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Gritty Heart: Improved Heart Rate Variability Markers of Adaptive Physiological Response in Grit

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ABSTRACT

Grit is a personality trait, conceptualized as perseverance of effort and consistency of interests in long-term goals. Previous research has shown that grit is associated with various positive outcomes, including well-being. Despite extensive research on grit, most studies relied on self-reported measures rather than objective measures. To address this gap, our study investigated the relationship between grit and physiological responses, focusing on resting-state heart rate variability (HRV)–a physiological marker of well-being and adaptability. Additionally, we examined whether this relationship was unique to grit and not explained by other related psychological constructs (i.e., conscientiousness and self-control). A total of 206 healthy college students participated in this study ($M_{age}=21.03$, SD = 2.48, age range = 18–33; 111 women). Results of hierarchical regression analyses showed that grit significantly predicted resting-state HRV measures (i.e., RMSSD, SDNN, and HF) even after controlling for conscientiousness, self-control, age, gender, and respiration rate. These findings suggest that grit may play an important role in maintaining improved biological responses in daily life, beyond the effects of neighboring constructs.

1 | Introduction

Grit is defined as a non-cognitive ability to persevere and maintain consistent passion for long-term goals even in frustrating situations (Duckworth et al. 2007), which is usefully described by its two subcomponents—perseverance of effort (PE) and consistency of interest (CI). Grit has been suggested to be associated with various positive outcomes, including academic achievement (Bowman et al. 2015; Duckworth et al. 2007; Jiang et al. 2019), career adaptability (Gregor et al. 2021; Li et al. 2021), subjective well-being (Jiang et al. 2020; Jin and Kim 2017; Zhang et al. 2024), and physical health (Knauft et al. 2024; Reed et al. 2013; Rhodes and Giovannetti 2022). For example, college students with high levels of grit were less likely to change majors and demonstrated a greater grade point average (Bowman et al. 2015). They also showed greater career adaptability through career exploration and decision self-efficacy (Li et al. 2021). Furthermore, because gritty individuals tend to perceive frustrating situations as less stressful (Knauft et al. 2024), they experience less burnout and better subjective well-being (Dam et al. 2019).

While prior studies have highlighted the positive consequences of grit, an ongoing debate concerns the incremental predictive validity of grit over conceptually related psychological constructs within its nomological network such as self-control and conscientiousness (Credé et al. 2017;

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Ponnock et al. 2020; Schmidt et al. 2018; Vazsonyi et al. 2019). Although these traits are conceptually and empirically related (Duckworth et al. 2007; Duckworth and Gross 2014), they are not identical. An increasing number of studies have shown that grit uniquely explains motivational, cognitive, and emotional outcomes above and beyond these neighboring constructs (Duckworth et al. 2007; Eskreis-Winkler et al. 2014; Gorin et al. 2024; Jiang et al. 2023; Suzuki et al. 2015). For instance, grit predicted high school graduation (Eskreis-Winkler et al. 2014), grade point average, and academic goal motivation among college students (Duckworth et al. 2007; Werner et al. 2019) even after controlling for conscientiousness. Similarly, grit had incremental utility when predicting individuals' mental and physical health outcomes (Hou et al. 2022; Kwon 2021). For example, one study showed that PE predicted subjective well-being beyond conscientiousness (Kwon 2021). Also, a recent meta-analysis showed that grit predicted subjective well-being above and beyond conscientiousness ($\beta = 0.38$; Hou et al. 2022).

Despite the evidence supporting the beneficial effects of grit, most previous research has relied on self-report rather than objective measures to examine its relationship with health outcomes. For example, in a study by Sharkey et al. (2017), individuals' healthcare management skills were measured using a self-report questionnaire, including items like, "Do you follow-up on any referrals for tests or check-ups or labs?". Accordingly, a recent review paper suggested that "Future research can also generate stronger evidence on the construct validity of grit through exploring how grit and its dimensions may relate to specific neurocognitive and physiological processes" (Datu 2021, p.11). Thus, incorporating a wider range of objective and physiological measures could offer better insight into the effect of grit over and above the related constructs.

