Heart Rate Variability as an Index of Resilience

Capt Eric An, BSC USAF; Anne A. T. Nolty, PhD*†; Stacy S. Amano, PhD*; Albert A. Rizzo, PhD‡; J. Galen Buckwalter, PhD†‡; Jared Rensberger, PhD**

ABSTRACT Introduction: Resilience is the ability to maintain or quickly return to a stable physical and psychological equilibrium despite experiencing stressful events. Flexibility of the autonomic nervous system is particularly important for adaptive stress responses and may contribute to individual differences in resilience. Power spectrum analysis of heart rate variability (HRV) allows measurement of sympathovagal balance, which helps to evaluate autonomic flexibility. The present study investigated HRV as a broad index of resilience. Materials and Methods: Twenty-four male participants from the Army National Guard Special Forces completed psychological measures known to relate to resilience and had HRV measured while undergoing stressful virtual environment scenarios. Pearson product-moment correlations were used to explore the relationships between HRV and resilience factors. All research was conducted with the oversight of the Human Subjects Review Committee of Fuller Theological Seminary. Results: Trends toward significance were reported in order to provide results that would reasonably be expected in a study of higher power. Trends between resilience factors and HRV were found only during specific stress-inducing simulations (see Tables III). Conclusion: Greater resilience to stress was associated with HRV during nonstress periods. Higher levels of resilience to traumatic events were associated with HRV during circumstances that were more stressful and emotionally distressing. Post hoc analysis revealed that specific factors including flexibility, emotional control, and spirituality were driving the relationship between general resilience and HRV following emotionally laden stressors. Less stress vulnerability was associated with HRV following intermittent brief stressors. In sum, HRV appears to represent some aspects of an individual's overall resilience profile. Although resilience remains a complex, multidimensional construct, HRV shows promise as a global psychophysiological index of resilience. This study also offers important perspectives concerning ways to optimize both physical and psychological health.

INTRODUCTION

An individual with a balanced, flexible autonomic nervous system easily transitions between high and low arousal states, rapidly modulating the physiological and emotional arousal elicited by environmental stressors.[1] Most individuals exhibit resilience and maintain relatively healthy levels of functioning despite stress or trauma.[2] In contrast, an individual with autonomic rigidity is less capable of effectively regulating arousal, leaving stress as a risk factor for the precipitation and exacerbation of a wide range of disorders.[3]

Sympathetic activation has an excitatory effect on the sinoatrial node that increases heart rate, whereas parasympathetic (vagal) activation has greater influence at rest and serves to maintain a baseline heart rate.[4] The two latencies of action produce oscillations in heart rate at different frequencies, which serve as the basis for heart rate variability (HRV), a noninvasive measure of the constant interaction between the sympathetic and parasympathetic effects on heart rate. Although HRV provides insight into autonomic flexibility that supports capacity for effective stress regulation, few researchers have focused on psychophysiological markers of stress resilience.[5]

According to the Task Force of the European Society of Cardiology and the North American Society of Pacing Electrophysiology,[6] HRV is the variation among a set of temporally ordered inter-beat intervals from a continuous measure of heart rate. The most basic component of HRV measurement is the time between one beat and the next. Power spectral analysis measures the power of high frequency (HF), fast acting influences (0.15–0.40 Hz) and low frequency (LF), slow acting influences (0.04–0.15 Hz) on heart rate. Although widely accepted that the HF range reflects vagal influence,[7] the exact physiological nature of the LF range and the LF to HF ratio (LF/HF) is debated.[8] Despite debate, many prominent researchers use LF HRV as a measure of sympathetic activity and LF/HF as a measure of sympathovagal balance between the sympathetic and parasympathetic influences on the heart.[9]

A balanced autonomic system is considered healthy because it can respond to a wide variety of physiological and environmental demands; however, a rigid autonomic system is less favorable given its tendencies to fixate to particular patterns.[10] Therefore, the heart rate of a healthy system oscillates spontaneously with a high HRV, whereas a diseased, dysregulated heart has little to no HRV. HRV may

*Graduate School of Psychology, Fuller Theological Seminary, 135 N Oakland Ave, Pasadena, CA 91101

†Headington Institute, 402 S Marengo Ave, Pasadena, CA 91101;

‡Institute for Creative Technologies, University of Southern California, 12015 E Waterfront Dr, Los Angeles, CA 90094

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serve as an easily measured output of autonomic flexibility, providing invaluable information regarding an individual's capacity for resilience.

