ISSN (P&E): 1996-7195, (O): 2957-899X DOI: https://doi.org/10.53350/pjmhs02026204.6

ORIGINAL ARTICLE

Integrating Sleep Quality, Cardiac Autonomic Function, Cognitive Processing Speed, and Academic Performance Assessment in Undergraduate Medical Students: A Pilot Study

ALI ZULQERNAIN[1], ZOHAIB SYED[2], RAI KHALID FAROOQ[3*]
[1]Department of Psychiatry, Niazi Medical & Dental College, Sargodha, Pakistan,
[2]Master Drug Development and Regulatory Affairs, University of Innsbruck, Innsbruck, Austria
[3]Department of Physiology, College of Medicine and Health Sciences, Arabian Gulf University, Manama, P.O Box 26671, Kingdom of Bahrain.
Correspondence to: Rai Khalid Farooq, **Email:** raikf@agu.edu.bh

This article may be cited as:
Zulqernain A, Syed Z, Farooq RK; Integrating Sleep Quality, Cardiac Autonomic Function, Cognitive Processing Speed, and Academic Performance Assessment in Undergraduate Medical Students: A Pilot Study. Pak J Med Health Sci, 2026; 20(04): 33-38.

Received: 02-01-2026
Accepted: 15-04-2026
Published: 30-04-2026

Check for updates

© The Author(s) 2026. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author(s) and source are credited.

ABSTRACT

Background: Poor sleep quality is common among medical students and has been associated with impaired learning, attention, and academic performance. Heart rate variability (HRV) provides a non-invasive measure of cardiac vagal modulation and may help explain the physiological pathway linking sleep and learning. Before a larger prospective study, protocol feasibility needed to be tested in a small student cohort.

Objectives: This pilot study evaluated the feasibility and acceptability of assessing sleep quality, cardiac autonomic function, reaction time, and examination performance in undergraduate medical students. A secondary objective was to estimate preliminary effect sizes for planning a larger study.

Methods: A single-center pilot observational study was conducted among 30 second-year medical students. Sleep quality was assessed using the Pittsburgh Sleep Quality Index. Resting heart rate, blood pressure, and 5-minute heart rate variability were recorded under standardized morning conditions. Root mean square of successive differences between normal heartbeats (RMSSD) was selected as the primary HRV index. Reaction time was assessed using an attention task. Academic performance was measured using a summative academic examination. Feasibility outcomes included recruitment rate, retention rate, data completeness, HRV recording success, participant acceptability, and achievement of predefined progression criteria.

Results: Twenty-eight students underwent the entire processes of study. In 29 out of 30 sessions, completeness of data was 96.4 and technical acceptable HRV recordings were accomplished. There were all the predetermined progression criteria that were met. Control: There were sixteen poor and fourteen good sleepers. Sleep deprived individuals were less RMSSD, with a high resting heart rate, slower reaction time, and lower grades on academic tests. RMSSD, reaction time, and examination performance had large preliminary effect sizes. There was a negative correlation between sleep quality measured by Pittsburgh Sleep Quality Index (PSQI) score and RMSSD and examination score.

Conclusion: The protocol was viable, acceptable and fit to be extended to a larger prospective study. Early evidence indicates that sleep quality could be linked with worse vagal modulation and slower cognitive processing, and worse performance in physiology exams amongst medical students.

Keywords: Sleep quality; Heart rate variability; RMSSD; Medical students; Reaction time; Academic performance; Pilot study; Feasibility study.

INTRODUCTION

Medical students frequently experience poor sleep quality because of academic workload, examination stress, irregular routines, and extensive screen exposure. Sleep supports memory consolidation and cognitive performance through several neural processes, including restoration of attention networks and stabilization of newly acquired information. Experimental and observational studies show that insufficient amount of good quality sleep impairs vigilance, psychomotor speed, working memory, and executive function[1,2]. On the contrary, good sleep quality was associated with better academic performance among medical students[3]. Disturbance of sleep has been linked with reduced learning capacity and lower academic achievement in students[1,4]. One possible physiological pathway linking sleep with academic performance is autonomic nervous system regulation, which can be measured by measuring heart rate variability (HRV). HRV is a non-invasive marker of cardiac autonomic control. Time-domain measures such as the root mean square of successive differences between normal heartbeats, or RMSSD, mainly reflect parasympathetic modulation[5,6]. Reduced vagal modulation has been associated with stress, fatigue, and impaired cognitive control[7,8].