To address this, we tested whether grit was associated with physiological features beyond self-control or conscientiousness. Specifically, we focused on heart rate variability (HRV) given its utility as a physiological indicator of health outcomes (Heiss et al. 2021; Kemp and Quintana 2013). HRV measures the difference between successive heartbeats on a millisecond scale, which is known to represent the status of the autonomic nervous system (Rajendra Acharya et al. 2006). According to the recently proposed Neurovisceral Integration Across a Continuum of Time (NIACT) model, higher HRV is an indicator of healthy vagal function assisting in everyday psychological moments as well as the ability to adjust flexibly to changes in the environment. Higher HRV significantly contributes to better physical and mental health and decreased risks of mortality in the long run (Kemp et al. 2017). Supporting the NIACT model, empirical studies have shown that higher HRV is related to affective, cognitive, and psychological flexibility (Allen et al. 2018; Grol and De Raedt 2020; Howell and Hamilton 2022; Keen et al. 2020), as well as better physical and mental health and healthy longevity (Kemp and Quintana 2013; Zulfiqar et al. 2010).

Given that HRV is associated with the ability to adapt to unfamiliar situations, some researchers suggested that HRV might be related to an individual's personality characteristics (Geisler et al. 2010; Huang et al. 2013; Shepherd et al. 2015; Silvia et al. 2014). Specifically, high levels of cheerfulness and calmness help people engage in more emotional regulation (e.g., refocusing, reappraisal), leading to higher HRV during rest (Geisler et al. 2010). Furthermore, another study showed that the Big Five dimensions of neuroticism and openness, as well as trait anxiety were associated with lower HRV during a resting period (Shepherd et al. 2015). Overall, these results demonstrated that the positive aspects of one's personality were associated with higher HRV indices (i.e., high levels of HRV), indicative of adaptive psychophysiological functioning.

Although empirical work examining the relationship between grit and HRV has been scarce, there is one study investigating such relationships while actively engaging in a task (Silvia et al. 2013). This study demonstrated that individuals with higher PE regulated their psychophysiological responses more flexibly (i.e., increased HRV) during tasks. Although this pioneering work provides valuable insights into the relationship between grit and HRV, it did not examine whether these effects remain significant when controlling for self-control and conscientiousness. Additionally, the study has a small sample size ($N = 36$), limiting the generalizability of the findings. Moreover, changes in HRV *during* tasks may reflect temporary psychophysiological adaptations to environmental challenges (Kemp et al. 2017). In fact, HRV during tasks can be affected by the characteristics of the tasks, such as cognitive workload (Luque-Casado et al. 2016). In contrast, resting-state HRV may manifest an individual's trait-like psychophysiological resources (Kemp et al. 2017). Thus, resting-state HRV may be a promising psychophysiological feature in explaining personality traits, as it is more apt to discuss how individuals differ in their stable behavioral patterns that influence their responses to various life events, rather than just a single event (DeYoung 2015; Nettle 2007). Therefore, with over 200 participants, we aimed to provide initial evidence of how grit is related to resting-state HRV, particularly in comparison to other relevant constructs (i.e., self-control and conscientiousness).

We hypothesized that gritty individuals would show high levels of HRV in a resting state. Gritty individuals maintain a strong positive attitude and experience more happiness than others not only upon facing difficulties (Gregor et al. 2021; Li et al. 2021; Toyama 2024) but also in daily life (Jiang et al. 2020; Khan and Khan 2017). Their tendency to see daily setbacks as temporary and opportunities to learn helps them perceive situations as less stressful than others (Estevez et al. 2023; Lee 2017; Yang et al. 2023). Furthermore, gritty individuals are less likely to show significant stress responses to the minor ups and downs of stressors. Indeed, gritty adolescents and adults had lower levels of perceived daily stress (Knauft et al. 2024; Lee 2017). These characteristics can lay a foundation for grittier individuals to have better autonomic regulation and higher resting-state HRV, reflecting their stable behavioral patterns and effective stress management.

In this study, we collected resting-state HRV data over a 10-min period and linked it with participants' self-reported grit using hierarchical linear regression analyses. To address the conceptual validity of grit, we included two covariates (i.e., self-control and conscientiousness) alongside grit when predicting HRV indices. We hypothesized that individuals with higher levels of grit would exhibit healthier vagal function, indicated by higher scores on HRV measures. Furthermore, we anticipated that grit would provide additional predictive utility for physiological measures beyond conscientiousness and self-control.

