Resilience of The Hellenic Navy Seals Assessed by Heart Rate Variability During Cognitive Tasks

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Research

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Abstract

Background

The interaction between high physical performance under extreme conditions and the simultaneous control of the cognitive executive functioning has been a subject of research in literature for the past few decades. Stroop test and Heart-rate variability (HRV), have been verified as a valuable clinical tool for the assessment of cerebral and autonomic/ cardiovascular stress responses respectively.

Objective

The investigation of HRV adaptive response to stress and cognitive stress resilience under strenuous conditions.

Methods

34 subjects were enrolled (n = 34). Of them, 18 were candidates under intense preparation for their enlistment in the Hellenic Navy SEALs (H.N.S.) and 16 were healthy controls, matched for sex and similar in age and demographics. All subjects underwent standard Color Word Stroop Testing, arithmetic stroop testing and emotional stroop testing, along with mental state and personality examination with the use of Symptom Checklist 90 Revised (SCL-90R) scl-90 and Eysenck Personality Questionnaire (EPQ), respectively. HRV variables in time and frequency domains recordings were acquired, during each aforementioned cognitive testing procedure.

Results

Our results showed that H.N.S.'s performance on both cognitive and emotion stroop tasks ($p \geq 0.054$ for all cognitive and emotion stroop tasks' features) was equivalent to controls even though they exhibited statistically significant lower levels of HRV in different time (ranged from $p < 0.01$ to $p < 0.05$) and frequency domain variables (ranged from $p < 0.01$ to $p < 0.05$). Finally, in a between group comparison of the psychometric tools, O.Y.K.s had significantly higher somatization, anxiety and neuroticism than controls.

Conclusion

In conclusion, these findings indicate flexible autonomic regulation (HRV) supports recovery following challenge during cognitive and emotional tasks (stroop tests), which in turn supports problem solving or adaptability skills. HRV measurement begins to be a sophisticated and relevant tool for both scientific

and clinical insights, promising to be an index regarding the psychophysiological resilience especially in the neurovisceral integration (NVI) model. However further longitudinal research on the field is required.

Introduction

The members of the Hellenic Navy Special Operations Command (SOC), the elite unit of the HN Special Operations Forces (SOF) community, should be able to demonstrate optimal performance in extreme conditions. These conditions require extraordinary physical stamina and excellent control of the cognitive executive functioning. As Paulus and colleagues have pointed out “Extreme environments are characterized as those situations that place a high demand on the physiological, affective, cognitive, and/or social processing resources of the individual.” (1).

Hellenic Navy **SE**a **A**ir **L**and (SEALs), known in Greece as N.H.S., are expertly trained to deliver highly specialized, intensely challenging warfare capabilities that are beyond the means of standard military forces. In order to do so, they must successfully attend the Basic Underwater Demolition School (BUD/S) of the Hellenic Navy Special Operations Command. A 32-week extremely intensive and high-risk training schedule with very low ratio of success. This military training program aims to develop the mental and physical stamina of the SEAL candidates and assesses them in physical conditioning, water competency, teamwork and mental tenacity. More specifically, special training objects such as combat diving, unconventional warfare techniques, amphibious operations, use of man-portable medium range weapon systems and standard explosives are included. A very strenuous and demanding part of the training program, is the so called "Hell Week".

The idea behind the structure and the intensity of the BUD/S, is to create training conditions similar to a combat. It is known that combat is one of the most stressful situations that human can face. It includes unexpected attacks and uncontrolled threads, that demand attention and rapid decision making. Under these circumstances, sympathetic nervous system and the “fight or flight” response are activated (2-5). Acute stress response, leads to certain physiological and psychological reactions. While it has an adaptive function, as it prepares the individual to cope with uncertainties and threats, negative effects may arise when this reaction is maintained in time (6).

