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HEART RATE VARIABILITY FOR EVALUATING COGNITIVE STRESS IN HEALTHY STUDENTS: THE INFLUENCE OF PHYSICAL FITNESS LEVEL

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Background. The impact of adaptation to physical loads on heart rate variability (HRV) responses during cognitive or emotional stress remains insufficiently studied. This study aimed to examine changes in HRV parameters among individuals with differing levels of adaptation to speed-strength physical loads while performing complex visual-motor reaction (VMR) tasks.

Materials and Methods. The study compared HRV metrics between trained males (22 karate athletes, Group T) and untrained males (26 students, Group UT). Groups did not differ significantly in age and anthropometric parameters. HRV was recorded both at rest and during three complex visual-motor choice reaction (VMCR) tests involving increasing numbers of stimuli – $VMCR_{60}$, $VMCR_{90}$, and $VMCR_{120}$. The following HRV indices were calculated: the heart rate (HR), the standard deviation of normal RR intervals (SDNN), the root mean square of successive differences (RMSSD), the percentage of successive interval pairs differing by more than 50 ms (pNN_{50}), the length of the short axis of the Poincaré plot (SD_1), and the length of the long axis of the Poincaré plot (SD_2)

Results and Discussion. At rest, values of SDNN, SD_1, RMSSD, and pNN_{50} were 11.80–43.01 % higher in group T than in group UT ($p < 0.05$), while HR was 7.40 % lower in group T ($p < 0.05$). A tendency towards the prevalence of persons with dominance of sympathetic tone within the group UT was observed. During VMCR tasks, HRV parameters changed in both groups. Specifically, SDNN decreased by 38–42 % ($p < 0.01$), with a more pronounced reduction in group T. We found a nearly significant strong negative correlation between SDNN reduction and the number of stimuli in the VMCR tests ($r = -0.99$, $p = 0.10$) in group UT. During the VMCR tasks, group T showed significant decreases in RMSSD ($p < 0.01$) and pNN_{50} ($p = 0.03$), whereas no significant changes were observed in group UT. A nearly significant strong negative correlation was found between pNN_{50} and the number of stimuli in group UT (r = -0.99, p = 0.08), in contrast to group T. The SD_1 decreased significantly during the VMCR tasks in both groups (p <0.01), with a nearly significant correlation between these changes and the number of stimuli in group T (r = -0.995, p = 0.06) and group UT (r = -0.992, p = 0.07). The effect of VMCR on SD_1 was more pronounced in group T. Furthermore, SD_2 significantly decreased during VMCR in both groups (p <0.01), with larger reductions observed in group T. Analysis of HRV at rest suggests that adaptation to speed-strength training is associated with an enhanced parasympathetic tone. Under cognitive load, there is a shift toward increased sympathetic activity. These changes are more pronounced and occur more rapidly in trained individuals, as indicated by the progressive alterations in specific HRV parameters among the untrained group during the sequential series of tests.

Conclusion. Individuals adapted to speed-strength training exhibited higher parasympathetic activity at rest and more efficient sympathetic responses to cognitive load, indicating superior autonomic regulation adaptability compared to untrained individuals.

Keywords: heart rate variability, physical loads adaptation, complex visual-motor reactions, speed-strength training, students

INTRODUCTION

Adaptation to stressors, including physical exercises, is a complex, multi-level process that results in the organism developing optimal strategies for adjusting to changes in both external and internal environments (Lisun & Uhlev, 2020). According to Hans Selye's General Adaptation Syndrome theory, adaptation to stress involves both non-specific systemic responses and specific mechanisms tailored to the stressor (Lisun & Uhlev, 2020; Ridkovets, 2015). These responses are mediated through a coordinated activity of the autonomic nervous system (ANS) and the hypothalamic-pituitary-adrenal (HPA) axis, resulting in widespread physiological changes that prepare the body to cope with and recover from stress. The activity of ANS centers serves to integrate the functions of various organ systems to achieve optimal adaptation and involves the activation of cardiovascular and vasomotor subcortical centers (Lisun & Uhlev, 2020).

Regular physical activity induces a range of both specific and non-specific adaptive responses, which can be assessed by analyzing the functional state of the ANS. The functional state of the ANS is reflected in variations in autonomic tone, which denotes the dynamic balance between sympathetic and parasympathetic activity (Sammito *et al.,* 2024; Shushkovska *et al.,* 2023). The parasympathetic system exerts its regulatory effects primarily via the vagus nerve, particularly through M-cholinergic receptors of the sinoatrial node, leading to an increase in the heart rate variability (Lisun & Uhlev, 2020; Ridkovets, 2015; Shushkovska *et al.,* 2023). Sympathetic activation is linked to the release of catecholamines, which stimulate β-adrenergic receptors and lead to a reduction in the heart rate variability (HRV), and in some cases, cause an onset of sinus tachycardia (Lisun & Uhlev, 2020; Shushkovska *et al.*, 2023).