The Pittsburgh Sleep Quality Index is widely used to assess sleep quality over the previous month and provides a validated method for classifying good and poor sleepers[9]. Reaction time testing provides a simple objective measure of processing speed and attention. The Deary-Liewald reaction time task is a validated computerized method for measuring simple and choice reaction time[10]. Combining these measures in medical students offers a way to study sleep, autonomic physiology, cognition, and learning within the same educational context. Yet fewer studies have included physiological measurements that may explain this relationship. Before conducting a larger study, a pilot phase was required to test recruitment, measurement feasibility, data quality, participant acceptability, and protocol burden. This pilot study therefore aimed to assess the feasibility of collecting sleep quality, HRV, reaction time, and academic performance data in undergraduate medical students. The secondary aim was to estimate preliminary effect sizes to guide sample size planning for a larger prospective study.

MATERIAL & METHODS

Study Design

It was an observational, pilot and feasibility study involving one center, that took place in a four-week teaching block in physiology. The research was aimed to gauge the feasibility and protocol performance and to estimate some basic effect sizes, but the basic hypothesis was not to be tested. The choice of reporting was informed by recommendations of pilot and feasibility research and STROBE principles of observational research[11,12].

Setting

The location of the study was a group of medical students in their undergraduate school years. The data collection was to be done during normal teaching weeks to determine whether the protocol would be able to work under normal educational conditions.

Participants

Medical second-year undergraduates were encouraged to join. Students were made aware that it was a voluntary exercise which did not affect academic assessment. The inclusion criteria consisted of the following: age 18 to 25 years, willingness to sign informed consent in writing and consent to use the scores of the physiology examination in research analysis. Restrictions included known cardiovascular disease, known sleep disorder, acute febrile illness, taking beta-blockers, stimulants, sedatives, antidepressants and, other drugs known to produce effects on autonomic functioning, smoking heavily, caffeine consumption within three hours of testing or vigorous exercise within 12 hours of testing.

Sample Size Justification

A formal power calculation was not performed because this was a pilot feasibility study. A target sample of 30 students was selected to assess recruitment, retention, measurement procedures, data completeness, and preliminary effect size estimates. Pilot study methodology recommends focusing on feasibility and estimation rather than definitive significance testing[11].

Progression Criteria

The protocol was considered suitable for progression to a larger study if recruitment, retention, and data completeness rates are greater than 80% and there are no major adverse events during the whole process.

Sleep Quality Assessment

Sleep quality was assessed using the Pittsburgh Sleep Quality Index. The PSQI contains 19 self-rated items and generates seven component scores. The global score ranges from 0 to 21, with higher scores indicating poorer sleep quality. A global score greater than 5 was used to classify poor sleep quality[9].

Physiological Measurements

All physiological recordings were performed between 08:00 and 10:00 AM in a quiet room. Participants were instructed to avoid caffeine, nicotine, heavy meals, and vigorous activity before testing. After 10 minutes of supine rest, a 5-minute heart rate recording was obtained. RR interval data were visually inspected before analysis. HRV analysis focused on RMSSD because it is a stable short-term measure of vagally mediated cardiac modulation and is recommended in psychophysiological research[5,6]. Resting heart rate was derived from the heart rate recording. Blood pressure was measured twice using an automated device, and the mean value was used for analysis.

