stress enhances performance, such as memory and task execution, whereas high stress can hinder it. Results from the modified PSS, PPSRS, and CBI also support this theory, demonstrating an inverted U-shaped relationship between stress and performance. Moderate stress fosters adaptive responses, including problem-solving and optimistic coping strategies, while excessive stress, particularly during the pandemic, can negatively affect wellbeing. Strong correlations between perceived stress, coping mechanisms, and stress responses further show that adaptive responses are optimal at moderate stress levels but decline under high stress. Based on these findings, there is a need for interventions to assist nursing students in managing stress effectively to enhance their performance and wellbeing.

However, the majority of respondents were significantly stressed regarding assignments and workload, as well as concerns about poor grades and pressure from the nature and quality of clinical practice, as shown in Table 2. Such stressors evoke emotional responses rather than social-behavioral and physical symptoms, as outlined in Table 3. These findings are also consistent with a previous study by Labrague (1).

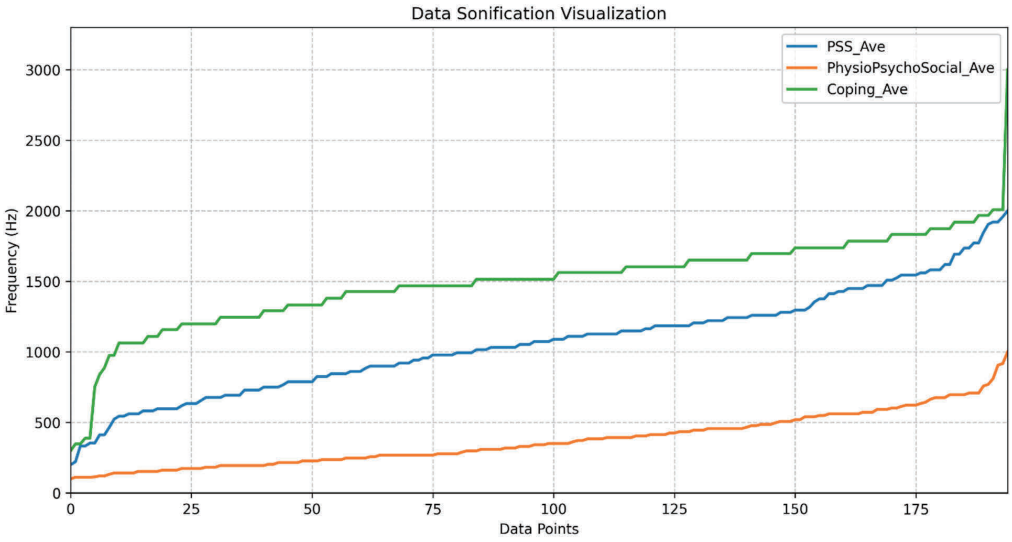
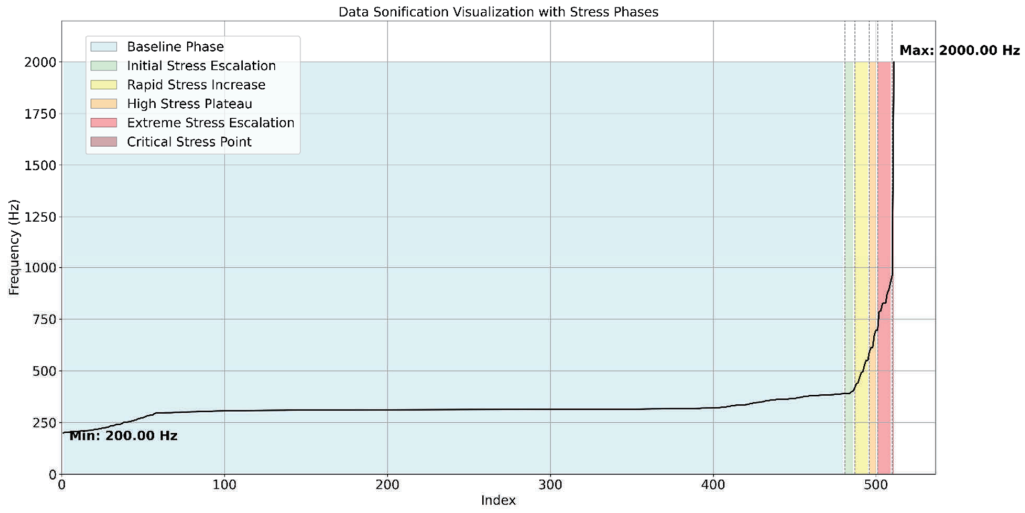