Psychophysiological Findings Using HRV

Low HRV has been associated with mental health difficulties such as anxiety disorders[11] and depression.[12] Post-traumatic stress disorder (PTSD) is also related to low HRV because of disruptions of autonomic function.[13] The hyperarousal cluster of PTSD symptoms in particular (eg, hypervigilance, concentration difficulties, and exaggerated startle responses) suggests attenuated parasympathetic activity and elevated sympathetic activity as a manifestation of the disorder.[14,15] Similarly, the intrusion symptoms of PTSD appear to be inversely related to HF HRV.[16] In addition, reduced HF HRV in military service members before being deployed has been predictive of postdeployment symptoms of PTSD.[17] HRV is also implicated in PTSD treatment studies where higher levels of baseline HF HRV have been predictive of PTSD symptom reduction following completion of trauma-focused psychotherapy.[18] On the contrary, higher HRV has been associated with greater executive functioning,[19] response inhibition,[20] and self-control.[21] Therefore, one physiological characteristic of individuals diagnosed with PTSD may be high LF/HF.

Further, the degree of autonomic hyperactivity exhibited by individuals with PTSD at rest (ie, higher LF HRV) is comparable to the degree of autonomic hyperactivity exhibited by individuals without PTSD who are actively engaging with stressors.[22] Low resting HRV has also been associated with difficulty formulating responses to safety signals when threatening stimuli may be present.[23] Thus, individuals with PTSD may be unable to deploy further autonomic responses to stressors given their autonomic activity just at rest.

Individuals with either PTSD or panic disorder have significantly higher LF HRV and lower HF HRV on power spectrum analyses, suggesting increased sympathetic activity.[24] However, unlike individuals with panic disorder, those with PTSD do not seem to exhibit any significant differences in LF HRV or HF HRV while actively engaging with stressors. Thus, chronic autonomic dysregulation—overstimulated sympathetic activity and decreased parasympathetic activity—may be a mechanism that maintains PTSD symptoms.[14]

Purpose of the Current Study

HRV is a psychophysiological measure of autonomic flexibility that, by proxy, reflects an individual's ability to regulate physiological and emotional responses in a healthy and flexible manner.[25] Power spectrum analysis of HRV allows measurement of sympathovagal balance via LF/HF, which evaluates autonomic flexibility of sympathetic and parasympathetic activity. The goal of the present study was to investigate whether LF/HF serves as a broad index of resilience by relating the degree of sympathovagal balance exhibited during varying levels of stress to factors known to influence resilience.

TABLE I. Demographic Characteristics for Male Participants

Characteristic	*n*	%
Age, years		
20–29	2	8.3
30–39	5	20.8
40–49	13	54.2
50–59	4	16.7
Ethnicity		
White/Caucasian	21	87.5
Hispanic	2	8.3
Asian	1	4.2
Education		
Some college	4	16.7
2-year college degree	2	8.3
4-year college degree	9	37.5
Master's degree	8	33.3
Professional degree	1	4.2
Military deployments		
0	6	25.0
1–2	10	41.6
3–4	7	29.2
5	1	4.2
Rank		
Enlisted	10	41.7
Officer	14	58.3

Note. $N = 24$.

Hypothesis

The degree to which individuals exhibit parasympathetic dominance (ie, lower LF/HF) during times of rest and sympathetic dominance (ie, higher LF/HF) during engagement in tense and possibly stressful activities followed by emotionally laden stressors was hypothesized to relate greater levels of resilience.

METHODS

The current study was part of an ongoing study by a large research university to investigate resilience among U.S. service members with the use of virtual environments.

Participants

Twenty-four male participants recruited from the Army National Guard Special Forces completed HRV measures. Most had served at least one deployment ($M = 1.8$, SD = 1.4), ages ranged from 26 to 56 ($M = 42.5$ years, SD = 7.9), and 16 of 24 participants endorsed a history of playing video games. Table I provides other demographic information.