Reaction Time Assessment

When testing reaction time, the ruler drop test was conducted: this is a simple psychomotor response speed and hand-eye coordination field measure that is common and popular. One was made quite comfortable and with the dominant hand, which would not touch anything, the thumb and index finger would be aligned to the bottom of a vertically hanging ruler. The researcher threw the ruler anywhere and any second and subjects were requested to embrace the ruler as fast as possible. In centimeters, the length that the ruler fell prior to being discovered was taken. Each of them was subjected to five trials and the analysis of these trials was made through the mean value. The distance with which the reaction occurred was then used to calculate reaction time using the standard free-fall equation. Ruler drop test is chosen as it is cheap, simple to use, has a minimal equipment requirement, and has been proven to be reliable and valid, as a reaction performance measure in educational and sports science applications[12].

Academic Performance

Academic performance was assessed using the percentage score in a summative physiology examination administered at the end of the teaching block. The examination consisted of single-best-answer multiple-choice questions covering physiology content taught during the study period.

Statistical Analysis

Most of the data items were analyzed descriptively. Continuous variables were reported as mean and standard deviation. Categorical variables were reported as frequency and percentage. Feasibility outcomes were reported with proportions and 95% confidence intervals. Students were classified as good sleepers or poor sleepers using the PSQI cutoff. Preliminary group differences were summarized using mean differences and Cohen's d effect sizes. Correlation coefficients were calculated to explore associations among PSQI score, RMSSD, heart rate, reaction time, and examination score.

RESULTS

Recruitment and Retention of Data

Thirty-four students were approached out of which thirty students agreed to participate, giving a recruitment rate of 88.2%. Twenty-eight participants completed all study procedures, (93.3%). Overall data completeness was 96.4%. HRV recordings were technically acceptable in 29 of 30 sessions, (96.7%). One recording was excluded because of movement artefact. No adverse events occurred during physiological recording or reaction time testing.

Progression Criteria

The entire planned feasibility and progress criteria were met. The recruiting percentage was 88.2 and this was higher than the target of 80. The retention rate was 93.3, and it basically means that the majority of participants who were enlisted took part in the study procedures. The level of data completeness was high (96.4) with a small amount of missing data in measured variables. Recording of heart rate variability was found to be technically acceptable in 96.7% of people. There were no reported adverse events and the feedback on participants showed that the study procedures were satisfactory. These results indicate that this protocol should be used in a bigger study.

A total of 30 undergraduate medical students took part in the study, and the mean age was 20.1 ± 1.3 years. The predefined PSQI cutoff was used to classify sixteen participants (53.3% poor sleepers) and fourteen (46.7% good sleepers). A total of 93.3% completed it. The distribution of age and sex was similar between the two groups of sleep quality. These control results suggest that the pilot sample represented the appropriate choice to determine the feasibility results and estimate the initial physiological correlations.

Initial grouping of the measures revealed that there were differences between good and poor sleepers on autonomic, psychomotor and academic measures. There was lower cardiac vagal modulation in poor sleepers compared to good sleepers as indicated by the lower values of RMSSD. Poor sleepers had a higher resting heart rate. The poor sleepers had a longer reaction time meaning that they respond slowly in terms of psychomotor responses. This group also had lower scores in physiology examination. RMSSD (d = 1.12) and reaction time (d = 0.88) and resting heart rate (d = 0.84) exhibited the largest effect size. These results indicate that these variables should be considered in the future in a larger, sufficiently powered study.

Exploratory correlation analysis indicated correlations between the quality of sleep and physiological variables. Otherwise, worse results of sleep quality as indicated in higher PSQI were linked to a lower value of RMSSD and physiology examination. Resting heart rate and reaction

time were also positively related with PSQI scores. These findings suggest that poorer sleep quality was related to lower parasympathetic modulation, higher resting cardiovascular activity, and slower psychomotor response. RMSSD had a positive correlation with examination score and reaction time had a negative correlation with examination score. Since it was pilot research, this should be extrapolated as preliminary estimates in the execution of subsequent research.