Currently, HRV analysis remains one of the most accessible and non-invasive approaches for evaluating the functional state of the autonomic nervous system, both at rest and under diverse physiological and psychological stressors (Peabody *et al.,* 2023; Bhattacharya *et al.,* 2023). HRV reflects the natural fluctuations in the duration of cardiac cycles (Kim *et al.,* 2018). These fluctuations can originate from either internal or external sources (Liashenko & Stetsenko, 2024; Kochyna *et al.,* 2020). In the absence of external stimuli, HRV arises from endogenous physiological processes and biological rhythms (Kochyna *et al.*, 2020). External influences on HRV include changes in body posture, physical exercises, emotional or psychological stress, and thermal stressors (Liashenko & Stetsenko, 2024; Ridkovets, 2015; Castaldo *et al.*, 2015). Given the primary role of the ANS in regulating heart rate (Dong, 2016), HRV analysis enables the objective assessment of sympathetic and parasympathetic activity (Slyvka et al., 2019). The most informative HRV markers related to stress include elevated sympathetic activity (reflected by decreased SDNN and SD_2 values) and diminished parasympathetic activity (indicated by reduced pNN_{50}, RMSSD, and SD_1) (Shushkovska *et al.,* 2023). The SDNN, RMSSD, and pNN_{50} indices are commonly used to evaluate parasympathetic regulation of cardiac rhythm, assuming the presence of a normal sinus rhythm and intact atrioventricular conduction (Liashenko & Stetsenko, 2024).

It is well established that enhanced regulatory and adaptive capacity is associated with increased parasympathetic activity at rest, which develops progressively through systematic training (Chakraborty *et al.,* 2023; Laborde *et al.,* 2017; Immanuel *et al.,* 2023).

Although the autonomic benefits of endurance training are well established (Laborde *et al*., 2017; Immanuel *et al*., 2023), the regulation of the heart rate variability (HRV) in athletes participating in speed- and power-focused sports remains comparatively underexplored (Kassiano *et al.*, 2021; Kanyhina *et al.,* 2020). Karate offers a particularly compelling model for such investigation. Unlike purely endurance-based disciplines, karate demands rapid bursts of speed-strength performance coupled with high levels of neuromuscular coordination (Chaabène *et al*., 2012; Franchini, 2023). This high-intensity, intermittent activity places significant demands on cardiovascular endurance, muscular strength, and anaerobic capacity, thereby engaging diverse physiological adaptation mechanisms.

Experimental evidence suggests that karate training is linked to structural brain adaptations, including increased gray matter volume in the frontal and temporal lobes (Duru & Balcioglu, 2018). Comparable findings indicate that regular physical activity, particularly aerobic and resistance training, can enhance gray matter volume across various brain regions or mitigate age-related decline (Erickson *et al*., 2014; Chieffi *et al*., 2017; Hvid *et al*., 2021; Raji *et al*., 2024). Notably, several of these regions are implicated in autonomic regulation and cognitive control, raising the possibility of cross-adaptation between physical fitness and autonomic responses to cognitive or psycho-emotional stressors.

Despite this potential, the impact of habitual physical activity on autonomic reactivity to cognitive and emotional challenges remains insufficiently understood. While some studies have examined heart rate variability (HRV) responses to such stressors in individuals with varying fitness levels (Chakraborty *et al.,* 2023; Luque-Casado *et al*., 2013; Hansen *et al*., 2004), their results are limited and often inconsistent. For instance, a recent study involving aerobically fit young adults reported lower resting heart rates but did not find reliably attenuated autonomic reactivity to cognitive stress (Mee *et al.*, 2023).

Despite growing evidence of exercise-induced neurophysiological changes, there remains a significant gap in understanding how chronic physical training influences ANS responses to non-physical stressors such as cognitive and emotional challenges. This limitation constrains our comprehension of the full spectrum of adaptations resulting from regular physical activity. Crucially, the ability to sustain stable performance under psychological stress is integral to effective motor task execution, efficient resource mobilization, and optimal post-exercise recovery (Slyvka *et al.,* 2019). Therefore, this study aimed to investigate changes in heart rate variability parameters in individuals with different levels of adaptation to speed-strength physical training during the performance of complex visual-motor reaction tasks.

