Heart Rate Variability-Measured Stress and Academic Achievement in Medical Students

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Highlights of the Study

- We studied the relationship between stress and academic achievement in medical students.
- Heart rate variability (HRV) is impacted by stress and is used for the objective assessment of stress.
- Medical students with higher stress measured by HRV have higher academic achievement, especially in written examinations.

Keywords

Clinical sciences · General practice · Primary health care · Medical education

Abstract

Objectives: Stress can affect learning and memory in students. Previous studies on stress in students were conducted mainly through surveys. We investigated how heart rate variability (HRV)-measured stress is related to academic achievement in medical students during clerkship. **Subjects and Methods:** A cross-sectional study was conducted. HRV measurements were performed in 97 third-year medical students during their family medicine clerkship course. Data on written and skilled examination scores of the end of the school year were also collected. We assessed the association between HRV-measured stress and written/skilled examina-

tion scores. **Results:** Written examination scores showed a positive correlation with standard deviation of the normal-to-normal intervals (SDNNs) ($r = 0.245$, $p = -0.016$), sympathetic nervous system/parasympathetic nervous system (SNS/PNS) balance ($r = 0.218$, $p = 0.033$), and stress index ($r = 0.381$, $p = 0.004$). Students with an unhealthy SDNN, a dominant SNS, and a high stress index had higher scores in written examinations than students with a healthy SDNN, a balanced SNS/PNS, and a normal stress index, respectively ($p = 0.004$, 0.018 , and 0.012 , respectively). Moreover, skilled examination scores were negatively correlated with BMI ($r = -0.249$, $p = 0.014$) and were higher in female students ($r = 0.240$, $p = 0.018$). Students with an abnormal autonomic balance diagram (ABD) had a higher score than students with a normal ABD ($p = 0.03$). **Conclusions:** This study shows that medical students with higher stress measured by HRV have higher academic achievement, especially in written exami-

nations. Further studies are needed to confirm the results of this study and to assess the long-term effects of HRV-measured stress on medical students.

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Published by S. Karger AG, Basel

Introduction

Globally, medical students experience a high degree of stress related to their academic load, such as a tremendous amount of learning, long semesters, a large number of examinations, and anxiety about a pass/fail grading system [1]. They also experience problems such as insufficient rest, low self-esteem, lack of sleep, and depressive mood. As a result, they suffer from a higher level of stress than college students of the same age in other disciplines [2]. However, the level of perceived stress varies depending on how they control and evaluate stressful situations or factors. If students perceive stress within the acceptable range, it can be helpful and motivating to do academic work as a coping mechanism [3, 4].

Stress is largely assessed by using questionnaires and by measuring objective physical responses [5–10]. Another method is to evaluate physiological and physical symptoms or signs objectively caused by stress using tests for endocrine function, immune function, or the autonomic nervous system (ANS). Heart rate variability (HRV) analysis is a reliable, reproducible, and noninvasive method for quantitatively evaluating sympathetic and parasympathetic activity [11]. HRV is known to associate with certain diseases, to relate an emotional condition and a stressful situation [9], and to correlate with mental and psychological states after stress due to various academic examinations in students [12]. However, little research has been done on the HRV-measured stress and its associations with academic achievement of medical students who frequently experience high levels of stress. Previous studies have reported that medical students are exposed to significant stressors during their medical training, and female medical students are particularly more affected than males [10, 13–15]. These results suggest that even if the stress is the same, there are various ways of coping with stress due to nonspecific reactions that cause different reactions depending on the subject or situation [3]. Therefore, the authors hypothesized that the stress response in male and female medical students is different and that appropriate stress can increase academic achievement. The purpose of this study was to examine HRV-measured stress in medical students during clinical clerkship and how HRV-measured stress relates to their academic achievement.