The pilot phase has revealed problems with the procedures that was used to make changes in the strict study protocol. A difference between the test time resulted in the standardization of the recordings between 08:00-10:00 AM. RMSSD was considered the main HRV outcome measure as it gave an understandable and transparent result of cardiac vagal-modulation. The reaction time experiment was standardized to enhance consistency among them. A one week sleep diary was included to determine sleep behavior in the period up to the academic assessment. Pre-assessment variability was reduced by administering written instructions on the preparation of caffeine, exercise, and sleep. Additional slots were considered to allow assessment to be done with scheduling conflicts and better retention in the bigger study.

Table 1: Feasibility Outcomes and Progression Criteria

Outcome	Predefined Threshold	Observed Result	Progression Decision
Recruitment Rate	>80%	88.20%	Achieved
Retention Rate	>90%	93.30%	Achieved
Data Completeness	>90%	96.40%	Achieved
HRV Recording Success	>90%	96.70%	Achieved
Adverse Events	None	None	Achieved
Participant Acceptability	Acceptable	Acceptable	Achieved

Table 2: Participant Characteristics

Variable	Total Sample (n=30)
Age (years), mean ± SD	20.1 ± 1.3
Good Sleepers, n (%)	14 (46.7%)
Poor Sleepers, n (%)	16 (53.3%)
Completed Study, n (%)	28 (93.3%)
Male, n (%)	13 (43.3%)
Female, n (%)	17 (56.7%)

Table 3: Preliminary Physiological and Academic Outcomes According to Sleep Quality. Values are presented as mean ± standard deviation.

Variable	Good Sleepers (n = 14)	Poor Sleepers (n = 16)	Mean Difference	Cohen's d
RMSSD (ms)	45.8 ± 12.4	31.6 ± 10.8	14.2	1.12
Resting Heart Rate (bpm)	69.5 ± 7.2	76.2 ± 8.5	-6.7	0.84
Reaction Time (ms)	485 ± 40	521 ± 42	-36	0.88
Examination Score (%)	76.4 ± 8.2	69.1 ± 9.5	7.3	0.73

Table 4: Exploratory Correlations Between Sleep Quality, Physiological Variables, and Academic Performance. Abbreviations: PSQI = Pittsburgh Sleep Quality Index; RMSSD = Root Mean Square of Successive Differences; HRV = Heart Rate Variability.

Variable Pair	Correlation Coefficient (r)	Direction
PSQI Score and RMSSD	-0.46	Moderate Negative
PSQI Score and Physiology Examination Score	-0.39	Moderate Negative
PSQI Score and Resting Heart Rate	0.41	Moderate Positive
PSQI Score and Reaction Time	0.37	Moderate Positive
RMSSD and Examination Score	0.34	Weak-to-Moderate Positive
Reaction Time and Examination Score	-0.36	Weak-to-Moderate Negative

Table 5: Summary of Protocol Modifications Following Pilot Study

Pilot Observation	Modification Implemented in Definitive Study
Variability in testing times	Standardized testing between 08:00 and 10:00 AM
Multiple HRV parameters increased complexity	RMSSD selected as primary autonomic outcome
Reaction time protocol required optimization	Standardized reaction time procedure adopted
Sleep behavior near examination period not captured	One-week sleep diary added
Inconsistent participant preparation	Written instructions regarding caffeine, exercise, and sleep provided
Scheduling conflicts occurred	Backup assessment sessions incorporated

DISCUSSION

The pilot study indicated that combined measurement, evaluating sleep quality, cardiac autonomic performance, reaction time and physiology examination performance is valid in a group of undergraduate medical students. Success in recruitment, retention, completeness of data and recording of HRVs surpassed predetermined levels of progression. Acceptability of participants was satisfactory, and there were no adverse events witnessed. The usefulness of the findings on the feasibility is that sometimes physiological investigations conducted in learning environments may be challenged due to practical constraints. Learners are pressed in time, examinations are tense, physiological measurements involve set-ups. In spite of these, the protocol had high retention and high data completeness. This will sustain the development of a bigger prospective research.