MATERIALS AND METHODS

The study included male students from Ivan Boberskyi Lviv State University of Physical Culture. The trained group (T) consisted of 22 highly qualified karate athletes (black belts, first-class athletes, or candidates for the title of Master of Sports), with a mean age of 19.14±2.25 years, an average height of 179.18±4.67 cm, and a body weight of 73.95±12.65 kg. All had more than five years of training experience. The untrained group (UT) included 26 students who did not engage in regular physical activity, with a mean age of 18.31±0.68 years, an average height of 179.21±7.14 cm, and a body weight of 73.50±11.00 kg. None of the participants self-reported a diagnosed cardiovascular disorder or related medical condition. All participants provided written informed consent, which included a brief explanation of the study's key procedures. The research was conducted in line with the principles of the Declaration of Helsinki on ethical research involving human subjects (World Medical Association, 2013) and the core bioethical principles outlined in the Council of Europe Convention on Human Rights and Biomedicine (Council of Europe, 1997).

The HRV recordings were conducted during the first half of the day with participants in a quiet, temperature-controlled environment, free from movement or emotional stress. All procedures adhered to established guidelines for standardizing HRV measurement and minimizing external influencing factors (Damoun *et al.,* 2024). During the first stage of the study, HRV was recorded for five minutes at rest in a seated position. To simulate the psycho-emotional stress conditions, the second stage of the study involved participants performing a complex visual-motor choice reaction (VMCR) task with feedback using the "Diagnost-1m" system. Three tests were performed with increasing numbers of stimuli (60, 90, and 120) – $VMCR_{60}$, $VMCR_{90}$, and $VMCR_{120}$. Participants were instructed to press a response button with the right hand for squares, with the left hand for circles, and to withhold their response for triangles (inhibitory signal). A feedback mode was used, where stimulus duration decreased after correct responses and increased after incorrect ones. The initial exposure time was set at 0.9 seconds, varying between 0.9 and 0.02 sec., with a constant interstimulus interval of 0.2 sec. (Makarenko *et al*., 2018).

Heart rate variability (HRV) was registered by Polar 800RS heart rate monitors. Data were analyzed with the Polar Pro Trainer 5.40.172 software. The following HRV indices were calculated: heart rate (HR); SDNN – the standard deviation of NN (normal RR) intervals; RMSSD – the square root of the mean squared differences of successive NN intervals; pNN_{50} (%) – the percentage of successive interval pairs differing by more than 50 milliseconds; SD_1 – the length of the short axis of the Poincaré plot ellipse; and SD_2 – the length of the long axis of the Poincaré plot ellipse, expressed in milliseconds (Bhattacharya *et al*., 2023; Immanuel *et al.,* 2023). Resting SDNN values were used to classify autonomic nervous system status into four functional types: 0–30 ms (hypersympathicotonic), 31–50 ms (sympathicotonic), 51–80 ms (normotonic), and 81–200 ms (vagotonic, indicating parasympathetic dominance) (Vovkanych & Kachmar, 2013).

The results were analyzed using standard statistical methods by the "Origin 2018" software. Data normality was assessed using the Shapiro–Wilk test. Differences between groups were tested with Student's *t*-test or the Mann–Whitney U test (when data deviated from normal distribution). To determine the statistical significance of the impact of the VMCR tests on HRV parameters across all three tests, one-way analysis of variance (ANOVA) was applied. The strength and direction of relationships between HRV changes and the number of stimuli in the VMCR test were assessed using Pearson's correlation coefficient, calculated with the Origin 2018 software package. The chi-squared test (χ^2 test) was used to compare the frequency distribution of different types of autonomic status among the study groups.

RESULTS AND DISCUSSION

Significant differences in HR, SDNN, SD_1, RMSSD, and pNN_{50} were observed between the two groups under resting conditions (see **Table**). The trained group (T) exhibited 11.8–43.0 % higher values across all HRV indices compared to the untrained group (UT), except for heart rate (HR), which was 7.4 % lower in the trained group (p <0.05).