Heart Rate Variability

Among the various psychophysiological reactions, the ones being associated with the cardiovascular system, such as heart rate and heart rate variability (HRV), are the first to be affected during stress. The cardiovascular system is under control of both the sympathetic and parasympathetic branches of the autonomic nervous system (7). It is regulated by complex central mechanisms, including lower-level reflex systems as well as higher neurobehavioral mechanisms. It has been suggested that resting measures of heart rate variability, is a reflection of the interplay between the aforementioned higher and lower mechanisms (8,9). There is a large body of research that has shown a direct link between cognitive processing and the cardiovascular system through autonomic vagal control (10). Based on evidence that prefrontal cortical substrates of top-down self-regulation influence cardiac activity primarily through the parasympathetic nervous system (11), two theoretical perspectives have emerged; Porges's Polyvagal Perspective (12) and Thayer's Neurovisceral Integration Model (8,13). In addition, Blons and his colleagues have pointed out (14), that heart rate variability is an index of how the brain achieves flexible control and adaptive regulations, allowing us to explore coordinated heart-brain interactions through the concept of neurovisceral integration. That is, by measuring time and frequency domains of HRV, we can assess central nervous processes, such as attentional control and emotional regulation (15).

An optimal level of HRV is associated with health and self- regulatory capacity, and adaptability or resilience (16). A growing body of evidence indicates that vagally mediated HRV have linked to self-regulatory capacity (17-19), emotional regulation (19,20), social interactions (21), one's sense of coherence (22), the personality character traits of self-directedness, and coping styles (23). In this framework there are also evidence showing a relationship between vagally-mediated resting HRV and performance on cognitive performance tasks requiring the use of executive functions (24).

In this sense Porges advocated that the evolution of the ANS, was central to the development of emotional experience and the social engagement system. Thus, human beings, are not limited to fight, flight, or freeze responses but simultaneously have the capacity of self-regulating behaviors when encounter challenges or stressors. His theory suggests that function of the ANS determines the boundaries for the range of one's emotional expression, quality of communication, and the ability to self-regulate emotions and behaviors. Consequently, the measurements of ANS activity could serve as a marker for one's ability to self-regulate (12).

Specifically, HRV are linked to performance of executive functions like attention and emotional processing by the prefrontal cortex (24). Afferent information processing by the intrinsic cardiac nervous system can modulate frontocortical activity and impact higher-level functions (25). A recent study found differences among the two sexes to stroop color word test (SCWT). In particular, cardiovascular autonomic response was more towards sympathetic activation in males than females, even with a stress of short duration, such as the SCWT (26).

Psychophysiological Measurements in Military

Until recently, there was limited literature on the psychophysiological responses of the military population in stressful situations, let alone of the special operation forces. On 2007, Morgan and his colleagues, conducted one of the first studies to assess the relation between cardiac vagal tone and performance in male military personnel exposed to high stress (27). They concluded that reduced vagal tone was associated with enhanced performance. This result was attributed to the ability of better emotion regulation and cognitive functioning when vagal tone is suppressed.

Helping to better understanding and enabling an improvement of current training methods of soldiers, Clemente-Suárez and Robles-Pérez, analyzed psychophysiological changes in a simulated urban combat (28). They focused on changes in cortical arousal, blood lactate, muscle strength, autonomic modulation and rate of perceived exertion. Their results led them to the conclusion, that urban combat produces high sympathetic nervous system stimulation. Nevertheless, despite the fact that there were alterations in basal psychophysiological states, rates of perceived exertion of the soldiers were below the physiological response. Others have compared elite and non-elite soldiers (3), acute high stress combat situations in professional soldiers (4) and autonomic and cortical response of soldiers in different combat scenarios (29).

Delgado-Moreno and his colleagues studied the effect of combat stress in the psychophysiological response and attention and memory of warfighters in a simulated combat situation (2). Their results led to the conclusion that higher psychophysiological activation correlated with poor memory performance, confirming the hypothesis that the activation of the sympathetic nervous system affects executive functions. It is worth mentioning that soldiers remembered more easily subjects that could pose physical harm on them in comparison to neutral stimuli indicating that cognitive processing is associated with emotional disturbance.

Taking into account the above considerations, it would be much advantageous if it is possible to quantitatively and objectively measure the individual resilience for the efficient stress management. The aim of the present study was to investigate the suitability of heart-rate variability (HRV) as a measure of stress resilience, by evaluating it both for mental (color wort & arithmetic stroop test) and emotional stroop test. To do this, we evaluated HRV parameters belonging both to time and frequency domain of HRV, by calculating the correlation of reactivity and recovery from the acute mental and emotional stroop stress, respectively, in Hellenic Navy SEALs (HNS) and healthy controls (HC). We hypothesized that HNS would have higher adaptive responses of reactivity and recovery from both mentally and emotionally stressful events.