Fig 3. Cumulative progression of 'Perceived Stress,' 'Response to Stress,' and 'Coping' with sound



Note : The Baseline Phase includes 480 points, with a mean frequency of 310.30 Hz and a standard deviation of 34.92 Hz. This is followed by the Initial Stress Escalation, which consists of 6 points with a mean frequency of 393.90 Hz and a standard deviation of 5.26 Hz, and a Rapid Stress Increase with a mean frequency of 486.99 Hz and a standard deviation of 49.36 Hz. The High Stress Plateau consists of 5 points, with a mean frequency of 637.18 Hz and a standard deviation of 44.64 Hz. The Extreme Stress Escalation shows a mean frequency of 827.80 Hz ($SD \pm 67.97$ Hz), culminating in the Critical Stress Point, which has only 2 points and a dramatic mean frequency of 1480.63 Hz, with a very large standard deviation of 734.49 Hz.

Fig 4. Composite sonification of 'Perceived Stress,' 'Response to Stress,' and 'Coping'

Students experience moderate levels of perceived stress, with a mean PSS score of 2.774 ($SD \pm 0.694$), ranging from 1.14 to 4.54. This perceived stress is closely mirrored in their physio-psycho-social responses, as evidenced by the strong positive correlation ($r = 0.89$) between PSS average and PPS average. The mean PPS score of 2.185 ($SD \pm 0.803$) suggests that while students' physiological, psychological, and social responses are generally lower than their perceived stress, they still exhibit significant variability. Interestingly, students' coping abilities show a mean score of 2.774 ($SD \pm 0.485$), which is identical to the mean perceived stress level but with less variability. This suggests that students are, on average, applying coping strategies at a level commensurate with their perceived stress. However, the moderate positive correlations between coping average and both PSS average ($r = 0.55$) and PPS average ($r = 0.61$) indicate that while coping mechanisms do increase with higher stress levels, this increase is not proportional to the rise in stress. This disparity suggests potential areas for improvement in stress management strategies among nursing students. The data underscore the need for targeted interventions to enhance coping skills, particularly for students experiencing higher levels of stress, as the current coping strategies may not be fully adequate to address the physio-psycho-social impacts of stress in their academic environment.

High levels of anxiety in nursing students are found primarily among female students, which is consistent with results from other studies conducted in 2019, such as those by Mirón *et al*., Quek *et al*., and Sanad, as cited in Savitsky *et al*. (42). Contributing factors include previously noted issues such as economic or financial constraints, as well as caring for children, social isolation, and uncertainty about the future (42).

Exposure to acute stress can even lead to drug use and abuse (43). Moreover, anxiety, fear, sadness, and post-traumatic stress disorder increase the potential for the use of addictive substances and alcohol as maladaptive means of coping (44). There is also evidence from human studies that supports the effect of stress on drug use (45-47). In fact, Sinha (48) describes how increased and repeated use of alcohol and binge drinking can lead to elevated basal cortisol levels, which contribute to neural changes that trigger a vicious cycle of increased desire for more alcohol and behavioral motivation tied to risky behavior. While this is outside the purview of the current study, the findings support the occurrence of this phenomenon among respondents and warrant further research in the future.