Procedures

Participants completed computer-based questionnaires and then were fitted with the BIOPAC MP150, a chest-mounted device that measures ECG amplitude patterns, respiration, and galvanic skin responses. A Sony HMZ-T1H head-mounted display had an Intersense InertiaCube[2] and a neoprene head-mounted display shield to remove peripheral visual stimuli. Participants used a Logitech Game Pad F510 to drive a Humvee during two combat scenarios while placed on a tactile transducer floor. They carried a mock M16A1 rifle to increase virtual environment immersion during two subsequent scenarios. Scenarios were run on an Intel Core i7–2600 8-core CPU running at 3.4 GHz with 8GB of RAM using two nVidia GeForce GTX570 graphics cards in an SLI configuration. The present study assessed LF/HF during the entire virtual simulation, which consisted of baseline periods and combat scenarios.

Baseline Periods

While fully equipped with psychophysiological and virtual reality equipment, participants engaged in a 2-minute physiological calibration period. The first minute served as the prestressor baseline period (baseline rest), where exposure to a period of complete silence and darkness determined the resting heart rate, HRV, respiration, and galvanic skin response. At approximately the one-minute mark, a 2-second startle-inducing stressor (loud white-noise) ascertained changes in their physiological responses. The remaining 58-second recovery time, or poststressor baseline period, returned participants to baseline physiological levels before they engaged in the first virtual environment scenario. We expected resilient individuals to exhibit parasympathetic dominance during the poststressor baseline period. After the first two virtual environments, mock rifles replaced the game pads for the final two scenarios. Before the start of the third environment, participants experienced another 2-minute calibration baseline period.

Virtual Combat Scenarios

There were four virtual environments involving combat-related scenarios of variable length. We assessed LF/HF during prestressor and poststressor events within combat scenarios. Prestressor events (see Fig. S1) involved various combat-related activities requiring vigilance toward possible environmental dangers. Poststressor events (see Fig. S2) followed startle-inducing, traumatic situations (eg, witnessing actual or threatened death or serious injury) within combat scenarios. In addition to eliciting a strong startle response, poststressor combat scenarios were used to evoke upsetting emotions (eg, fear, helplessness, and sadness) given their traumatic content.

MEASURES

Resilience

The Connor-Davidson resilience scale (CD-RISC) is comprised of 25 items, each rated on a 5-point scale from 0 (not true at all) to 4 (true nearly all of the time), giving a maximum possible score of 100.[26] Higher scores reflect greater resilience to stress. Connor and Davidson found the scale to have strong internal consistency ($\alpha = 0.89$),[26] as was the case for this study ($\alpha = 0.91$). The Headington Institute Resilience Inventory (HIRI) measured specific factors that confer general resilience to traumatic events.[27] The HIRI includes 38 Likert-type characteristics of resilient individuals, each rated as to how well it seems to characterize the respondent, from 1 (not at all) to 7 (very well): Adaptive Engagement ($\alpha = 0.80$), Spirituality (0.89), Emotional Regulation (0.74), Behavioral Regulation (0.69), Physical Fitness (0.41), Sense of Purpose (0.71), and Life Satisfaction (0.52).

The stress vulnerability scale (SVS) contains 20 items, each rated from 1 (always) to 5 (never).[28] Lower scores indicate greater resistance to stress, and higher scores, greater vulnerability to stress. Internal consistency in the present study was moderate ($\alpha = 0.72$).

PTSD Symptoms

The 20-item PTSD Checklist-5 assesses the 20 DSM-5 symptoms of PTSD.[29] Respondents rate each item from 1 (not at all like me) to 5 (very much like me). Four subscales group symptoms into the four DSM-5 clusters of PTSD symptoms: Intrusion ($\alpha = 0.57$), Avoidance ($\alpha = 0.86$), Negative Alterations in Cognitions and Mood ($\alpha = 0.68$), and Alterations in Arousal and Reactivity ($\alpha = 0.86$).