Subjects and Methods

Study Subjects

A cross-sectional study was conducted. The third year at the Pusan National University School of Medicine is a clerkship year that includes a required 4-week family medicine rotation. As part of the family medicine clerkship course, all students were asked to measure their own HRV. Then, professors educated students to interpret their HRV results and helped them plan how to manage their stress through interviews and stress management. In this study, we utilized the data of 97 third-year students (participation rate = 77.6%) who were nonpregnant and whose HRV was measured between February and November 2016 at the Family Medicine Clinic of Pusan National University Yangsan Hospital. In Korea, medical school begins in February and ends in November. Other data collected included age, gender, anthropometric parameters, smoking status, amount of alcohol consumed, written examination score, and skill examination score. We also conducted individual interviews with students with high stress indices measured by HRV.

Heart Rate Variability

Data collection and HRV analysis were performed using SA-2000E HRV analytic equipment (Medicore Co. Ltd., Seoul, Korea) according to the guidelines of the task force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology [11]. To control diurnal variation, HRV was measured over a period of 5 min between 10:00 a.m. and 12:00 p.m. in a quiet environment at room temperature. Participants were asked to abstain from drinking alcohol 1 day before and from smoking or drinking any caffeinated drinks at least 2 h before HRV testing. Each participant was seated in a chair, and electrodes were placed on the wrists and left foot. The participants were instructed to breathe at a normal rate during HRV measurement. Before the measurement, the participants rested for at least 10 min, breathing spontaneously without talking. The parameters measured in the evaluation of HRV were grouped into 2 categories: time and frequency domains. The mean heart rate and standard deviation of normal-to-normal intervals (SDNNs) were used for time-domain analysis. We also measured the physical stress index (PSI), an indicator that represents the degree of load on the ANS control system. The frequency domain was composed of total spectral power, low-frequency power (LF, 0.04–0.15 Hz), high-frequency power (HF, 0.15–0.40 Hz), and LF/HF ratio. Power in the HF band is an indicator of parasympathetic nervous activity, whereas power in the LF band mostly reflects sympathetic nervous activity. The LF/HF ratio is a general balance indicator used to evaluate sympathetic nervous system/parasympathetic nervous system (SNS/PNS) balance. A high ratio implies intensified activity of SNS or suppression of PNS. LF and HF were represented by 2 graphic views: SNS/PNS and autonomic balance diagrams (ABDs). The stress index was calculated using the HRV parameters proposed in a previous study [16].

Anthropometric Measures and Sociodemographic Factors

BMI was defined as weight (kg) divided by height squared (m^2). Percentage body fat was assessed by bioelectric impedance analysis (Inbody 720; Biospace Co. Ltd., Seoul, Korea). Participants were classified into underweight ($<18.5 \text{ kg/m}^2$), normal weight ($18.5\text{--}22.9 \text{ kg/m}^2$), overweight ($23\text{--}24.9 \text{ kg/m}^2$), or obese ($>25 \text{ kg/m}^2$) groups based on BMI according to the Asian-Pacific cutoff points [17]. Smoking status was classified as participants who had never

Table 1. Basal characteristics of the subjects

	Male (<i>n</i> = 48)	Female (<i>n</i> = 49)	Total (<i>n</i> = 97)
Smoking status ^a			
Never smoker	34 (70.8)	49 (100.0)	85 (85.6)
Ex-smoker	5 (10.4)	0 (0.0)	5 (5.2)
Current smoker	9 (18.8)	0 (0.0)	9 (9.3)
Excessive drinking ^b	23 (47.9)	9 (18.4)	32 (33.0)
Written examination score	55.7±6.6	58.2±8.2	57.0±7.5
Skill examination score ^c	48.1±8.0	52.7±10.4	50.4±9.5
BMI ^a	24.2±2.7	20.2±1.9	22.2±3.1
Obesity degree ^a			
Underweight	0 (0.0)	10 (20.4)	10 (10.3)
Normal	16 (33.3)	37 (75.5)	53 (54.6)
Overweight	18 (37.5)	0 (0.0)	18 (18.6)
Obese	14 (29.2)	2 (4.1)	16 (16.5)
Body fat percent	25.4±13.7	24.9±7.1	25.1±10.9