The emotional responses, such as anxiety and worry, as observed in Table 2, could serve as acute stress stimuli that possibly activate neural circuitries, such as the Hypothalamic-Pituitary-Adrenal (HPA) axis, in mobilizing individuals to respond adaptively to maintain optimal psychological wellbeing. The HPA axis and its regulation are essential for adaptive responses to stress (49-52). Additionally, the stress elicited from poor grades may have activated acute stress pathways that did not result in high levels of social, behavioral, and physical symptoms, as outlined in Table 3. It is possible that chronic stress was not at play, as it would have activated immune pathways that lead to physical symptoms, such as catching a cold easily.

Unsurprisingly, the majority of respondents were not stressed by the COVID-19 pandemic but from issues related to their assignments and work load and this is consistent with previous findings from Labrague (1). Importantly, the COVID-19 era was unique for nursing students who were burdened with the additional intricate dynamics of on-line classes which resulted in stress. This then elicited coping behaviors as outlined in Table 4 and which showed that students were more engaged in problem-solving behaviors and optimistic coping behaviors than resorting to avoidance behaviors. These findings are consistent with the findings of Savitsky *et al*. (42).

SEM (Figure 1) provided strong support for the significant negative relationship between coping skills and physio-psycho-social stress levels in nursing students ($\beta = -0.301$, $p < .001$), indicating that students with better coping skills tend to experience lower stress. Similarly, the analysis revealed a significant negative relationship between age group and stress levels ($\beta = -0.160$, $p = .035$), suggesting that older students experience less stress. However, the relationship concerning gender and stress was not supported, as the model indicated a positive relationship ($\beta = 0.182$, $p = .268$). Additionally, the analysis of demographic factors such as marital status, income, ethnicity, and being the first in the family to attend college did not show significant relationships with stress levels, with *p*-values exceeding .05. While the proposed SEM revealed significant relationships for coping skills and age, the overall fit indices indicated that the model could be improved, with a Chi-square of 1015.32 ($p < .05$), a CFI of 0.804, and an RMSEA of 0.101. These results suggest that while the model captures important relationships, additional complexities in the data may not be fully explained by the current model.

The averaged values in Figure 3 of the modified Perceived Stress Scale (PSS) are represented by a sine wave with a frequency range of 200 Hz to 2000 Hz. Its mathematical representation is given by $f_{PSS} = \left(\frac{PSS - PSS_{min}}{PSS_{max} - PSS_{min}}\right)(2000 - 200) + 200$. Higher stress levels correspond to higher frequencies, and the sine wave produces a pure, smooth tone that makes changes in stress levels easily perceivable. In contrast, the averaged values of the modified Physio-Psycho-Social Scale (PPSRS) are characterized by a square wave with a frequency range of 100 Hz to 1000 Hz, mathematically represented as $f_{PPSRS} = \left(\frac{PPSRS - PPSRS_{min}}{PPSRS_{max} - PPSRS_{min}}\right)(1000 - 100) + 100$. The square wave creates a more distinct, "harsh" sound, and its lower frequency range helps distinguish it from PSS measurements. Lastly, the averaged values of the modified Coping Behavior Inventory (CBI), or "Coping," are represented by a triangle wave with a frequency range of 300 Hz to 3000 Hz, expressed mathematically as $f_{CBI} = \left(\frac{CBI - CBI_{min}}{CBI_{max} - CBI_{min}}\right)(3000 - 300) + 300$. The triangle wave provides a softer, more melodic sound and has the highest frequency range among the three variables. The frequency-value relationship for all variables follows a Frequency Mapping Function expressed as $f = \left(\frac{x - x_{min}}{x_{max} - x_{min}}\right)(f_{max} - f_{min}) + f_{min}$, where x represents the value of the variable (PSS Ave, PhysioPsycho-Social Ave, and Coping Ave) and f is the resulting frequency, with subscripts *min* and *max* denoting the minimum and maximum values. For normalization, this function scales values to a range of 0 to 1, setting the minimum at 0, the maximum at 1, and proportionally scaling intermediate values. It then maps the normalized values (0-1) to the target frequency range (e.g., PSS Ave, PhysioPsychoSocial Ave, and Coping Ave), creating a linear mapping where lower variable values correspond to lower frequencies and higher values yield higher frequencies. Each variable is assigned a distinct frequency range to prevent confusion, with sine waves representing PSS Ave, square waves for PhysioPsychoSocial Ave, and triangle waves for Coping Ave. An audio overlay function combines these segments into a single, temporally aligned audio file, while an animation function utilizes FuncAnimation to create a dynamic visualization of the data over time. Finally, video-audio synchronization merges the generated video and audio into a cohesive multimedia file using moviepy, enhancing the clarity and interpretability of the data.