It should be noted that the ability to actively resist and recover from the stressors in the environment is called resilience (30). 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 (31).

Materials And Methods

Ethical approval

The study was approved by the Ethics Committee of Harokopio University of Athens and was conducted in accordance with the Declaration of Helsinki. These studies were conducted after review and approval by the Hellenic Navy General Staff.

Subjects

Eighteen candidates HNS (age 24.2 ± 3.4 years, height 180.4 ± 1.7 cm, body mass 78.0 ± 12.7 kg, body mass index 24.4 ± 0.2) and 16 HC with matching demographic and body characteristics participated in the study. The HNS participated in the Basic Underwater Demolition SEAL (BUD/S) training of the Hellenic Navy Special Operations Command from September 2018 to April 2019.

Exercise training program

Hellenic Navy Special Operations Command (SOC) is the elite unit of the HN Special Operations Forces (SOF) community. HN SOC mission is to conduct unconventional warfare and amphibious operations in and out of Greek national territory area as NATO's member. This study was conducted right before the most demanding military training week (Hell Week) of the Basic Underwater Demolition School (BUD/S) of the Hellenic Navy Special Operations Command. During this period, candidates participate in five days of continuous training with mental and physical fatigue. Each candidate has no sleep during the entire week, stays wet almost all the time, walks and runs more than 300 km, and does physical training for more than 20 hours per day, while experiencing a continuous psychological pressure to perform optimally.

Procedure

The study was conducted at the Laboratory of Psychophysiology of the First Psychiatric Clinic of National and Kapodestrian University. HSN were examined during the tenth week of their training, right before the beginning of the “Hell Week”. HC were recruited over a six-month period. Each participant was entering the laboratory separately. Upon entering, a wristband was placed on their wrist for the psychophysiological measurement. Afterwards, in a randomized order, to avoid sequence effect, they were given two questionnaires and took part in three cognitive tasks. The duration of the procedure was 25 minutes (± 5 min.).

Materials

Psychometric and neuropsychological tools

Symptoms Checklist 90 Revised (SCL-90R): It is a self-report instrument, used as a screening tool for current mental state. It consists of 90 questions which describe psychological, behavioral and somatic symptoms separated in nine sub-categories. These sub-categories are: somatization, obsessive compulsive, interpersonal vulnerability, depression, anxiety, hostility, phobic anxiety, paranoid ideation psychoticism. It is based on a 5-point Likert scale from 0=not at all to 4= very much. In addition to the score extracted for each sub-category, there are three more indices: the global severity index, the positive symptom distress index and the positive symptom total.

Eysenck Personality Questionnaire (EPQ): It is a three-dimensional personality assessment tool. It consists of 84 questions. Out of these 84 questions 24 define the dimension of psychoticism (P), 22 the dimension of neuroticism (N), 19 the extraversion (E) and finally, 19 the dimension of lie (L).

Color-Word Stroop: Color-Word Stroop is a neuropsychological test measuring the executive functions and more specifically the inhibition control. It was first presented by John Ridley Stroop on 1935. It has been proven that this task is very difficult to do and leads in slow, error-prone responding due to the phenomenon of interference. In the present study we used three sheets consisting of 100 words each. The first sheet included color-words written in black ink (RED, BLUE, GREEN), repeated in random order. The second sheet consisted of symbols printed in color (XXXX, XXXX, XXXX) and finally, the third sheet included color-words written in a different color of the color they were describing (RED, BLUE, GREEN). In the last sheet participants had to name the color ignoring the word itself. For every sheet they had 1 min to read as many words or colors as possible. For every participant we kept track of the number of words read, the number of mistakes made and the number of mistakes made and then corrected.