Psychophysiological Data

We obtained data for HRV according to the guidelines set forth by the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology,[6] using frequency analyses. HRV data were obtained using the BIOPAC MP 150 which had channels for galvanic skin response (GSR100C), ECG (ECG100C), and respiration (RSP100C), with baselines recalibrated whenever participants changed to different body postures to reduce concerns regarding movement artifacts.

DATA ANALYSES

We extracted HRV data using an in-house custom designed MATLAB program, visually inspecting ECG data for artifacts and ectopic beats using Acqknowledge software. We either deleted or replaced all such artifacts using cubic splines, depending on suitability of surrounding data,[6] and then used fast-Fourier transformation for power spectrum analysis of the 1-minute recordings. Outliers were changed to the average of other scores in respective recording periods. As per Task Force recommendations,[6] we performed all power spectrum analyses with data expressed in normalized units.

Using SPSS Version 19, we used Pearson product-moment correlations to explore the relationships between LF/HF and resilience factors, and total PCL scores as a covariate because

TABLE II. Comparison of Stress Vulnerability, CD-RISC, and HIRI Scores to Normative Data

Variable	Descriptive Data *M* (SD)	Normative Data *M* (SD)	*z* score (%)
SVS	**17.24** (7.47)	23.47 (10.09)[a]	−0.62 (26.76)***
CD-RISC	**82.84** (9.31)	75.90 (12.96)[a]	0.54 (70.54)**
	82.84 (9.31)	80.40 (12.80)[b]	0.19 (57.53)
HIRI total	**39.26** (4.08)	38.53 (4.49)[a]	0.16 (56.36)*
Adaptive engagement	6.01 (0.59)	5.76 (0.80)[a]	0.31 (62.17)
Spirituality	4.76 (1.90)	**5.15** (1.66)[a]	−0.23 (40.90)*
Emo Reg & Cog Clar	5.74 (0.69)	5.43 (0.91)[a]	0.34 (63.31)
Behavioral regulation	5.60 (0.74)	5.59 (0.77)[a]	0.01 (50.40)
Physical fitness	5.19 (1.06)	4.87 (1.34)[a]	0.24 (59.48)
Sense of purpose	6.03 (0.57)	5.93 (0.79)[a]	0.13 (55.17)
Life satisfaction	5.93 (0.62)	5.80 (0.81)[a]	0.16 (56.36)

[a]HIRI humanitarian aid-worker norms.
[b]Connor & Davidson, 2003.
Emo Reg & Cog Clar, emotional regulation & cognitive clarity.
$^{*}P < 0.05$.
$^{**}P < 0.01$.
$^{***}P < 0.001$

PTSD symptoms are related to abnormal HRV.[14] Logarithmic transformations, to ensure that the violation of normalcy did not have any significant effect on the results, were not necessary. We reported trends toward significance in order to provide results that would reasonably be expected in a study of higher power.

RESULTS

Descriptive Information

During baseline periods, LF/HF was lower in prestressor events (M = 2.02, SD = 1.15) and higher in poststressor events (M = 3.49, SD = 1.76). During combat scenarios, LF/HF was also lower in prestressor events (M = 5.68, SD = 3.00) and higher in poststressor events (M = 9.25, SD = 4.90). Table II provides means, standard deviations, and z scores for the main study variables. Overall, study participants appeared to possess significantly higher resilience than normative populations,[26,27] as evidenced by lower SVS scores, higher CD-RISC scores, and higher total HIRI scores.

Relationships Between HRV and Resilience to Stress and Trauma

Trends between LF/HF and resilience factors and between LF/HF and SVS scores seem to partially support the first part of the hypothesis (see Table III).

During baseline rest, there appeared to be a weak trend toward a significant negative correlation between LF/HF and CD-RISC scores after controlling for total PCL scores, r (21) = −0.28, P = 0.20. This finding suggests that parasympathetic dominance during baseline rest may be associated with greater resilience to stress. In addition, after exposure to combat-related, startle-inducing stressors, there appeared to be a weak trend toward a significant positive correlation between LF/HF and total HIRI scores, r (22) = 0.32, P = 0.13, even after controlling for total PCL scores, r (21) = 0.31, P = 0.16. These findings possibly suggest that sympathetic dominance after exposure to combat-related, startle-inducing stressors may be associated with higher resilience to traumatic events in general.