2 | Methods

2.1 | Participants

Our study was approved by the Institutional Review Board of the authors' university. Written informed consent was provided by all participants prior to the beginning of the experiment. We recruited 211 university students who were either enrolled in Introduction to Psychology courses ($n = 143$) or received monetary compensation ($n = 68$). All participants were Korean. Each participant received extra credits or 20,000 KRW (~15 USD) for participation. Three participants who did not pass at least one out of the two attention check questions (e.g., "Answer with 'strongly agree' to this item") and two participants who were excluded during preprocessing due to low-quality electrocardiograms (ECG) data were omitted from further analyses. Therefore, our final sample included 206 participants ($M_{age} = 21.03$, SD = 2.48, age range = 18–33; 111 women).

2.2 | Procedure

When signing up for the study and on the day before participation, participants were instructed not to smoke, eat, drink, or exercise within 1–2 h before the study session, in line with previous studies (Hallman et al. 2011; Jennings et al. 1992; Li et al. 2024; Ottaviani et al. 2008; Wells et al. 2012), as these factors may impact HRV measures (Bodin et al. 2017; Romanowicz et al. 2011). Additionally, individuals taking any medication were not eligible to participate. Upon arriving at the laboratory, participants were given instructions about the procedure in a quiet room. Before starting the experiment, participants self-reported their intake of nicotine, food, and beverages within the past 1–2 h and indicated whether they were taking any medication. Participants who reported consuming nicotine, food, or beverages, or indicated that they were currently taking medication, were not allowed to take part in the study ($n = 1$). Next, participants completed a series of questionnaires online, which took approximately 5 min in total. All questionnaires were translated and back-translated by corresponding authors, who are fluent in both Korean and English. After finishing the survey, the experimenter asked participants to attach three patches to their body (right clavicle, left iliac crest, and right ankle) to measure HRV. The ECG were recorded for 10 min. During the data recording, participants looked at the blank screen until the recordings were done.

2.3 | Questionnaires

2.3.1 | Grit

Grit was measured using the 12-item Grit Scale (Duckworth et al. 2007), which was translated into Korean. Grit has two facets (CI: Consistency of Interest; PE: Perseverance of Effort) and each facet was measured with six items on a 5-point Likert scale (1 = *strongly disagree*, 5 = *strongly agree*). The average grit score was calculated by averaging the PE (e.g., "I am a hard worker") and the reversed-scored CI (e.g., "I have been obsessed with a certain idea or project for a short time but later lost interest"). Therefore, higher scores indicate higher levels of grit. Internal consistency of the scale, indexed by Cronbach's alpha, was $\alpha = 0.77$ (CI: $\alpha = 0.73$; PE: $\alpha = 0.77$).

2.3.2 | Self-Control

We measured self-control using the 11-item Korean version of the Brief Self-Control Scale (BSCS; Hong et al. 2012) on a 5-point Likert scale (1 = *strongly disagree*, 5 = *strongly agree*), which was originally developed by Tangney et al. (2004). BSCS measures two aspects of self-control: self-discipline (e.g., "I am good at resisting temptation" and "I have a hard time breaking bad habits") and concentration (e.g., "I am able to work effectively toward long-term goals" and "I am lazy"). Negatively worded items were reverse-coded so that higher scores represent greater self-control. Internal consistency was Cronbach's $\alpha = 0.80$.

2.3.3 | Conscientiousness

Conscientiousness was assessed using the translated 12-item Conscientiousness subscale of the Big Five Inventory-2 (BFI-2; Soto and John 2017), which was administered on a 5-point Likert scale (1 = *strongly disagree*, 5 = *strongly agree*). Conscientiousness consists of organization (e.g., "Keep things neat and tidy" and "Tends to be disorganized"), productiveness (e.g., "Is efficient, gets things done" and "Has difficulty getting started on tasks"), and responsibility (e.g., "Is dependable, steady" and "Sometimes behaves irresponsibly") subcomponents. Negatively worded items were reverse-coded such that higher scores indicate greater conscientiousness. Internal consistency was Cronbach's $\alpha = 0.85$.

2.4 | Heart Rate Variability Assessment

To obtain HRV measures, we carefully followed Standardized guidelines in *Psychophysiology* (Quigley et al. 2024) and previous studies (Fanti et al. 2017; Li et al. 2024; Watford et al. 2020). ECG was obtained using Biopac MP36 (Biopac Inc., Santa Barbara, CA) at a 2000 Hz sampling frequency (https://www.biopac.com/wp-content/uploads/ECG-Guide.pdf). We attached three electrodes to the participants for the configuration of a Lead II ECG. The electrodes were placed as follows: A negative electrode below the right clavicle, a positive electrode above the left iliac crest, and a ground electrode on the right ankle. ECG data was preprocessed by the Kubios software v.4.1.0 (Tarvainen et al. 2014) with a 1 Hz high-pass filter and moving-average filtering (https://www.kubios.com/downloads/HRV-Scientific-Users-Guide.pdf).