The initial physiological results were in line with existing sleep and autonomic physiology. Reduced RMSSD and elevated resting heart rate was indicated in poor sleepers. RMSSD is typically considered an indicator of cardiac vagal modulation measured under controlled conditions [4,5]. Past HRV standards and psychophysiological guidelines advocate short-term HRV recording, under the condition that posture, time of the day, breathing state, artefact correction, and pre-test limitations are factored into consideration [4,5]. This relationship is found between poor sleep quality and less RMSSD can be attributed to the fact that sleep disturbance and stress are both interconnected with an autonomic imbalance. In a meta-analysis study carried out by Kim et al., stress was found to correlate with decreased HRV, particularly those related to parasympathetic activity [6]. Academic stress is often experienced among medical students, and this can be combined with insufficient sleep to negatively affect autonomic control.

The response time results are also in line with the previous literature. Loss of sleep affects the ability to concentrate, be alert, and speed of motor actions [1,3]. In comparison to simple reaction time, reaction time needs more thinking since the students are expected to differentiate between the stimuli, and choose the appropriate response. The reduced response time of poor sleepers is evidence that poor sleep can have an effect on cognitive processing speed potentially related to academic performance. The research results on scholastic performance might be viewed with some reservations since hypothesis testing was not powered. Nonetheless, the findings trend was still in line with the previous research on medical students. Mirghani et al. indicated that academic performance was positively related with good sleep quality in medical students [10]. Evidence related to sleep loss and decreased learning capacity and academic performance was also reviewed by Curcio et al. [1]. The current pilot incorporates a physiological aspect by incorporating RMSSD and reaction time.

The research added to the improvement of the protocols directly. The pilot study justified a more complex and defendable larger study design. To minimize multiple tests and enhance interpretability, RMSSD was chosen as the primary autonomic biomarker. As the primary cognitive measure, reaction-time was chosen since it exhibited better conceptual relevancy when it comes to performance on exams. The pilot also demonstrated the necessity of strict schedule of recordings, better instructional preparation of pre-test, and inclusion of sleep diary (13-18).

The pilot study strengths involve physiological measures are standardized, there is high retention, data completeness is high, and direct measurement of academic performance within a physiology course. Validated tools were also used in the study and the focus of the study was on effect size estimation as opposed to overinterpretation of statistical significance. The limitations are to be recognised. It had a small sample size and was limited to one institution. The quality of sleep was self-reported. No objective measures of sleep like measures of actigraphy or polysomnography were taken. Considering the nature of the study as observational, the preliminarily associations should be considered thus hypothesis-generating.

Effect sizes recorded in this pilot should be adequate to warrant the inclusion of adequate sample size, in the larger study. It must incorporate data of sleep diary, strict adherence to HRV recording conditions, and moderation of stress, caffeine, physical exercise, screen-time and baseline academic performance abilities. Longitudinal would provide an opportunity to more effectively assess changes in relations over time between sleep and autonomic functioning, cognitive processes and academic achievements.

CONCLUSION

This pilot and feasibility study showed that assessment of sleep quality, short-term recording of HRV and reaction time testing and academic performance evaluation were successfully combined in medical students in their undergraduate years. All the fixed progression criteria was met. There is initial indication that sleep quality can be poor which may be correlated with reduced vagal modulation, reduced processing speed, and reduced performance on physiology examination. These findings justify a further larger adequately powered prospective study.

DECLARATION

Conflict of Interest: The authors declare no conflict of interest.

Funding: This research did not receive any external funding.

Author's Contribution: All authors contributed equally in the complication of current study.

Acknowledgments: The authors express their sincere gratitude to all colleagues and participants for their valuable contributions to this study.

Data Availability Statement: The data that supports the findings of this research are available on request from Corresponding Author.