The HRV indices of trained (n = 22) and untrained (n = 26) persons (M±σ)

HRV indices	Group	Rest	$VMCR_{60}$,	$VMCR_{90}$	$VMCR_{120}$	F (F_{crit}); p
HR, bpm	T	76.0±10.0	81.8±11.4	78.6±9.7	79.0±8.83	1.2 (2.7); 0.298
	UT	82.1±10.8*	87.8±12.0*	83.2±10.1#	85.4±11.3*	1.2 (2.7); 0.327
SDNN, ms	T	87.3±25.5	53.6±12.8	50.5±8.9	51.3±11.2	27.1(2.7); <0.001
	UT	73.9±26.1*	52.4±16.3	53.6±23.2	45.5±17.4#	7.3 (2.7); <0.001
SD_1, ms	T	42.5±13.0	27.8±10.0	27.2±8.2	26.0±10.1	12.1(2.7); <0.001
	UT	35.5±16.0*	24.8±10.0	26.8±13.1	24.4±11.1	4.3 (2.7); 0.007
SD_2, ms	T	118.0±34.0	67.3±17.5	65.5±13.2	65.6±16.8	31.0(2.7); <0.001
	UT	105.5±38.3	67.5±21.5	69.7±30.8	63.3±28.8	10.6 (2.7); <0.001
RMSSD, ms	T	54.3±19.0	39.2±13.8	38.1±11.4	36.6±14.1	6.8 (2.7); <0.001
	UT	42.0±21.7*	34.6±14.1	37.8±18.6	34.3±15.7	1.1 (2.7); 0.367
pNN_{50}, %	T	12.5 (8.3; 16.3)	6.6 (3.7; 9.6)	7.3 (3.4; 14.1)	5.9 (3.3;9.7)	3.1 (2.7); 0.03
	UT	6.0 (3.8; 13.0)	5.6 3.1; 9.9)	7.8 (2.7;12.5)	4.9 (2.1;11.7)	0.5 (2.7); 0.653

Note: significance level of differences between groups: * – p <0.05; # – p <0.10

We evaluated the participants' autonomic status based on individual SDNN values measured during rest (Vovkanych & Kachmar, 2013; Sammito *et al.*, 2024). The majority in both groups were classified as vagotonic (T – 54.5 %, NT – 36 %) or normotonic (T – 45.5 %, NT – 40 %) (**Fig. 1**). A key difference between groups was the presence of sympathicotonic (20 %) and hypersympathicotonic (4 %) individuals exclusively in the NT group. According to the chi-squared criterion, the difference between the groups approached the level of statistical significance ($\chi^2 = 6.19$, $\chi^2_{crit} = 6.25$ at $p = 0.1$).

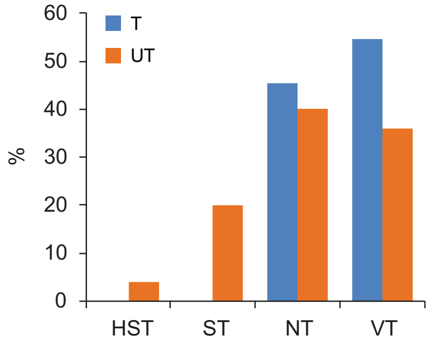

Fig. 1. Autonomic status of trained and untrained individuals at rest. The horizontal axis shows the percentage of hypersympathicotonic (HST), sympathicotonic (ST), normotonic (NT), and vagotonic (VT) individuals based on SDNN values

During the complex visual-motor choice reaction tasks (VMCR), both groups exhibited similar relative changes in HR (**Fig. 2*A***). However, ANOVA showed that the effect of CVR tasks on HR was not statistically significant (p = 0.298 for group T; p = 0.327 for group UT). The difference in mean HR between the groups observed at rest was also evident during both the RV_{60} and RV_{120} tests (see **Table**).

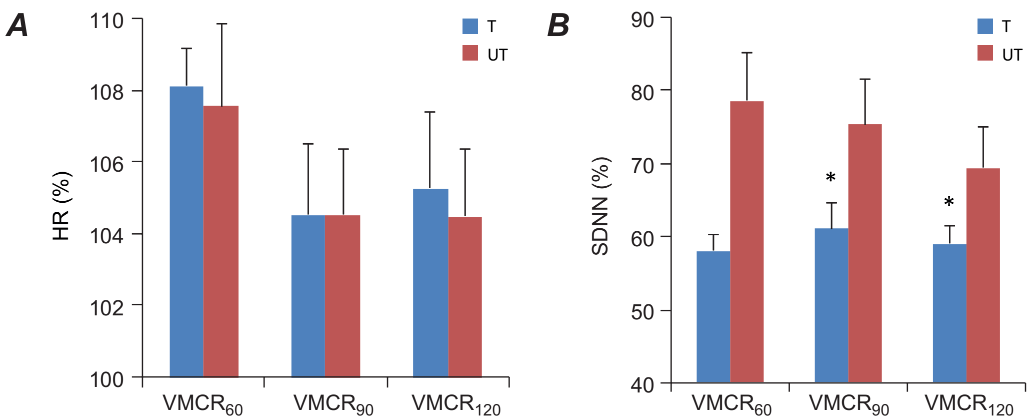

Fig. 2. Relative changes in heart rate (HR) and SDNN during a feedback-based VMCR task. Panel A shows HR, and panel B shows SDNN percentage shifts in trained (T) vs. untrained (UT) groups across task stages. Resting values were baseline (100 %). * – indicates statistical significance ($p < 0.05$)