Post hoc analysis revealed possible trends toward significant correlations between LF/HF and several HIRI subscales. After exposure to combat-related, startle-inducing stressors, there were trends toward significant positive correlations between LF/HF and Emotional Regulation, r (22) = 0.33, P = 0.12, and Adaptive Engagement, r (22) = 0.39, P = 0.06. After controlling for total PCL scores, trends were still observed between LF/HF and Emotional Regulation, r (21) = 0.31, P = 0.15, and Adaptive Engagement, r (21) = 0.39, P = 0.07. These findings possibly suggest that sympathetic dominance after exposure to combat-related, startle-inducing stressors is likely associated with higher emotional control and flexibility.

Further, during baseline rest, there appeared to be a weak trend toward a significant positive correlation between LF/HF and Emotional Regulation after controlling for total PCL scores, r (21) = 0.30, P = 0.17. This finding possibly suggests that sympathetic dominance during baseline rest may be associated with higher emotional control. In addition, a weak trend toward a significant positive correlation between LF/HF and Spirituality appeared to be observed after exposure to combat-related, startle-inducing stressors, r (22) = 0.30, P = 0.15, even after controlling for total PCL scores, r (21) = 0.30, P = 0.16. These findings possibly suggest that sympathetic dominance after exposure to combat-related,

TABLE III. Correlations Between Low to High Frequency HRV Ratios, Stress Vulnerability, Resilience, and HIRI

Var	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
1.	—												
2.	**0.33**^	—											
3.	**0.55****	0.20	—										
4.	**0.37** ^^	**0.22**	**0.79*****	—									
5.	0.02	**0.35** ^^	−0.04	−0.25	—								
6.	−**0.28** ^^	−0.11	−0.15	0.18	−**0.53***	—							
7.	0.02	0.08	0.03	**0.31**^	−**0.62****	**0.79*****	—						
8.	−0.04	0.07	0.13	**0.39**^	−**0.61****	**0.69*****	**0.77*****	—					
9.	0.08	0.21	0.13	**0.30**^	−**0.37** ^^	**0.64****	**0.72*****	**0.39** ^^	—				
10.	**0.30**^	−0.02	0.20	**0.31**^	−0.25	0.15	**0.57****	**0.45***	0.16	—			
11.	−0.19	−0.14	−0.09	0.08	−**0.49***	**0.49***	**0.59****	**0.52***	0.02	**0.33**^	—		
12.	−0.13	−0.13	−0.21	−0.04	−**0.53****	0.26	**0.54****	**0.36** ^^	0.07	**0.47***	**0.46***	—	
13.	0.07	−0.10	−0.07	0.15	−**0.47***	**0.60****	**0.59****	**0.69*****	0.11	**0.35**^	**0.65****	0.20	—
14.	−0.13	0.16	−0.16	0.05	−0.08	**0.57****	**0.64****	**0.44***	**0.34**^	0.21	**0.54****	0.22	**0.48***

Var, Variable; 1, LF/HF during prestressor baseline periods; 2, LF/HF during poststressor baseline periods; 3. LF/HF during prestressor combat scenarios; 4, LF/HF during poststressor combat scenarios; 5, SVS; 6, CD-RISC; 7, HIRI Total Score; 8, Adaptive Engagement; 9, Spirituality; 10, Emotional Regulation and Cognitive Clarity; 11, Behavioral Regulation; 12, Physical Fitness; 13, Sense of Purpose; 14, Life Satisfaction and Social Support.

^ $P \leq 0.20$.

^^ $P \leq 0.10$.

* $P < 0.05$.

** $P < 0.01$.

*** $P < 0.001$.

startle-inducing stressors may be associated with a stronger level of spirituality.

There appeared to be a trend toward a significant negative correlation between LF/HF and SVS scores after exposure to combat-related, startle-inducing stressors, $r\ (22) = -0.27$, $P = 0.20$, which disappeared after controlling for total PCL scores. There appeared to be a trend toward a significant positive correlation between LF/HF and SVS scores after exposure to brief, startle-inducing stressors, $r\ (21) = 0.35$, $P = 0.10$. This finding possibly suggests that parasympathetic dominance after exposure to brief, startle-inducing stressors may be associated with less vulnerability to stress.