Kubios automatically detected R waves by adapting a QRS detection algorithm that corrects inaccurate R-peaks, including ectopic beats (see Lipponen and Tarvainen 2019, for its validity). Specifically, detected artifact beats are replaced by a 4 Hz cubic spline interpolation. Also, the detrending method, which removes very low frequency trend components, is applied for every RR interval data to eliminate the nonstationarity problem. In our sample, none of the participants had a beat correction rate higher than 5% ($M = 0.19$, $SD = 0.44$; range: 0% to 3.38%), indicating the high quality of our data. Following automatic correction, we visually inspected the ECG data and manually edited the noise segments within it ($M = 3.75$ s). As a result, the ECG data from 13 participants included data loss exceeding 5 s due to movement-induced noise, and we excluded two participants whose R-peaks were not properly identified due to numerous motion artifacts. Of note, removing participants whose beat correction rate exceeded 1% ($n = 5$) did not significantly alter the pattern of the results (see Table S1).

Based on previous studies, we calculated the following variables using Kubios with default settings as indices for cardiac parasympathetic control in the time domain (Li et al. 2024; Malik et al. 1996; Pereira et al. 2017): square root of the mean squared differences between successive RR intervals (RMSSD) and pNN50 divided by the total number of RR intervals (pNN50). In addition, the absolute power of the High-Frequency band (HF; 0.15–0.4 Hz) was calculated as it reflects cardiac parasympathetic control in the frequency domain (Li et al. 2024; Watford et al. 2020) applying FFT-based Welch's periodogram. In brief, higher values of these variables indicate greater psychophysiological adaptability. Log-transformation was conducted with HF to adjust for its non-normality (Kuo et al. 1999). We note that concerns about the interpretation of the Low-Frequency band (LF) and LF/HF ratio have been raised (Billman 2013) and thus these measures were not included in the present analysis.

2.5 | Data Analysis

We used SPSS 22.0 to conduct correlation and hierarchical regression analyses to test our hypotheses. Confidence intervals (95%) of regression coefficients were acquired by conducting 5000 bootstrap resampling. In addition, based on previous research suggesting their influence on HRV (Quigley et al. 2024; Voss et al. 2015), age, gender, and respiration rate were entered into the models as covariates in step 1 of the hierarchical regression analysis. In step 2, grit was added to the model to test the degree to which grit contributed to the prediction of HRV. In step 3, self-control and conscientiousness were included in the model to examine the unique contributions of grit in predicting HRV, above and beyond the effects of these related yet distinct psychological constructs.

3 | Results

3.1 | Descriptive Statistics and Correlation Analysis

Descriptive statistics and correlation results are presented in Table 1. As expected, there were significant positive correlations among HRV responses (i.e., RMSSD, pNN50, and HF) and among personal characteristics (i.e., grit, self-control, and conscientiousness). Self-control showed significant positive correlations with RMSSD, pNN50, and HF ($0.145 \leq rs \leq 0.161$), while conscientiousness showed a marginally significant correlation with HF ($r = 0.135$, $p = 0.052$) and significant positive correlations with RMSSD ($r = 0.159$, $p = 0.022$) and pNN50 ($r = 0.166$, $p = 0.017$). Grit showed significant positive correlations with HRV measures ($0.215 \leq rs \leq 0.236$).

3.2 | Regression Analysis

To test the extent to which individual differences in grit predict HRV at rest, we conducted three-step hierarchical regression analyses. In the first step, we included demographic information (i.e., age and gender) and respiration rate as a predictor for HRV responses. The results showed that while neither age nor gender predicted any HRV responses (Table 2), respiration rate significantly predicted HF ($B = -5.707$, $SE = 1.348$, $p < 0.001$). In the second step, we added grit as a predictor. Similar to the first step, age and gender did not predict HRV responses, while respiration rate predicted HF alone ($B = -5.855$, $SE = 1.320$, $p < 0.001$). Additionally, grit significantly predicted RMSSD ($B = 6.769$, $SE = 1.822$, $p < 0.001$), pNN50 ($B = 5.693$, $SE = 1.561$, $p = 0.001$), and HF ($B = 0.452$, $SE = 0.135$, $p = 0.001$). Finally, to examine how grit uniquely predicts HRV responses compared to other relevant traits, we added self-control and conscientiousness in the third step. Grit still significantly predicted the HRV responses even when including the control variables. Specifically, only grit significantly predicted RMSSD ($B = 7.001$, $SE = 3.062$, $p = 0.021$), whereas covariates such as age, gender, respiration rate, self-control, and conscientiousness did not. Similarly,

TABLE 1 | Descriptive statistics and correlations for variables.