Data were presented as *n* (%) or mean ± SD. In men and women, excessive alcohol ingestion was defined as >3 drinks (40 g) and >2 drinks (20 g) per day, respectively, based on standard drink sizes described in WHO guidelines. ^a *p* < 0.001. ^b *p* < 0.005. ^c *p* < 0.05 by χ^2 test.

smoked (smoked <100 cigarettes in their lifetime and not currently smoking), ex-smokers (smoked ≥100 cigarettes in their lifetime and currently a non-smoker), and current smokers (smoked ≥100 cigarettes in their lifetime and currently a smoker). In men and women, excessive alcohol ingestion was defined as >3 drinks (40 g) and >2 drinks (20 g) per day, respectively, based on standard drink sizes described in WHO guidelines [18]. Academic performance was assessed by summative written and skill examination scores at the end of the third year. The written examination consisted of 400 multiple-choice questions. The score was transformed to a value on a 100-point scale. The skill examination was operated with 12 stations, including 6 clinical performance examination stations and 6 objective structured clinical examination stations. The skill examination score also totals a maximum of 100 points.

Statistical Analysis

Data are presented as either number (%) or mean ± SD. Analysis of continuous variables was performed using 2-sample *t* test, and categorical variables were analyzed using the χ^2 test for comparison of the 2 groups. ANOVA was used to compare means among the 3 groups. Pearson correlation coefficients were used to examine the correlation between summative written or skill examination scores at the end of the third year and other variables. The data were analyzed using IBM SPSS Statistics 24.0 (IBM, Chicago, IL, USA). A *p* value <0.05 was considered statistically significant.

Results

General Characteristics of Subjects

The male-to-female ratio was 0.98. In total, 18.8% of male students were current smokers, but none of the female students were smokers. The proportion of male stu-

dents with heavy drinking was 47.9%, which was 2.6 times higher than that of female students. A significantly higher proportion of male students (29.2%) than female students (4.1%) were obese. Most female students were normal or underweight. There was no significant difference in the written examination scores between male and female students at the end of the third year, but the female mean score in skill examinations was more than 4 points higher than the male mean score (*p* < 0.05, Table 1).

HRV Parameters

Female students had an unhealthy tachogram ratio 11.6 times higher than in that in males, unhealthy R-R interval variability 13.6 times higher than that in males, and abnormal ABD 2.7 times higher than that in males. On the other hand, there was no gender difference in the other variables (Table 2).

Stress Variabilities and Academic Achievement

The correlation coefficient between the written examination score and the skill examination score was 0.370 (*p* < 0.001). Factors correlating positively with the written examination score were PNS (*r* = 0.218, *p* = 0.033), SDNN (*r* = 0.245, *p* = 0.016), SNS/PNS balance (*r* = 0.218, *p* = 0.033), and stress index (*r* = 0.381, *p* = 0.004), while factors that showed significantly negative correlation with the written examinations score were BMI (*r* = -0.224, *p* = 0.027), obesity degree (*r* = -0.194, *p* = 0.016), and excessive drinking (*r* = -0.245, *p* = 0.016). The one factor cor-