On the other hand, in Figure 4, the Frequency Mapping Function is defined as $f(I) = \frac{(I - I_{min})}{(I_{max} - I_{min})} \times (f_{max} - f_{min}) + f_{min}$, where $f(I)$ represents the output frequency in Hz, I is the input

intensity in dB, I_{min} and I_{max} are the minimum and maximum intensity values, respectively, with f_{min} = 200 Hz and f_{max} = 2000 Hz. This creates a linear mapping within the human audible frequency range, with a lower bound of 200 Hz (approximately the G3 musical note) and an upper bound of 2000 Hz (approximately the B6 musical note). The sample rate is set at 44,100 Hz, following the Nyquist-Shannon sampling theorem, which states that the sample rate must exceed twice the maximum frequency ($f_s > 2f_{max}$), ensuring accurate reproduction of the highest frequency of 2000 Hz. Following this, the Sine Wave Generation equation $y(t) = Asin(2\pi f(I)t)$ describes the audio signal at time *t*, where *A* is the amplitude and $f(I)$ is the mapped frequency. To map the time position of each data point, the Time-Position Mapping equation $p(i) = i \times \frac{T_{total}}{N}$ is used, where *p*(*i*) indicates the position in milliseconds for data point *i*, T_{total} is the total duration in milliseconds, and *N* is the number of data points. The Complete Sonification Function is expressed as $S(I,t,i) = Asin\left(2\pi f(I)\left(t - p(i)\right)\right)H\left(t - p(i)\right)$, where *S*(*I*,*t*,*i*) is the complete sonification signal and *H*(*t*) is the Heaviside step function, with *i* being the index of the data point. The Total Audio Signal is calculated using $Y(t) = \sum_{i=0}^{N-1} S(I_i, t, i)$, where *Y*(*t*) is the final composite audio signal and I_i is the intensity value at index *i*. Finally, the Frame Rate Conversion is defined as $t_{frame} = \frac{i}{fps}$, where $fps = 30$ frames per second, indicating the time of frame *i*. This ensures smooth visual perception. The 17.03-second data sonification (in mono format) streamlines data representation.

The smooth sound generated in Figure 4 reflects the ongoing experience of stress and coping, with variations in amplitude and frequency indicating different stress levels. An increase at the midpoint suggests heightened stress or intensified coping, while repeating patterns indicate recurring stressors. The wide frequency range highlights the complexity of stress, and a gradual decrease towards the end signifies reduced stress or improved coping skills. The inferred stress phases among nursing students identify their primary stressors, particularly "stress from assignments and workload." While most respondents reported moderate stress levels, with a typical score indicating moderate stress, high stress was linked to concerns about grades, pressures of clinical practice, unfamiliarity with ward facilities, and conflicting teacher instructions. The Baseline Phase indicates stable stress levels, with a frequency of 0.5 Hz, while the Initial Stress Escalation Phase corresponds to heightened anxiety during exams and demanding assignments, with a frequency of 1.0 Hz. The Rapid Stress Increase Phase is noted at a frequency of 1.5 Hz, with high stress responses recorded in 60% of participants. Emotional symptoms, such as worry and nervousness, were common, especially during the COVID-19 outbreak, where 70% reported increased anxiety. Students demonstrated effective coping strategies, with high scores in problem-solving behaviors (e.g., 80% adopting different strategies) and optimistic coping behaviors (e.g., 75% maintaining a positive attitude), which helped them manage their stress. These phases describe how nursing students navigate academic challenges, with emotional responses predominating while actively employing strategies to mitigate stress.