Variable	*M*	SD	1	2	3	4	5
1. RMSSD	29.531	14.761					
2. pNN50	11.274	12.886	0.962***				
3. HF	5.627	1.038	0.895***	0.814***			
4. Grit	3.140	0.538	0.236**	0.229**	0.215**		
5. Self-control	3.192	0.585	0.161*	0.145*	0.155*	0.634***	
6. Conscientiousness	3.318	0.621	0.159*	0.166*	0.135†	0.698***	0.675***

Note: $N = 206$.
†$p < 0.10$.
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

TABLE 2 | Hierarchical regressions of associations between grit and HRV.

	RMSSD				pNN50				HF			
	B	**95% CI**	R^2	ΔR^2	***B***	**95% CI**	R^2	ΔR^2	***B***	**95% CI**	R^2	ΔR^2
Step 1			0.010	0.010			0.004	0.004			0.073**	0.073**
Respiration Rate	−23.037	[−61.921, 17.893]			−12.616	[−46.709, 25.179]			−5.707***	[−8.354, −3.066]		
Age	−0.324	[−1.158, 0.617]			−0.196	[−0.852, 0.564]			−0.033	[−0.085, 0.030]		
Gender	1.517	[−2.643, 5.735]			0.367	[−3.294, 3.791]			−0.041	[−0.318, 0.227]		
Step 2			0.070**	0.060***			0.059*	0.056**			0.127***	0.054**
Respiration Rate	−25.248	[−63.629, 13.584]			−14.476	[−47.838, 22.404]			−5.855***	[−8.436, −3.280]		
Age	−0.490	[−1.261, 0.418]			−0.336	[−0.981, 0.424]			−0.044	[−0.094, 0.017]		
Gender	1.430	[−2.570, 5.441]			0.294	[−3.235, 3.709]			−0.047	[−0.320, 0.220]		
Grit	6.769***	[3.250, 10.410]			5.693**	[2.680, 8.832]			0.452**	[0.192, 0.724]		
Step 3			0.070*	0.000			0.060†	0.000			0.128***	0.001
Respiration Rate	−25.101	[−62.326, 13.346]			−15.404	[−47.264, 21.115]			−5.949***	[−8.554, −3.255]		
Age	−0.490	[−1.281, 0.446]			−0.344	[−1.015, 0.441]			−0.045	[−0.095, 0.017]		
Gender	1.442	[−2.450, 5.478]			0.246	[−3.227, 3.657]			−0.051	[−0.323, 0.220]		
Grit	7.001*	[0.847, 12.952]			5.741*	[0.412, 11.118]			0.514*	[0.103, 0.933]		
Self-Control	0.098	[−5.259, 5.957]			−0.598	[−5.328, 4.649]			−0.060	[−0.398, 0.315]		
Conscientiousness	−0.372	[−5.081, 4.162]			0.461	[−3.542, 4.491]			−0.024	[−0.358, 0.308]		

Note: $N = 206$.
Abbreviations: B = unstandardized coefficient; CI = confidence interval.
†$p < 0.10$.
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

grit was the sole variable that predicted pNN50 ($B = 5.741$, $SE = 2.740$, $p = 0.037$). Also, grit ($B = 0.514$, $SE = 0.205$, $p = 0.012$) and respiration rate ($B = -5.949$, $SE = 1.361$, $p < 0.001$) predicted HF. Overall, individuals with higher levels of grit tended to exhibit greater HRV (i.e., RMSSD, pNN50, and HF), which is representative of adaptive physiological response (Table 2). Compensation type, whether extra credits or monetary, did not moderate the effects of grit on any type of HRV responses ($ps > 0.05$). As a robustness check, we replicated the analyses by randomly splitting the data in half. The direction and effect sizes remained largely consistent (see Tables S2 and S3).