Number Stroop: Number Stroop is based on the principles of Color-Word Stroop, but instead of using stimuli of words and colors it measures the interference phenomenon by using size and value. The present study used a computerized version of the test. In total they had been created three conditions: congruent condition (the bigger number in size was also the bigger in value), incongruent condition (the bigger number in size was the smaller in value) and the neutral condition (numbers had the same size in the size comparison test and the same value in the value comparison test). Each participant had to peak the bigger of two numbers presented on a computer screen either according to its size or according to its value, by pressing the corresponding arrow on the keyboard. Each test (size or value) was presented in a random order and it consisted of 180 repetitions. These 180 repetitions had been divided in 6 groups of 30 comparisons, with a fixation point being presented on the screen for 500msec between every group. For every participant we measured the reaction time and the number of mistakes made.

Emotion Stroop: Emotion Stroop measures how the magnitude of an emotional reaction in words believed to have a negative meaning, interferes in the execution of a task irrelevant to these words. Studies have showed that reaction time in negative words is bigger in comparison to neutral words. This difference has been attributed to the effect that negativity has on humans. The present study used a computerized version of the task. During the procedure, a ring was divided in a number of colors. In the center of the ring words were appearing, each of different color. Participants had to match the word's color with the same color on the ring, by using the mouse. The task was consisted of 60 negative and 60 neutral words, each word presented randomly five times, each time painted in a different color.

Psychophysiological measurement

In order to measure autonomic response, First Psychiatric Clinic of National and Kapodestrian University has developed a collaboration with Sentio Solutions Inc., which provides the Laboratory of Psychophysiology with a wristband called "FEEL". FEEL's technology makes it capable of measuring: heart rate variability, electrodermal response and temperature. Utilizing four built-in sensors in the wristband, FEEL collects information on the aforementioned biosignals and analyzing them using the most modern technological methods. Advanced technologies related to artificial intelligence and signal process algorithms are in position to track down emotional reactions while participants wearing the wristband and execute various tasks. Heart rate is detected through a sensor that works as a plethysmograph. Changes in heart rate and heart rate variability are thought to indicate changes in participants' emotional state. More specifically, regarding heart rate variability, it is able to give information for 77 different features which include time domain (e.g. *mean HR, std HR, mean HRV, SDNN, mean first difference and mean second difference*) and frequency domain (e.g. *LF, MF, HF, LF/HF, total power content*), as well as non-linear and wavelet features.

Data analysis

Values are presented as absolute and relative frequencies for nominal variables concerning demographic data and as mean and standard deviation for the continuous variables regarding the scales investigated in this work. Normality assumption was examined via Shapiro–Wilks test for both groups Control and Experimental (32). Comparisons between the aforementioned groups as regards the HRV levels were performed by using parametric and non-parametric tests with selected significance level of 5%. Specifically, two independent samples t-test was conducted for testing the equality of mean values between HNS and HC for normally distributed variables, as well as, Mann-Whitney test was conducted for testing the equality of median values between HNS and HC for non-normally distributed variables (33,34). The effect size was evaluated by calculating Hedges' g value (35) and eta square (36). Data analysis was performed using statistical software of IBM SPSS (Version 23).

Results

Eighteen Hellenic Navy SEALs (HNS) participants and 16 HC were included in the analysis. Table 1 presents the demographic characteristics of the two groups. The majority of subjects were unmarried with a mean age of 28.65 years.

Table 1

Demographic characteristics of participating subjects per group

Demographic Characteristics		All	HNS	HC
Number of participants		34 (100%)	18 (52.9%)	16 (47.1%)
Age (years)		28.65 ± 9.76	24.17 ± 3.35	33.69 ± 12.08
Years of Education		15.42 ± 1.75	15.76 ± 0.97	15.06 ± 2.29
Family Status	Unmarried	28 (82.4%)	16 (88.9%)	12 (75.0%)
	Married	5 (14.7%)	2 (11.1%)	3 (18.8%)
	Divorced	1 (2.9%)	0 (0.0%)	1 (6.3%)
Right-handed		33 (97.1%)	18 (100%)	15 (93.8%)
Health Problem (No)		34 (100%)	18 (100%)	16 (100%)

Regarding the psychometric evaluation, HC had statistically significantly lower mean level at the category of Somatization (0.51±0.38) compared to HNS (1.34±0.61) ($t(15,16)=-4.706$, $p<0.01$) with a large size effect Cohen's d equal to 0.87 (Table 2). In addition, HC had statistically significantly lower mean level at the category of Anxiety (0.78±0.71) compared to HNS (1.26±0.56) ($t(15,16)=-2.184$, $p=0.037<0.05$) with a large size effect Cohen's d equal to 0.75 (Table 2), and statistically significantly higher mean level at the trait of Neurotism (10.63±6.09) compared to participants (7.00±3.41) ($t(15,16)=2.093$, $p=0.047<0.05$) with a size effect Cohen's d equal to 0.70.