Table 2. Stress-related heart rate variables of study subjects

	Male (<i>n</i> = 48)	Female (<i>n</i> = 49)	Total (<i>N</i> = 97)	<i>p</i> value
<i>Time domain</i>				
SDNN, unhealthy	10 (20.8)	11 (22.4)	21 (21.6)	0.847
Tachogram, unhealthy	1 (2.1)	12 (24.4)	13 (13.1)	0.001
Histogram, unhealthy	28 (59.6)	33 (67.3)	61 (62.9)	0.358
RRV, unhealthy	1 (2.1)	14 (28.6)	15 (15.5)	<0.001
PSI, unhealthy	5 (10.4)	7 (14.2)	12 (12.4)	0.563
<i>Frequency domain</i>				
TP reduction	15 (31.3)	21 (42.9)	36 (37.1)	0.237
LF reduction	11 (22.9)	17 (34.7)	28 (28.9)	0.201
HF reduction	11 (22.9)	18 (36.7)	29 (29.9)	0.137
LF/HF ratio				
Low	5 (10.4)	8 (16.3)	13 (13.4)	0.539
Normal	38 (79.2)	34 (69.4)	72 (74.2)	
High	5 (10.4)	7 (14.3)	12 (12.4)	
SNS/PNS balance				
SNS dominant	14 (29.2)	17 (34.7)	31 (32.0)	0.383
PNS dominant	7 (14.6)	11 (22.4)	18 (18.6)	
Balanced	27 (56.3)	21 (42.9)	48 (51.5)	
ABD, abnormal	4 (8.3)	11 (22.4)	15 (15.5)	0.039
Stress index, high	9 (18.8)	10 (20.4)	19 (19.6)	0.838

Data were presented as *n* (%). SDNN, standard deviation of the normal-to-normal intervals; RRV, R-R interval variability; PSI, physical stress index; TP, total power; LF, low-frequency group; HF, high-frequency group; SNS, sympathetic nervous system; PNS, parasympathetic nervous system; ABD, autonomic balance diagram.

relating positively with the skill examination score was gender (female; $r = 0.240$, $p = 0.018$), while BMI ($r = -0.249$, $p = 0.014$) correlated negatively with the skill examination score (Table 3).

Academic Achievement by Stress Variabilities

Students with unhealthy SDNN scored 4 points higher ($p = 0.004$) than those with healthy SDNN in the written examination, but no difference was observed in skill examination scores. In SNS/PNS balance, students with predominantly sympathetic nerve activity had a higher written examination score (5 points, $p = 0.018$) than students with a balance between the sympathetic nerve and parasympathetic nerves ($p = 0.018$); however, no difference was observed in skill examination scores. Students with abnormal ABDs did not differ in the written examination scores compared to students with normal ABDs, whereas students with abnormal ABD scores had a higher skill examination score (5 points, $p = 0.03$) than those with normal ABDs. Students with a higher stress index had a higher written examination score (6 points, $p = 0.012$) than students with normal stress, but no difference was seen in the skill examination scores (Table 4).

Discussion

HRV is a biological marker of stress in humans. Current neurobiological evidence suggests that HRV is impacted by stress and supports its use for the objective assessment of stress [19]. In this study, we aimed to examine the characteristics of HRV in medical students and to ascertain how the stress relates to academic achievement in medical students during clerkship.

Everyone experiences stress; however, even if stress is experienced in similar conditions, the level and duration of stress and physical response of each person to stress are not the same due to individual characteristics [19]. High efficiency of students' intellectual activities can be achieved through high tension mechanisms [3]. Medical students have a high level of stress due to excessive academic load, frequent examination, fear of failure due to pass/fail grading system, peer relations, and financial issues. It is not easy to manage such stresses in real-life situations. Some medical students even suffer from depression, anxiety, psychological distress, or burnout [20]. Although academic pressure is a stress factor, academic achievement is an important indicator of educational