Data sonification reveals that perceived stress, stress responses, and coping mechanisms operate as an interconnected system, where each component dynamically influences and responds to the others. Higher scores indicate higher frequencies (and vice versa), with increasing perceived stress frequencies (which signify heightened stress) often leading to elevated coping frequencies. The frequencies of stress responses correspond with changes in perceived stress, demonstrating a synchronization between perceived stress and stress responses. Meanwhile, coping efforts tend to peak slightly after stress levels, establishing a reactive relationship.

This study, alongside Labrague's analyses (1, 53), found moderate-to-severe stress levels among nursing students, pinpointing key stressors such as "worries about grades," "assignments and workload," and "unfamiliarity with ward facilities". These stressors correspond with common challenges noted in Labrague's umbrella review (53), which includes academic demands and faculty interactions. Both studies identify academic stress as a significant factor and reveal that nursing students predominantly use problem-solving and optimistic coping strategies, such as setting objectives and maintaining a positive attitude, to manage stress. Collectively, these translate to "effective coping" (53) where there is a low reliance on avoidance behaviors and more on active strategies. Since improved coping skills are associated with lower stress levels (Figure 1), this reinforces the importance of "effective coping" in student wellbeing (53).

IMPLICATION FOR NURSING EDUCATION AND RESEARCH

In this study, most students experienced stress at a moderate level, with high levels noted as being associated with increased workload, assignments, and clinical environments. The results of this study can inform nursing education leaders, particularly those within this college, about necessary revisions to policy, student expectations, and the unique needs of this institution's students. Further research is needed to identify specific interventions to reduce high stress in nursing students while maintaining the rigor of preparation for the transition to practice. Additionally, the current study could be replicated with a larger, multi-school sample in the post-pandemic environment.

CONCLUSION

The findings of the present study indicate that COVID-19 significantly impacted nursing students in an urban college, eliciting moderate levels of stress. The relationship between stress and coping among these students is complex, with perceived stress closely linked to physiological, psychological, and social responses, as well as coping strategies. Some respondents reported high stress levels, primarily due to workload and assignments, which manifested as emotional symptoms addressed through problem-solving behaviors. The overall results suggest that the stressors associated with a professional nursing program, the challenges of studying in an urban environment, and the demands of personal and employment obligations during the pandemic contributed to these moderate stress levels. Interestingly, this stress may have triggered enhanced neurophysiological mechanisms that improved psychological wellbeing. While the study's findings are limited to a single urban nursing college and are not generalizable to all urban nursing education programs, they contribute valuable insights to the existing literature and introduce innovative investigative approaches, such as data sonification. This auditory representation reveals the synchronization or divergence of perceived stress, stress responses, and coping efforts, highlighting their interrelationships. Temporal dynamics indicate that rising frequencies correspond to increasing stress levels, while stable baselines suggest effective coping strategies. This multisensory approach enriches data interpretation by uncovering intricate patterns often obscured in traditional visual analyses, thereby deepening the understanding of the interplay between stress, wellbeing, and coping strategies. Future research should aim to expand this work by including larger groups of respondents from various institutions.

CONFLICTS OF INTEREST STATEMENT

Each author confirms that they have no conflicts of interest. All co-authors have thoroughly reviewed and approved the content of the manuscript, and there are no financial interests to disclose. We affirm that this submission represents original work.

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AUTHORS' CONTRIBUTIONS

Dr. Joannes Paulus Tolentino Hernandez prepared, analyzed, and validated the data statistically and implemented data sonification, including the curation of audio files and the dataset. All the authors equally participated in the conception of this study, the literature search, the drafting and revising of the paper, the final approval of the paper, and the agreement to be accountable for the integrity of the results. All authors read and approved the final manuscript.

AVAILABILITY OF DATA AND MATERIAL

The audio files for Figure 3 and Figure 4, which are used to support the findings of this study, have been deposited in jphernandezrn on GitHub at https://github.com/jphernandezrn/Dataset-Sonification.

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DECLARATIONS

Consent for publication

Each author has agreed to the publication of this study.

Competing interests

The authors declare that they have no competing interests to disclose.

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