DISCUSSION

HRV and Resilience

Using LF/HF as a measure of autonomic balance, the current study's hypotheses were partially supported. Notably, we found possible trends toward correlations between resilience factors and LF/HF only during specific stress-inducing simulations.

Resilience

Greater resilience to stress appeared to be associated with parasympathetic dominance during times of rest. Maintaining parasympathetic dominance during rest may be essential to thrive in the face of adversity, which is consistent with associations between low HRV and pathophysiology[4] and with several psychological disorders,[10,12,30] and between high HRV and adaptive stress responses.[31] Sustaining parasympathetic dominance during times of rest may be a key component of high HRV, which may be important for resilience against stress and mental illnesses.

Higher levels of resilience to traumatic events appeared to be associated with sympathetic dominance following emotionally laden stressors. Post hoc analysis revealed that specific factors including flexibility, emotional control, and spirituality were driving the relationship between general resilience and sympathetic dominance following emotionally laden stressors. Individuals with higher flexibility may activate appropriate sympathetic dominance during tense situations requiring sustained attention, as is consistent with findings that flexibility is associated with appropriate, adaptive HRV across varying stressful simulations.[1,10] Similarly, individuals with higher emotional control may activate appropriate sympathetic dominance during tense situations requiring sustained attention, as is consistent with findings that adaptive emotional regulation relates to higher HRV.[25] Likewise, individuals with higher spirituality may exhibit sympathetic dominance following emotionally laden stressors. One's relationship with a higher power may facilitate adaptive, sympathetic responses to challenging and stressful situations, as is consistent with findings that spirituality buffers individuals against stress.[32] In addition, post hoc analysis revealed that individuals with higher emotional control may exhibit sympathetic dominance during times of rest, which is inconsistent with findings that lower emotional stability and control relates to tendencies of exhibiting more reactive sympathetic activity.[33] One explanation may be that the baseline rest simulation inadvertently primed participants to be more vigilant because of the possible experience of unpredictability during this simulation.

Less stress vulnerability appeared to be associated with parasympathetic dominance following simple, brief stressors (eg, loud white noise), which was a specific class of stress stimulations used to assess one's ability to quickly shift from sympathetic to parasympathetic activity. Individuals who perceive themselves as being less vulnerable to stress may be more likely able to swiftly vary physiological and emotional responses when experiencing stress. This is consistent with findings that a higher capacity to resist stress is associated with the autonomic nervous system's ability to quickly and flexibly regulate physiological and emotional arousal when facing environmental stressors.[1,14,22]

HRV as an Index of Resilience

In sum, LF/HF appears to represent some aspects of an individual's overall resilience profile. During rest or intermittent brief stressors, LF/HF seems to provide information regarding an individual's capacity for stress resistance and resilience. During circumstances that are more stressful and emotionally upsetting, LF/HF seems to reflect an individual's capacity for resilience to traumatic events. When measuring LF/HF during both nonstress and stressful periods, LF/HF seems to reveal how resilient an individual is.

Limitations and Directions for Future Research

The results presented in this study should be considered in light of several limitations. First and foremost, there are limitations to the generalizability of the sample because of the small sample size. In addition, the participants consisted of a specialized subgroup of military service members (ie, Special Forces). Participants were also all males and showed a higher baseline of resilience than normative samples consisting of both males and females. At the same time, the resilient nature of this population helped identify markers of resilience. Second, inferences about causal effects cannot be drawn because of the cross-sectional nature of the study. Longitudinal studies would help to further elucidate the effects of various resilience variables and HRV. Third, the findings may be limited by response biases and defense distortions because of self-report measures.

Clinical Implications

The results of the present study suggest that HRV and virtual simulations can be used to approximate resilience in a Special Forces population. This study also offers important perspectives concerning ways to optimize both physical and psychological health. By influencing stress reactivity in biological systems such as the autonomic nervous system, certain resilience factors appear to improve HRV and guide one's capacity to flexibly and adaptively manage environmental stressors. Furthermore, conferring resilience and promoting health can involve the development and reinforcement of factors like flexibility, emotional control, and spirituality.

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