Table 2

Independent sample t – test for equality of SCL & EPQ mean values between HNS and HC

Variable	**HC (N=16) (Mean±St.Dev)**	**HNS (N=17) (Mean±St.Dev)**	**Independent samples' t test**	**Effect size Cohen's d**
SCL-90R				
Somatization	**0.51±0.38**	**1.34±0.61**	**-4.706****	**0.87**
Anxiety	**0.78±0.71**	**1.26±0.56**	**-2.184***	**0.75**
EPQ				
Neurotisism	**10.63±6.09**	**7.00±3.41**	**2.093***	**0.70**

*p<.05, **p<.01

Table 3

Independent sample t – test for equality of stroop mean values between HNS and HC

Variable	HC (N=16) (Mean±St.Dev)	HNS (N=18) (Mean±St.Dev)	Independent samples' t test	Statistical Significance p value	Effect size Cohen's d
CWS sheet 1 words sum	135.13±15.09	144.39±18.06	-1.611	0.117	0.55
CWS sheet 2 words sum	94.38±13.09	104.06±14.93	-1.998	0.054	0.69
CWS sheet 3 words sum	62.00±17.37	67.33±14.94	-0.962	0.343	0.33
NS size RT congruent condition	0.91±0.29	0.78±0.08	1.806	0.081	0.64
NS size RT incongruent condition	0.99±0.31	0.86±0.10	1.554	0.139	0.59
NS size RT neutral condition	1.14±0.37	0.94±0.15	1.958	0.066	0.73
NS size mistakes congruent condition	2.40±1.88	3.78±2.53	-1.742	0.091	0.61
NS value RT congruent condition	0.77±0.23	0.73±0.11	0.807	0.426	0.23
NS value RT incongruent condition	0.83±0.22	0.78±0.12	0.924	0.362	0.29
NS value RT neutral condition	0.82±0.22	0.76±0.10	1.083	0.287	0.36

Table 4

Mann-Whitney U test for equality of stroop median values between HNS and HC

Variable	HC (N=16) (Median ± interquartile range)	HNS (N=18) (Median ± interquartile range)	Mann-Whitney U	Statistical Significance p value	Effect size Cohen's d
CWS sheet 1 mistakes	0.00±0.00	0.00±0.00	130.50	0.646	0.16
CWS 1 sheet 1 fixed mistakes	0.00±0.00	0.00±1.00	113.50	0.297	0.37
CWS sheet 2 fixed mistakes	1.00±2.00	1.00±2.25	116.00	0.347	0.34
CWS sheet 3 mistakes	0.00±0.00	0.00±1.00	130.00	0.646	0.17
CWS sheet 3 fixed mistakes	0.00±1.00	1.00±3.00	102.50	0.154	0.51
NS value mistakes congruent condition	0.00±0.00	0.00±0.25	122.00	0.656	0.16
NS value mistakes incongruent condition	1.00±3.00	1.00±2.00	109.00	0.361	0.33
NS value mistakes neutral condition	0.00±1.00	0.00±1.00	129.00	0.845	0.08
ES total RT for negative words	0.97±0.30	0.93±0.13	110.00	0.561	0.22
ES mistakes for negative words	0.00±1.00	0.00±1.00	114.00	0.667	0.16
ES total RT for neutral words	0.96±0.28	0.95±0.15	118.00	0.750	0.12
ES mistakes for neutral words	0.00±0.25	0.00±0.25	122.00	0.896	0.07

No statistically difference was observed in any of the Stroop tasks between HC and HNS (Tables 3 & 4). However, statistically significant differences were found on the physiological measurements recorded during the neuropsychological tasks. More specifically, regarding the time domain of HRV, HC was statistically significantly higher than the HNS group in the SDNN median level ($U=25$, $p=0.017<0.05$) with a small size effect equal to 0.24 (Table 5).