We further conducted facet-level analyses to explore whether the same patterns were found in the two subcomponents of grit (i.e., PE and CI) when predicting HRV responses. Results are presented in Tables S4 and S5. Consistent with the results from the main analysis, most of the covariates, including age, gender, self-control, and conscientiousness, did not predict any of the HRV metrics, except the effect of respiration rate on HF. When PE was included in the model along with age, gender, and respiration rate, PE significantly predicted RMSSD ($B = 5.122$, $SE = 1.519$, $p = 0.001$) and pNN50 ($B = 4.367$, $SE = 1.332$, $p = 0.001$). Also, PE ($B = 0.375$, $SE = 0.103$, $p < 0.001$) and respiration rate ($B = -6.125$, $SE = 1.464$, $p < 0.001$) significantly predicted HF. In the final model, which included self-control and conscientiousness, PE significantly predicted RMSSD ($B = 4.552$, $SE = 1.963$, $p = 0.021$) and pNN50 ($B = 3.742$, $SE = 1.723$, $p = 0.031$). Additionally, both PE ($B = 0.376$, $SE = 0.133$, $p = 0.005$) and respiration rate ($B = -6.056$, $SE = 1.494$, $p < 0.001$) significantly predicted HF. A similar pattern emerged for the CI component of grit: After accounting for age, gender, and respiration rate, CI significantly predicted RMSSD ($B = 3.668$, $SE = 1.542$, $p = 0.018$) and pNN50 ($B = 3.026$, $SE = 1.352$, $p = 0.026$). Also, CI ($B = 0.212$, $SE = 0.105$, $p = 0.046$) and respiration rate ($B = -5.609$, $SE = 1.493$, $p < 0.001$) significantly predicted HF. However, these relationships became non-significant ($ps > 0.10$) in the final model that controls for self-control and conscientiousness.

4 | Discussion

Here, we investigated the association between grit and resting-state HRV, a well-recognized psychophysiological marker of well-being (Kemp et al. 2017). Our results demonstrated that grit was positively associated with all three resting-state HRV indices including RMSSD, pNN50, and HF. These findings extend previous work that examined the relationship between grit and stress-induced HRV (Silvia et al. 2013). Considering that higher HRV has been linked with reduced threat perception and less prioritization of negative information (Motro et al. 2021) that might lead to decreased stress levels (Thayer et al. 2012), gritty individuals—who appraise situations more positively and view setbacks as opportunities to learn—may tend to achieve more adaptive health outcomes.

Total grit and its subcomponents showed similar patterns in predicting resting-state HRV measures in positive directions; however, the effects were relatively weaker for the CI component. One possible explanation for this discrepancy could be the nature of PE and CI in relation to physiological regulation. By definition, PE reflects sustained effort and resilience despite setbacks, which likely requires effective regulation of stress responses when facing challenges (Duckworth et al. 2007). In contrast, CI, which reflects the ability to maintain stable interests over time, may involve less active stress management and physiological regulation. Accordingly, a recent meta-analytic study showed that PE exhibited stronger relationships with self-reported subjective well-being than CI (Hou et al. 2022).

It is important to note that the observed grit-HRV findings were not explained by self-control and conscientiousness. These results align with prior research, which found that conscientiousness was not linked to HRV (Shepherd et al. 2015; Silvia et al. 2014). Similarly, a meta-analytic study showed only a weak positive association between self-control and resting-state HRV ($r = 0.11$; Holzman and Bridgett 2017). Our findings also showed similar small effect sizes between self-control and resting-state HRV ($0.14 \leq rs \leq 0.16$), and the association between HRV and grit remained significant even after controlling for self-control and conscientiousness. Together, these results suggest that the predictive validity of grit on HRV is distinct from that of self-control and conscientiousness, indicating that grit captures unique psychophysiological processes not fully accounted for by these related constructs. This highlights grit as a potentially valuable predictor of HRV, reflecting stable, trait-like individual differences in physiological regulation.

By incorporating an established health-related physiological measure in the regression models, we found that grit is associated with the body's ability to manage stress and relaxation. Although grit was assessed using a self-reported measure, incorporating an objective indicator such as HRV can provide a more comprehensive understanding of how this personality trait influences biological processes (Diamond and Otter-Henderson 2007). Specifically, our findings with resting-state HRV suggest that grit may be linked to effective autonomic functioning, reflecting the body's capacity to adapt to stressors. This aligns with previous studies exploring the biological mechanisms of grit through various physiological measures, including salivary cortisol and cardiac sympathetic activity (Hoferichter and Raufelder 2023; Silvia et al. 2013), as well as functional neuroimaging-based brain activity and connectivity (Park et al. 2023; Wang et al. 2017). Together, these studies contribute to a growing body of evidence highlighting the physiological foundations of grit and its impact on well-being.