Table 3. Correlation between stress variabilities and academic achievement

	Written examination score	Skill examination score
Written examination score	1	0.370 (<0.001)
Skill examination score	0.370 (<0.001)	1
Gender (male 1, female 2)	0.136 (0.183)	0.240 (0.018)
BMI	-0.224 (0.027)	-0.249 (0.014)
Body fat percent	0.105 (0.304)	0.004 (0.971)
Obesity	-0.194 (0.057)	-0.180 (0.078)
Smoking status	0.036 (0.724)	-0.032 (0.753)
Excessive drinking	-0.245 (0.016)	0.007 (0.942)
SDNN	0.245 (0.016)	0.048 (0.640)
Tachogram, unhealthy	0.045 (0.667)	-0.049 (0.897)
Histogram, unhealthy	0.065 (0.532)	0.014 (0.897)
RRV, unhealthy	0.034 (0.740)	-0.024 (0.816)
PSI, abnormal	0.186 (0.071)	-0.006 (0.952)
TP reduction	0.034 (0.744)	0.072 (0.481)
LF reduction	-0.034 (0.743)	0.076 (0.462)
HF reduction	0.021 (0.836)	0.090 (0.378)
LF/HF ratio	-0.049 (0.636)	-0.014 (0.891)
SNS/PNS balance	0.218 (0.033)	0.053 (0.608)
ABD, abnormal	0.120 (0.247)	0.165 (0.111)
Stress index	0.381 (0.004)	0.153 (0.266)

Data were presented as correlation coefficient (*p* value). Bold values indicate statistically significant results. SDNN, standard deviation of the normal-to-normal intervals; RRV, R-R interval variability; PSI, physical stress index; TP, total power; LF, low-frequency group; HF, high-frequency group; SNS, sympathetic nervous system; PNS, parasympathetic nervous system; ABD, autonomic balance diagram. Smoking status: 1 never smoked; 2 ex-smoker; 3 current smoker; excessive drinking: 0 no; 1 yes; SDNN: 0 normal, 1 abnormal; tachogram, unhealthy; histogram, unhealthy, RRV, unhealthy; PSI, abnormal; TP reduction; LF reduction; HF reduction; ABD, abnormal: 1 no, 2 yes; LF/HF ratio: 1 low, 2 normal, 3 high; SNS/PNS balance: 1 SNS dominant, 2 PNS dominant, 3 balanced; stress index: 1 normal, 2 high.

outcomes. As reported in previous studies [2, 21], the results of this study showed that stress measured by HRV was also related to academic achievement.

Although appropriate stress is beneficial in stimulating learning and memory in students, previous studies showed mixed results between stress and academic achievement [6, 8, 9, 22]. Some studies have reported a negative correlation [6], others have shown a positive correlation [8], and yet others have reported no relationship [9] between stress and academic achievement. A previous study found that optimal stress levels could improve academic achievement, which supports an inverted-U relationship between stress and performance [5]. An analysis of academic achievement according to the stress level

Table 4. Differences of academic achievement by results of stress variabilities

	Written examination score	Skill examination score
SDNN		
Healthy (<i>n</i> = 76)	55.8±7.1 ^a	49.7±8.8
Unhealthy (<i>n</i> = 21)	61.2±8.1 ^a	52.3±12.1
SNS/PNS balance		
SNS dominant (<i>n</i> = 31)	59.5±7.8 ^b	50.7±9.5
PNS dominant (<i>n</i> = 18)	57.5±7.8	50.8±8.6
Balanced (<i>n</i> = 48)	54.7±6.2 ^b	49.6±9.5
ABD		
Normal (<i>n</i> = 82)	56.6±7.5	49.8±8.7 ^c
Abnormal (<i>n</i> = 15)	59.3±7.5	55.5±11.4 ^c
Stress index		
Normal (<i>n</i> = 78)	56.2±7.2 ^d	49.6±8.8
High (<i>n</i> = 19)	62.3±6.0 ^d	53.0±11.8

Data were presented as mean ± SD. SDNN, standard deviation of the normal-to-normal intervals; SNS, sympathetic nervous system; PNS, parasympathetic nervous system; ABD, autonomic balance diagram. ^a *p* = 0.004. ^b *p* = 0.018. ^c *p* = 0.03. ^d *p* = 0.02.