During emotion stroop, HC had statistically significantly higher mean level of the std HR (12.14±4.35) compared to HNS (8.63±2.03) ($t(24)=2.292$, $p=0.045<0.05$) with a large size effect equal to 1.17 (Table 6). In addition, during the same task, HC had statistically significantly higher SDNN mean level

(0.17±0.02) compared to HNS participants (0.11±0.05) (t(24)= 4.340, p=<0.01) with a large size effect equal to 1.17 (Table 6).

Table 5

Independent sample t – test for equality of HRV mean values between HNS and HC

Variable	HC (Mean±St.Dev)	HNS (Mean±St.Dev)	Independent samples' t test	Effect size Hedges' g
Emotion Stroop				
Std HR	**12.14±4.35**	**8.63±2.03**	**2.292***	**1.17**
SDNN	**0.17±0.02**	**0.11±0.05**	**4.340****	**1.46**

*p<.05, **p<.01

Table 6

Mann-Whitney U test for equality of HRV median values between HNS and HC

Variable	HC (Median ± interquartile range)	HNS (Median ± interquartile range)	Mann-Whitney U	Effect size η^2 (r^2)
Number Stroop (size comparison)				
SDNN	**0.14±0.04**	**0.08±0.05**	**25***	**0.24**

*p<.05

Differences found also on the frequency domain of HRV both for the number and emotion stroop. During the size comparison of the number stroop, HC had statistically significantly higher power content at different frequency bands (VLF/LF/MF) mean level (843.30±457.86) compared to HNS participants (424.24±421.26) (t(22)=2.234, p=0.036<0.05) with a large size effect equal to 0.96 (Table 7). In addition, HC had statistically significantly higher total power content mean level (4597.55±2422.19) compared to HNS (2435.26±2278.38) (t(22)=2.148, p=0.043<0.05) with a large size effect equal to 0.92 (Table 7).

Regarding emotion stroop, HC had statistically significantly higher power content at different frequency bands (VLF/LF/MF) mean level (1540.12±501.12) compared to HNS (784.28±656.18) (t(24)=3.011, p=0.006<0.01) with a large size effect equal to 1.27. In addition, HC had statistically significantly higher total power content mean level (8207.77±2320.34) compared to HNS (4096.89±2997.71) (t(22)=3.574, p=0.002<0.01) with a very large size effect equal to 1.51 (Table 7).

Table 7

Independent sample t – test for equality of mean values between HNS and HC

Variable	HC (N=11) (Mean±St.Dev)	HNS (N=14) (Mean±St.Dev)	Independent samples' t test	Effect size Hedges' g
Number Stroop (size comparison)				
power content at different frequency bands (VLF/LF/MF)	**843.30±457.86**	**424.24±421.26**	**2.234***	**0.96**
total power content	**4597.55±2422.19**	**2435.26±2278.38**	**2.148***	**0.92**
Emotion Stroop				
power content at different frequency bands (VLF/LF/MF)	**1540.12±501.12**	**784.28±656.18**	**3.011****	**1.27**
total power content	**8207.77±2320.34**	**4096.89±2997.71**	**3.574****	**1.51**

*p<.05, **p<.01

Correlation was conducted for each group separately, between the psychometric tools and the measurements of HRV and blood test for both number and emotion stroop. Regarding time domain of HRV, moderate negative correlations were found between SDNN during the size comparison of number stroop and three out of nine categories of SCL-90R questionnaire; somatization (*r(23)=-.452, p<.05*), anxiety (*r(23)=-.457,p<.05*) and hostility (*r(23)=-.445, p<.05*) (Table 8).