The SDNN values declined during VMCR testing in both groups (**Fig. 2*B***), as confirmed by ANOVA ($p < 0.001$). The relative reduction in SDNN was significantly greater in the trained group (T) compared to the untrained group (UT) ($p < 0.05$), indicating a more rapid and pronounced shift in autonomic balance toward sympathetic dominance. Correlation analysis revealed a strong negative correlation between SDNN and the number of stimuli in the UT group, showing a trend toward significance (r = -0.99, p = 0.10), whereas no significant association was observed in the T group (r = 0.299, p = 0.81).

During the CVR tests, group T exhibited a significant reduction in RMSSD (**Fig. 3*A***), decreasing by 25–30 %, as confirmed by ANOVA ($p < 0.001$). In contrast, ANOVA did not confirm significant changes in RMSSD in group UT group (p = 0.367). These findings indicate that performing VMCR tasks in group T led to a pronounced reduction in parasympathetic activity, which was absent in group NT, suggesting a possible imbalance in regulatory mechanisms.

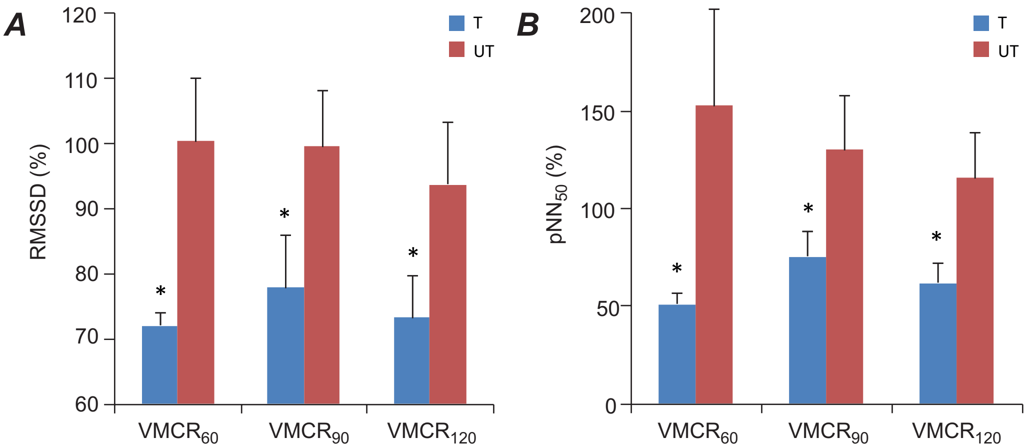

Fig. 3. Relative changes in RMSSD and pNN_{50} during a feedback-based VMCR task. Panel A shows RMSSD, and Panel B shows pNN_{50} percentage shifts in trained (T) vs. untrained (UT) groups across task stages. Resting values were baseline (100 %). * – marks significant group differences ($p < 0.05$)

During VMCR testing (see **Table**, **Fig. 3*B***), a significant decrease in pNN_{50} was observed in group T (p = 0.03), while no significant changes were noted in group UT (p = 0.653). A strong negative correlation between pNN_{50} and the number of stimuli was observed in the UT group, showing a trend toward statistical significance (r = –0.99, p = 0.08), whereas no significant association was found in the T group (r = 0.455, p = 0.69).

Statistical analysis of SD_1 (see **Table**, **Fig. 4*A***) showed a reduction during VMCR tasks in both group T (p <0.001) and group UT (p <0.01). This indicates a decrease in parasympathetic tone in both groups. The impact of CVR on SD_1 was more substantial in group T, showing a nearly significant correlation between SD_1 changes and the number of stimuli in group T (r = -0.995, p = 0.06) and in group NT (r = -0.992, p = 0.07).

A reduction in SD_2 was also observed during VMCR testing in both groups (see **Table**, p <0.001). The changes were more pronounced in group T (**Fig. 4*B***). Correlation analysis in group T did not reveal a significant association between SD_2 changes and the number of stimuli (r = -0.597, p = 0.59). In the untrained group (UT), a strong negative correlation was observed (r = -0.943), though it was not statistically significant (p = 0.22).