REFERENCES

1. Curcio G, Ferrara M, De Gennaro L. Sleep loss, learning capacity and academic performance. Sleep Med Rev. 2006;10(5):323-337. doi:10.1016/j.smrv.2005.11.001
2. Goel N, Rao H, Durmer JS, Dinges DF. Neurocognitive consequences of sleep deprivation. Semin Neurol. 2009;29(4):320-339. doi:10.1055/s-0029-1237117
3. Mirghani HO, Mohammed OS, Almurtadha YM, Ahmed MS. Good sleep quality is associated with better academic performance among Sudanese medical students. BMC Res Notes. 2015;8:706. doi:10.1186/s13104-015-1712-9
4. Hershner SD, Chervin RD. Causes and consequences of sleepiness among college students. Nat Sci Sleep. 2014;6:73-84. doi:10.2147/NSS.S62907
5. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Heart rate variability: standards of measurement, physiological interpretation and clinical use. Circulation. 1996;93(5):1043-1065.
6. Laborde S, Mosley E, Thayer JF. Heart rate variability and cardiac vagal tone in psychophysiological research: recommendations for experiment planning, data analysis, and data reporting. Front Psychol. 2017;8:213. doi:10.3389/fpsyg.2017.00213
7. Kim HG, Cheon EJ, Bai DS, Lee YH, Koo BH. Stress and heart rate variability: a meta-analysis and review of the literature. Psychiatry Investig. 2018;15(3):235-245. doi:10.30773/pi.2017.08.17
8. Thayer JF, Hansen AL, Saus-Rose E, Johnsen BH. Heart rate variability, prefrontal neural function, and cognitive performance: the neurovisceral integration perspective on self-regulation, adaptation, and health. Ann Behav Med. 2009;37(2):141-153. doi:10.1007/s12160-009-9101-z
9. Buysse DJ, Reynolds CF 3rd, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. Psychiatry Res. 1989;28(2):193-213. doi:10.1016/0165-1781(89)90047-4
10. Eldridge SM, Chan CL, Campbell MJ, Bond CM, Hopewell S, Thabane L, et al. CONSORT 2010 statement: extension to randomised pilot and feasibility trials. BMJ. 2016;355:i5239. doi:10.1136/bmj.i5239
11. Ferreira S, Raimundo A, Del Pozo-Cruz J, Leite N, Pinto A, Marmeleira J. Validity and reliability of a ruler drop test to measure dual-task reaction time, choice reaction time and discrimination reaction time. Aging Clin Exp Res. 2024 Mar 7;36(1):61. doi: 10.1007/s40520-024-02726-6. PMID: 38451364; PMCID: PMC10920456.
12. von Elm E, Altman DG, Egger M, Pocock SJ, Gotzsche PC, Vandenbroucke JP. The Strengthening the Reporting of Observational Studies in Epidemiology statement: guidelines for reporting observational studies. Lancet. 2007;370(9596):1453-1457. doi:10.1016/S0140-6736(07)61602-X
13. Shen L, Mortezaagha P, Rahgozar A. Benchmarking machine learning architectures for menstrual recovery prediction using physiologically informed synthetic wearable data. Scientific Reports. 2026 Jun 8.
14. Shu Y, Qiang L, Liu Q, Xu Y, Huang C, Yao X. Development and validation of an interpretable multi-task prediction model based on heart rate variability for discriminating depression, anxiety and psychiatric comorbidities: a machine learning-driven retrospective study. BMC psychiatry. 2026 Dec;26(1):300.
15. Bahameish M, Stockman T, Requena Carrión J. Strategies for reliable stress recognition: A machine learning approach using heart rate variability features. Sensors. 2024 May 18;24(10):3210.
16. Liu S, Cui Y, Chen M. Heart rate variability: A multidimensional perspective from physiological marker to brain-heart axis disorders prediction. Frontiers in Cardiovascular Medicine. 2025 Nov 6;12:1630668.
17. Ng SM, Ho JH, Chan BT. Multimodal wearable sensor-based stress detection: machine learning pipeline with systematic feature selection and key biomarker insights. Biomedical Physics & Engineering Express. 2026 Apr 1;12(2):025032.
18. Sabbadini R, Italiano GF. Machine Learning and ECG-Derived Biomarkers for Objective Pain Assessment: An Explainable AI Approach Toward Precision Pain Management. Pain Research and Management. 2026;2026(1):5131891.

Publisher's Note:
Pakistan Journal of Medical & Health Sciences (Pak J Med Health Sci) remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.