Table 8

Correlations between time domain of HRV during number stroop and psychometric tools

	Somatisation	Anxiety	Hostility	General symptom index	Psychotism
Number Stroop (size comparison)					
SDNN	-.452*	-.457*	-.445*	-.412	-.127

*p<.05, **p<.01

Correlations were found also for the features representing frequency domain of HRV and the psychometric questionnaires. More specifically, power content at different frequency bands (VLF/LF/MF) measured during the size comparison of number stroop, was found to be correlated negatively in a moderate way with the categories of somatization (*r(23) =-.458,p<.05*) and hostility (*r(23) = -.427, p<.05*) from the SCL-90R questionnaire (Table 9). Also, total power content was found to be negatively correlated with somatization (*r(23) = -.426, p<.05*) (Table 9). Regarding frequency domain of HRV during emotion stroop, a moderate negative correlation was found between extroversion from the EPQ questionnaire and power content at different frequency bands (VLF/LF/MF) (*r(23)=-.523, p<.01*) and total power content (*r(23) =-.481, p<.05*) (Table 9).

Table 9

Correlations between frequency domain of HRV during number and emotion stroop and psychometric tools

	Somatization	Hostility	Extraversion
Number Stroop (size comparison)			
power content at different frequency bands (VLF/LF/MF)	-.458*	-.427*	-.071
total power content	-.426*	-.413	-.071
Emotion Stroop			
power content at different frequency bands (VLF/LF/MF)	-.199	.323	-.523**
total power content	-.280	.217	-.481*

*p<.05, **p<.01

Discussion

The aim of this study was to investigate the possibility of heart-rate variability (HRV) as a measure of stress resilience, by evaluating it both for mental (color word & arithmetic stroop test) and emotional stroop test. To do this, we evaluated HRV parameters belonging both to time and frequency domain of HRV, by calculating the correlation of reactivity and recovery from the acute mental and emotional stroop stress, respectively, in Hellenic Navy SEALs (HNS) and healthy subjects (HC). We hypothesized that HNS with higher resting vagal control would have higher adaptive responses of reactivity and recovery from both mentally and emotional stressful events.

Our results showed that HNS's performance on both cognitive and emotion stroop tasks was equivalent to HC even though they exhibited statistically significant lower levels of HRV in different time and frequency domain variables. This fact appears to contradict the existing literature regarding the magnitude of the HRV features both in time and frequency domain. To be more specific, HNS were found to have lower: standard deviation of NN intervals (SDNN), standard deviation of HR, frequency bands

(VLF/LF/HF) and total component power than controls. Furthermore, SDNN during the size comparison of number stroop seem to correlate negatively with the categories of somatization, anxiety and general symptom index from SCL-90 questionnaire, as well as with psychotism from EPQ questionnaire. Also, negative correlation was found between power content at different frequency bands (VLF/LF/HF) and total content power with somatization, hostility and extraversion for both number and emotion stroop. Moreover, cortisol and the fraction of cortisol/testosterone were negatively correlated with SDNN of HNS during the size comparison at the number stroop. Finally, in a between group comparison of the psychometric tools, HNS had significantly higher somatization, anxiety and neuroticism than controls.

It is known that HRV indexes neurocardiac function and is generated by heart-brain interactions and dynamic non-linear autonomic nervous system processes (37). It helps us to adapt to environmental and psychological challenges and reflects regulation of autonomic balance. The predisposition to a stressful stimulus activates sympathetic nervous system and deactivates parasympathetic nervous system. Thayer and his colleagues, by introducing the Neurovisceral Integration Model, referred to a link between cognitive processing and autonomic functioning (38). According to Neurovisceral Integration Model, prefrontal cortex plays an important role in the modulation of subcortical cardio-acceleratory circuits via an inhibitory pathway that is associated with vagal function and that can be indexed by HRV. It is, also, known that higher levels of resting vagally-mediated HRV are linked to performance of executive functions like attention and emotional processing by the prefrontal cortex (37). As a matter of fact, a growing number of studies have specifically linked vagally mediated HRV to self-regulatory capacity and emotional regulation (24). Porges suggests that the healthy function of the social engagement system depends upon the proper functioning of the vagus nerves and that that the evolution and healthy function of the ANS determines the boundaries for the range of one’s emotional expression (12).