among female college students in Pakistan showed that the students with appropriate stress (mildly tense or moderately tense) had higher academic achievement than the very tense (and not tense) students [5]. However, a previous study reported that the precise shape of the inverted-U-shape curve may vary for different personal characteristics [22]. As such, there are various results concerning the relationship between stress and academic achievement. The reason why previous research results were inconsistent could partly be explained by the fact that their subjects were different [22] and that researchers relied heavily on self-reported questionnaires as a tool for measuring stress [5–9]. In self-reported questionnaires, it is common to use the average of the factors to be measured, which is somewhat ambiguous for use as concrete guidance in actual educational situations. Therefore, we attempted to analyze and interpret the changes in cognitive and psychological states of learners during the learning process by measuring physiopsychological reaction [23]. Physiopsychological response is an objective indicator, which can explain the state of the object under investigation at various levels without undue interference or influence on learning. Therefore, it is relatively easy to capture the cognitive and psychological states of objects that cannot be observed with the naked eye and allows evaluators to deepen their understanding of learners [23]. It seems

that when students are not stressed, students do not pay much attention, but as stress increases, they focus on their work and improve their academic performance. However, if stress is sustained, it can have a negative effect on academic achievement, and excessive stress appears to reduce achievement levels [5]. This should be taken into account when teaching or counseling students.

Among the methods for confirming the physiological response, HRV is used as an index to evaluate the physiological adaptability of the subject to a changing environment in various clinical experiments involving changes in the ANS. In addition, the test for HRV is recognized as useful in confirming the ANS activity and balance level in objectively evaluating the psychological and emotional states of an individual [24]. Nonetheless, we were not able to find a study that measured and interpreted HRV in the context of testing or learning. However, the present study using HRV has shown that a certain degree of stress has a positive effect on academic achievement by confirming that SDNN, SNS/PNS balance, and stress index are positively correlated with examination scores. When the stress lasts for a certain length of time, the mind and body can be kept in a balanced state by the principle of homeostasis; thus, stress in the form of a little tension becomes a person's driving force and increases one's efficiency and productivity. This degree of stress can be beneficial both physically and mentally. However, when people are less able to cope with stressors or repeated stress, the ANS activity is reduced and unbalanced, resulting in emotional anxiety and depression, and constant tension of the ANS. As a result, mental or physical dysfunctions or illnesses appear, making it essential to recognize and manage stress for good health. In addition, stress experienced by medical students during their education greatly influences their psychological attitudes as students and as physicians in the future. This can seriously affect the formation of doctor-patient relationships and the quality of medical care [25]. Doctors are exposed to high levels of stressors from emotions that arise in the context of patient care to the situations in which they practice [26]. Nevertheless, the problems for medical students are that stress is a part of the medical schooling that is to be endured in the future, and the level of interest and recognition of the college or professors in the stress of medical students is very low. Therefore, schools need to understand the relationship between HRV-measured stress and academic achievement and provide students with effective counseling and educational programs for stress management based on HRV results.

Medical students, regardless of gender, suffer from many stresses as well as general stress. In general, medical

students are constantly undergoing some level of stress. However, in this study, the female students were more stressed. In addition, female students scored better than male students in both written and skilled examinations. Female students are more likely than male students to have higher academic achievement [27], and female students are more likely to perceive stress than male students. Previous studies have shown inconsistent results regarding gender difference in academic performance, but in general, female medical students in Korea and China have significantly higher scores than male students, as supported by the results of the present study [27, 28]. In previous studies, the gender differences were explained by the findings that female students had higher perceptions of academic performance, internal motivation for academic achievement, and more academic planning activity than male students [13]. In addition, female students were more likely to focus their perceived stress on academic performance than male students [14]. In other words, it may be interpreted that female students tend to react more sensitively than male students to similar situations or to the environment in general. In addition, as female students perceive the amount and the complexity of the workload increases significantly more than the male student, they are more likely to suffer more serious academic stress than male students, thereby experiencing more emotional and physical exhaustion [15].