Our findings suggest that individuals who regularly engage in speed–strength training, such as karate athletes, exhibit distinct heart rate variability (HRV) profiles at rest compared to the control group. Specifically, the trained group (T) demonstrated higher values of RMSSD, pNN_{50}, and SD_1, indicating enhanced parasympathetic tone under resting conditions. These results align with previous studies (Dong, 2016; Laborde *et al.,* 2017; Chakraborty *et al.,* 2023; Liashenko & Stetsenko, 2024) showing that adaptation to endurance-oriented physical training is associated with increased parasympathetic activity of the ANS at rest. Similar patterns have been observed in other athletic populations, including team sports. For instance, S. Chakraborty *et al*. reported that basketball players, like swimmers, exhibited elevated RMSSD and reduced resting heart rate compared to sedentary individuals (Chakraborty *et al*., 2023), reflecting

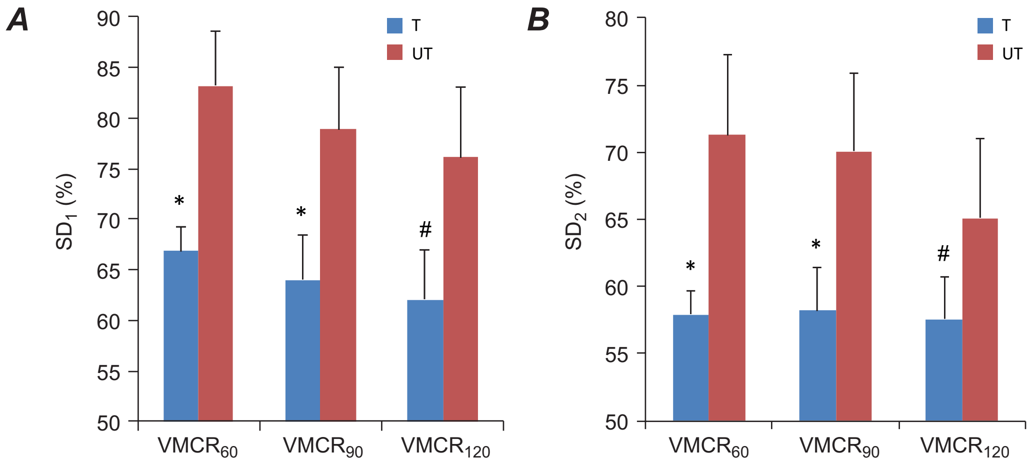

Fig. 4. Relative changes in SD_1 and SD_2 during a feedback-based VMCR task. Panel A displays SD_1 and Panel B displays SD_2 percentage shifts in trained (T) vs. untrained (UT) groups across task stages. Resting values were the 100 % baseline. * – indicates significance ($p < 0.05$); # – indicates a trend ($p < 0.10$)

greater parasympathetic modulation. Evidence from combat sports also supports this trend. P. Bhattacharya *et al*., in a study involving school-aged participants, found that young karate athletes had significantly higher high-frequency (HF) power and lower HF/LF ratios (vagal index) than their non-athlete peers (Bhattacharya *et al.*, 2023), further indicating a shift toward parasympathetic dominance. It is well established that individuals with a vagotonic pattern of autonomic regulation exhibit more energy-efficient physiological functioning and greater resilience to extreme stressors (Shushkovska *et al*., 2023). Our study confirms notable differences in resting cardiac function between trained and untrained males, aligning with existing research. I. Hornby-Foster *et al*. (2025) showed that both endurance and resistance training lower the resting heart rate, largely due to an increased stroke volume and arterial compliance. These adaptations enhance cardiac efficiency by reducing workload. P. Gröpel *et al*. (2018) found lower resting HR and reduced stress reactivity in active individuals, linked to stronger parasympathetic tone and weaker sympathetic activation. A. T. Corkery *et al*. (2021) noted that aerobic training induces greater cardiovascular benefits than resistance training, evidenced by lower baseline HR and more stable responses to homeostatic challenges.