Essentially, high HRV should reflect the same context-appropriate precision estimates that act to inhibit the influence of irrelevant distractors. Such distractors would otherwise be inappropriately appraised as salient and trigger priors for a withdrawal in vagal tone and reduce HRV. This basic notion that inappropriate appraisals of and subsequent attention to goal-irrelevant stimuli should lead to both task errors and reduced HRV, may further help explain why high HRV can predict better performance in cognitive control tasks. In other words, higher HRV may index a greater tendency, either in general or during a task, to assign high precision to prefrontal levels of control that are sensitive to goals and context. These high prefrontal precision estimates will in turn prevent distracting, task inappropriate responses to irrelevant stimuli, and therefore improve performance. A salient example refers to the relationship between HRV and performance in the presence of emotional distractors (such as emotion stroop) (39).Taken together our results showed that the HNS exhibited equivalent performance regarding the cognitive and the emotional operations but they exhibited inferior HRV during the exposition to the tasks inducing these cognitive and emotional functions. These observations appear to be incompatible with the prevailing view as mentioned above that higher HRV is associated with greater capacity for emotion regulation (20,40) and with greater performance on several cognitive tasks involving attention, working memory, and inhibitory control (13).The aforementioned discrepancy regarding higher levels of HRV and intact cognitive performance, could also be understood considering the cognitive efficiency and the physical exhaustion. Cognitive efficiency (CE) is a multifaceted construct that describes the ability to reach learning, problem solving, or instructional goals through optimal use of mental resources. CE can be defined as optimal effort needed to perform a task, optimal performance on a task, or as the relationship between maximum performances on a task while exerting minimum effort (41).

Furthermore, as we found different characteristics between mental and emotional stress and different relationships with stress resilience measures as they are reflected by the in HRV changes, it is necessary to consider stress types differently for further stress analysis. In particular, the effect of fatigue effect on HRV cannot be ignored, since physical activities can be a severe effect of respiratory sinus arrhythmia especially on high frequency HRV parameters. (42,43). In this framework it is reasonable to bring in mind that the group of the HNS group had been submitted in exhaustive physical exercises before the experimental investigation.

The obtained associations between the psychometric variable and the HRV patterns on the on hand and physiological parameters (i.e cortisol & fraction of testosterone and cortisol) and HRV changes on the other hand might be better understood considering the neurovisceral integration (NVI) model proposed to account for observed relationships between peripheral physiology, cognitive performance, and emotional/physical health (21).

The obtained associations between the psychometric variable and the HRV patterns on the on hand and physiological parameters (i.e cortisol & fraction of testosterone and cortisol) and HRV changes on the other hand might be better understood considering the neurovisceral integration (NVI) model proposed to account for observed relationships between peripheral physiology, cognitive performance, and emotional/physical health (21). In this perspective there are empirical findings indicating that lower patterns of HRV has all been associated with affective disorders such as depression and anxiety (44-46) while higher patterns of HRV has been associated with better hypothalamic-adrenal-pituitary (HPA) axis function, reduced inflammation, andreduced risk for cardiovascular disease (47-51).

Limitations

Current research results have been obtained from too few subjects to generalize the conclusions, so it is essential to support them through follow-up studies.

Conclusions

In conclusion, these findings indicate flexible autonomic regulation supports recovery following challenge, which in turn supports problem solving or adaptability skills. The response/ recovery parameters established in the present study could be applied to predict soldier problem solving as well as resilience to environmental stressors. However, 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. Heart-rate variability is a fascinating observation and insight in its mechanisms is increasing. One main issue remains that interindividual differences are high and statistical effects are usually shown only on the group level. HRV measurement begins to be a sophisticated and relevant tool for both scientific and clinical insights, especially in the neurovisceral integration (NVI) model. Overall, the neurovisceral integration (NVI) model will enable to integrate previous findings from different disciplines and to stimulate new research questions, predictions, and designs regarding self-regulation.

Declarations

Ethics approval and consent

The study was approved by the Ethics Committee of Harokopio University of Athens and was conducted in accordance with the Declaration of Helsinki. These studies were conducted after review and approval by the Hellenic Navy General Staff.

Consent for Publication

Not Applicable

Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author under reasonable request.

Competing interests

The authors declare that they have no competing interests

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Authors' Contributions

SM and CP conceived and designed the experiments; GV performed the experiments; FB and GV analyzed the data; AP, NG, MK reagents/materials/analysis tools; SM, GV, CrP, CP and LS wrote the manuscript. CP and LS supervised the project. All authors read and approved the final manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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