As described above, this study examined the relationship between stress and academic achievement of medical students using HRV, a biological marker of stress. As a result, it was found that the higher the stress level, the higher the students' paper-written test scores, and that there was a gender difference in the stress level. These findings reveal that stress is not a factor that negatively affects all medical school students collectively but that stress can also act partially positively on students. Stress may have a positive effect, at least partially, on the academic achievement of students. In addition, this study has suggested that understanding students' stress levels can help them manage school and academic achievement. In particular, this study is meaningful in that it attempted more objective and scientific measurements of psychological construct by measuring stress using biological markers, rather than self-administered questionnaires in the context of clinical clerkship.

Even at the same level of stress, ways of coping with stress can be different. In a previous study in Korea, the most common coping styles of medical students were the avoidance and problem-focused coping strategy [29]. These 2 are known as conflicting strategies. Students who better adapt to stressful situations used problem-focused

coping strategies, and students with low level of adaptation and high depression used avoidance coping strategies [29]. Stress coping styles can be diverse and culturally different. Therefore, it will be necessary to guide and support each student to have a healthy coping method considering cultural and individual characteristics so that they can achieve academic achievement and adapt well.

Our study has several limitations. First, each medical school has its own characteristics and rules which decide teaching and learning methods. These differences may limit the generalizability of our findings, even though a high proportion of third-year students participated in this study. Second, HRV was measured only once in this study. The degree of stress may vary depending on when the HRV assessment is performed because students need a period of adaptation to settle into the pace and expectations of the clerkship year. Also, stress as measured by HRV does not only mean stress associated with school-work but also reflects everyday life and general health. Nevertheless, HRV represents the overall autonomic context, and previous studies revealed that at rest, HRV indicators have good reliability, repeatability, and reproducibility [11, 17]. Especially, good reproducibility was shown when HRV was measured repeatedly over 12-month intervals in patients with type 1 diabetes mellitus [30]. Therefore, HRV at rest can be considered as the usual stress, and previous studies have measured HRV once as in this study. Third, this study aimed to increase the validity of academic stress measurement by measuring the stress level of students in the same clinical clerkship. However, in order to investigate the level of stress of students and how they respond to various clinical clerkship situations, such as on rounds and in the operating room, patient management and in-depth qualitative research through tools such as observation and interview should be conducted in the future. Fourth, the cross-sectional nature of the study prevented us from confirming the impacts of stress-measured HRV in academic performance. In the present study, we are unable to infer causality from our findings. There is still controversy regarding stress and learning. During learning, stress can improve memory formation (leading to stronger memories), while also compromising your memory (leading to the risk of dropping out of the test [21]). Fourth, stress is a very complicated concept. It would be difficult to determine the presence of stress and its severity by measuring HRV alone. Finally, this study was conducted at a single site. Despite these limitations, the strengths of this study were that students' stress was measured more objectively using HRV, instead of a subjective questionnaire; also, academ-

ic performance was a comprehensive evaluation (the written examination and the skill examination), not a one-time evaluation.

Conclusion

Medical students with higher stress measured by HRV were found to have higher academic achievement, especially in written examinations. Female students are more likely to suffer academic stress than male students. This suggests that appropriate stress can have a positive impact on school performance in medical students. However, replication of this study will be needed in order to confirm the results of this first-stage study to measure medical students' stress using HRV, and additional studies are required to assess the long-term effects of HRV-measured stress on medical education.

Statement of Ethics

As this study used pre-existing, de-identified data, it was exempt from the institutional review board (IRB No. 05-2017-102).

Conflict of Interest Statement

There are no conflicts of interest.

Funding Sources

The authors did not receive any funding.

Author Contributions

Yoo H.H. and Lee S.Y. conceived and designed the study, collected the data, and wrote the paper. Yune S.J., Kam B.S., and Im S.J. collected the data and analyzed the data. All authors discussed the results and contributed to the final manuscript.

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