Autonomic nervous system (ANS) adaptation to exercise occurs across three regulatory levels: central (cerebral cortex, hypothalamus, brainstem), intermediate (integrative brainstem centers), and peripheral (receptors, effector organs). At the central level, training enhances neuroplasticity in autonomic nuclei, notably by increasing BDNF and TrkB expression in the paraventricular nucleus (PVN) and reducing phosphorylated CaMKIIβ in the rostral ventrolateral medulla (RVLM), thereby modulating sympathetic outflow (Lee *et al.,* 2020). Physical activity also preserves vagal preganglionic neurons in the *nucleus ambiguus* and dorsal motor nucleus of the *vagus* (DMV), reinforcing parasympathetic control of heart rate (Korsak *et al*., 2023; Fisher *et al*., 2016). Intermediate regulation involves central command from the motor cortex and reticular formation, coordinating parasympathetic inhibition and sympathetic activation, with modulation via baroreflex and chemoreflex pathways (Wan *et al*., 2023; Mee *et al*., 2023). Peripherally, regular exercise enhances baroreflex sensitivity by increasing vascular compliance (Hornby-Foster *et al.,* 2025). Our findings of heightened parasympathetic tone in speed–strength athletes support the notion that ANS adaptations to physical activity may be broadly consistent across diverse sports disciplines.

There is a broad consensus that cognitive and emotional stressors elicit changes in HRV indicative of a shift in autonomic balance toward sympathetic dominance (Kochyna *et al.*, 2020; Shushkovska *et al*., 2023). However, the extent to which physical training influences the speed and magnitude of these autonomic responses has been addressed in only a limited number of studies (Chakraborty *et al*., 2023; Luque-Casado *et al*., 2013; Hansen *et al.,* 2004). The findings to date remain inconclusive, highlighting the need for further investigation. Particularly, A. Luque-Casado *et al*. (2013) reported that individuals with lower fitness levels exhibited a significant progressive decrease in HRV indices, particularly RRi and RMSSD, during a series of cognitive tasks. In contrast, individuals with higher fitness levels maintained much more stable HRV values throughout testing. Their data also suggest a tendency for higher RRi, SDNN, and RMSSD values in fitter individuals during cognitive tasks, though these differences did not reach statistical significance. Similarly, A. L. Hansen *et al*. (2004) found no significant differences in HRV parameters between groups with different fitness levels. However, after cognitive testing, the HF power, reflecting parasympathetic activity, was higher in the trained group (Hansen *et al*., 2004). Conversely, some studies contradict these findings. For example, although Chakraborty *et al*. observed differences in HR, RMSSD, and HF power at rest between athletes (basketball players and swimmers) and untrained individuals, they found no significant HRV differences between groups during cognitive testing (Chakraborty *et al*., 2023).

A comparison of our findings with those of previous studies investigating HRV responses to cognitive stress reveals both consistent patterns and noteworthy distinctions. Firstly, we confirmed the observations of many authors regarding the increase in sympathetic tone of the ANS under psycho-emotional and cognitive loads (Kochyna *et al*., 2020; Shushkovska *et al*., 2023; Shvets, 2020). The overall direction of these changes was similar in individuals regardless of their training status. Consistent with the findings of Luque-Casado *et al*. and Chakraborty *et al*., we observed only a trend toward differences in mean HRV values between groups with different fitness levels during the complex visual-motor choice reaction tests (Luque-Casado *et al*., 2013; Chakraborty *et al.,* 2023). However, previous studies did not analyze relative changes in HRV parameters compared to baseline levels. Such an approach can reduce the impact of individual HRV variability on assessing the effects of experimental factors. When averaging the relative changes in HRV parameters, we observed a greater degree of sympathetic activation during testing in trained individuals compared to the untrained group. Our data confirm the progressive changes in HRV parameters in the untrained group across the series of tests and the lack of significant changes in the athlete group, a pattern also reported by A. Luque-Casado *et al*. (2013). Therefore, it can be hypothesized that one manifestation of adaptation to physical training is a faster and more pronounced shift in ANS activity toward sympathetic dominance in response to cognitive stress.

CONCLUSION

The obtained results indicate a higher parasympathetic activity in individuals adapted to speed-strength training during resting conditions. During the performance of complex visual-motor choice reaction tasks, trained individuals demonstrated more pronounced and faster changes in HRV parameters (SDNN, RMSSD, pNN_{50}, SD_1, SD_2), reflecting a more effective activation of the sympathetic division of the autonomic nervous system.

In untrained individuals, HRV changes were less pronounced but gradually increased throughout the series of tests. These observed differences point to a higher adaptability of the higher regulatory centers of the ANS to cognitive stressors in individuals who regularly engage in speed-strength physical training.

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COMPLIANCE WITH ETHICAL STANDARDS

Conflict of Interest: the authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Animal Rights: this article does not include animal studies.

Human Rights: the study was carried out in compliance with the principles outlined in the Declaration of Helsinki, with ethical approval obtained from the Ethics Committee of Ivan Boberskyi Lviv State University of Physical Culture (protocol No 29/2025 of June 29, 2025).