There are at least three limitations that should be considered for future research. First, short-term HRV indices tend to have lower test–retest reliability compared to long-term HRV measures (Dekker et al. 1996). However, this may not significantly affect our results as the values of RMSSD and HF have shown strong test–retest correlations ($r \approx 0.80$) over a 2-month period (Sinnreich et al. 1998). RMSSD and pNN50 have also demonstrated high intra-individual reliability, with test–retest correlations reaching 0.90 over a 7-day interval (Farah et al. 2016), indicating that short-term HRV measurements can indeed be practical. Nonetheless, future studies employing long-term HRV measures or repeated short-term HRV assessments could further strengthen the validity of the present findings.

Second, our sample is limited to Korean college students, which restricts the generalizability of our findings. Research has shown that resting-state HRV measures, such as HF, pNN50, and RMSSD, can differ based on race (Reed et al. 2006; Wang et al. 2005); therefore, the relationships between grit and resting-state HRV may vary across cultural contexts. However, a recent meta-analytic study has shown that the beneficial effects of grit on health outcomes are invariant across cultures (see Hou et al. 2022 for a review). This might be because grit can satisfy basic human needs, which are important in human well-being across cultures (Chen et al. 2015; Deci and Ryan 1985). Specifically, gritty individuals, who tend to follow self-selected long-term goals regardless of socio-cultural values, might fulfill their autonomy needs, which, in turn, can boost their well-being. Supporting this notion, empirical studies have found that grit is positively related to autonomy needs satisfaction across cultures (Jin and Kim 2017; Marcelo-Torres et al. 2024). Thus, we believe a similar pattern might emerge in the context of psychophysiological adjustment across different cultures. Nevertheless, future studies should consider expanding the sample to include populations with more diverse demographics, racial, and cultural backgrounds.

Third, it is possible that participants' physical activity levels may have influenced the HRV results. Previous research has established that physical activity and fitness are significant factors affecting HRV (Carter et al. 2003; Rennie et al. 2003; Rossy and Thayer 1998; Sloan et al. 2009). For instance, individuals who frequently engage in fitness activities (i.e., high-fitness group) tend to exhibit higher vagally mediated HRV compared to those who do not exercise regularly (i.e., low-fitness group) (Rossy and Thayer 1998). Thus, one might argue that the observed relationship between grit and HRV is due to a spurious effect of exercise. However, for this explanation to hold, a strong relationship between grit and exercise would be necessary. Prior research suggests that the correlation between grit and physical activity is weak, if present at all (rs = 0.15 to 0.18; Reed et al. 2013; Reed 2014), making this alternative explanation unlikely. Regardless, we encourage future research to replicate our findings while controlling for individual physical fitness.

This study finds that resting-state HRV is associated with grit over and above other psychological factors (i.e., self-control and conscientiousness). Identifying physiological markers of grit holds significant theoretical and practical implications. Theoretically, it provides an objective validation of grit, deepening our understanding of how this trait influences not only achievement but also psychophysiological well-being. Practically, it provides a fundamental basis for intervention. Since grit is a malleable trait influenced by other psychological and contextual factors (Alan et al. 2019; Cross 2014; Duckworth et al. 2007; Park et al. 2020), developing interventions to enhance grit may help people improve stress management, build resilience, and contribute to better overall health outcomes.

Author Contributions

Jaehoon Yoo: conceptualization, data curation, formal analysis, investigation, methodology, writing – original draft, writing – review and editing. **Boyoon Kim:** conceptualization, data curation, investigation, writing – original draft, writing – review and editing. **Sujin Park:** conceptualization, data curation, investigation, writing – original draft, writing – review and editing. **Jeewon Jeon:** conceptualization, data curation, investigation. **Chaebin Yoo:** conceptualization, data curation, investigation. **M. Justin Kim:** conceptualization, funding acquisition, project administration, supervision, writing – original draft, writing – review and editing. **Daeun Park:** conceptualization, funding acquisition, project administration, supervision, writing – original draft, writing – review and editing.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding authors upon reasonable request.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.