AUTHOR CONTRIBUTIONS

Conceptualization, [L.V.]; methodology, [L.V., M.F.]; validation, [L.V., M.F.]; formal analysis, [L.V., M.F.].; investigation, [L.V., M.F., B.K.]; resources, [B.K.]; writing – original draft preparation, [L.V., M.F.]; writing – review and editing, [L.V., M.F., B.K]; visualization, [L.V., M.F.] supervision, [L.V.]; project administration, [L.V.]; funding acquisition, [-].

All authors have read and agreed to the published version of the manuscript.

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ВАРІАБЕЛЬНІСТЬ СЕРЦЕВОГО РИТМУ ЯК КРИТЕРІЙ КОГНІТИВНОГО СТРЕСУ ЗДОРОВИХ СТУДЕНТІВ: ВПЛИВ РІВНЯ ФІЗИЧНОЇ ПІДГОТОВКИ

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Обґрунтування. У вивченні особливостей змін варіабельності серцевого ритму (ВСР) під час когнітивних чи емоційних навантажень в осіб із різним рівнем адаптації до фізичних навантажень наявні лише поодинокі дослідження. Метою наших досліджень було вивчити зміни показників ВСР осіб із різним рівнем адаптації до швидкісно-силових фізичних навантажень під час виконання ними складних зорово-моторних реакцій.

Матеріали та методи. Порівнювали показники тренованих осіб (22 каратисти, група Т) і нетренованих осіб (26 студентів, група НТ). Групи суттєво не відрізнялися за віком і антропометричними параметрами. ВСР реєстрували у стані відносного спокою та під час виконання трьох тестів складної зорово-моторної реакції вибору (ЗМРВ) зі збільшенням кількості стимулів – PB_{60}, PB_{90} та PB_{120}. Було розраховано такі показники ВСР: частота серцевих скорочень (HR); стандартне відхилення нормальних інтервалів RR (SDNN); квадратний корінь зі суми квадратів різниці величин послідовних пар інтервалів NN (RMSSD); відсоток послідовних пар інтервалів, що відрізняються більш ніж на 50 мс (pNN_{50}); довжина короткої осі діаграми Пуанкаре (SD_1) та довжина довгої осі діаграми Пуанкаре (SD_2).

Результати. У стані спокою в групі Т значення SDNN, SD_1, RMSSD та pNN_{50} були на 11,80–43,01 % вищими, ніж у групі НТ (p <0,05), тоді як ЧСС була на 7,40 % нижчою в групі Т (p <0,05). У групі НТ спостерігали більшу кількість осіб із домінуванням симпатичного тонусу. Під час виконання завдань ЗМРВ параметри ВСР змінювалися в обох групах. Зокрема, SDNN зменшився на 38–42 % (p <0,01), з більш вираженим зниженням у групі Т. Ми виявили тенденцію до сильної негативної кореляції між зниженням SDNN та кількістю стимулів у тестах ЗМРВ (r = -0,99, p = 0,10) у групі НТ. Під час виконання завдань ЗМРВ група Т показала значне зниження RMSSD (p <0,01) та pNN_{50} (p = 0,03), тоді як у групі НТ суттєвих змін не спостерігали. Була тенденція до сильної негативної кореляції між pNN_{50} та кількістю стимулів у групі НТ (r = -0,99, p = 0,08), на відміну від групи Т. SD_1 значно знизився під час завдань ЗМРВ в обох групах (p <0,01), з тенденцією до кореляції між цими змінами та кількістю стимулів у групі Т (r = -0,995, p = 0,06) та групі НТ (r = -0,992, p = 0,07). Вплив VMCR на SD_1 був більш вираженим у групі Т. Крім того, SD_2 значно знизився під час ЗМРВ в обох групах (p <0,01), причому більше зниження спостерігали в групі Т. Аналіз ВСР у стані спокою свідчить про те, що адаптація до швидкісно-силових тренувань пов'язана з посиленням парасимпатичного тонусу. Під когнітивним навантаженням спостерігали зсув у бік підвищеної симпатичної активності. Ці зміни більш виражені та відбуваються швидше у тренованих осіб, про що свідчать прогресивні зміни специфічних параметрів HRV у нетренованій групі під час послідовних серій тестів.

Висновки. Особи, адаптовані до швидкісно-силових тренувань, демонстрували вищу парасимпатичну активність у стані спокою та більш ефективні симпатичні реакції на когнітивне навантаження, що свідчить про кращу адаптивність автономної регуляції, порівняно з нетренованими особами.

Ключові слова: варіабельність серцевого ритму, адаптація до фізичних навантажень, складні зорово-моторні реакції, швидкісно-силові навантаження, студенти

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